Springer Geography

Uday Chatterjee
Nairwita Bandyopadhyay
Martiwi Diah Setiawati
Soma Sarkar *Editors*

Urban Commons, Future Smart Cities and Sustainability

Springer

Springer Geography

The Springer Geography series seeks to publish a broad portfolio of scientific books, aiming at researchers, students, and everyone interested in geographical research.

The series includes peer-reviewed monographs, edited volumes, textbooks, and conference proceedings. It covers the major topics in geography and geographical sciences including, but not limited to; Economic Geography, Landscape and Urban Planning, Urban Geography, Physical Geography and Environmental Geography.

Springer Geography—now indexed in Scopus

Uday Chatterjee · Nairwita Bandyopadhyay ·
Martiwi Diah Setiawati · Soma Sarkar
Editors

Urban Commons, Future Smart Cities and Sustainability

Springer

Editors
Uday Chatterjee
Department of Geography
Bhatter College Dantan
Paschim Medinipur, West Bengal, India

Nairwita Bandyopadhyay
Department of Geography
Haringhata Mahavidyalaya
Nadia, West Bengal, India

Martiwi Diah Setiawati
National Research and Innovation Agency
Research Center for Oceanography
Jakarta, Indonesia

Soma Sarkar
School of Development Studies
Tata Institute of Social Sciences
Mumbai, Maharashtra, India

ISSN 2194-315X ISSN 2194-3168 (electronic)
Springer Geography
ISBN 978-3-031-24766-8 ISBN 978-3-031-24767-5 (eBook)
https://doi.org/10.1007/978-3-031-24767-5

This Springer imprint is published by the registered company Springer Nature Switzerland AG
The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

Dedicated to
Young Scholars in the Field of Urban Studies, Urban Planning, City Planners and Smart City Policymakers

Foreword

I am delighted to write the foreword to this anthology titled *Urban Commons, Future Smart Cities and Sustainability* which aims to engage its readers in critical discussions on the emerging questions of sustainability, environmental governance and urban planning pertaining to the various common property resources. The book is edited by a vibrant team of young scholars, Dr. Uday Chatterjee, Dr. Nairwita Bandyopadhyay, Dr. Martiwi Diah Setiawati and Ms. Soma Sarkar. The editors come from the fields of geography, marine sciences and development studies. Published by Springer, this edited volume is dedicated to young scholars, planners, practitioners and policymakers.

Across the world, cities and towns are increasingly facing myriad challenges of population growth, rapid urbanisation, environmental degradation and contestation over the governance and management of urban commons. In the early 1990s, Ostrom (1990) emphatically raised the question of 'governing the commons'. Examining the governance of urban local commons in 2000, I presented a conference paper that discussed the various conflicts plaguing the process of solid waste management in a small peri-urban settlement located in the Chennai Metropolitan Region

(Dahiya 2000). This action research-based study revealed the emergence of day-to-day conflicts that arose between the Valasaravakkam town's local government and a community-based organisation particularly when the latter attempted to start and manage a system of self-help solid waste collection service in the urban neighbourhood. In the past decade, Foster and Iaione (2015) offered 'a more articulated and pluralistic account of the urban commons than currently exists in legal scholarship' (p. 287). More recently, Ramos and his coeditors (2021) have discussed some of the emerging issues on urban commons in their *Cosmo-Local Reader*.

Due to the daunting urban challenges, national governments are under pressure to improve the governance and management of urban commons and resources in order to cater to the needs of city dwellers. As cities bring together multifarious activities and opportunities, they serve as hubs of connectivity, centres of creativity, incubators of innovation and quick adopters of new technologies. All of this helps cities to act as engines of economic growth and centres of social change and advancement.

Cities need proper urban policies, governance and planning approaches that embody the ever important principles of inclusivity, sustainability and resilience (Dahiya 2012a, 2012b, 2014; Dahiya and Das 2020; Das and Dahiya 2020; Haase et al. 2018). Under the *2030 Agenda for Sustainable Development* (United Nations 2015), these principles are emphasised in the Sustainable Development Goal (SDG) 11, which aims 'to make cities and human settlements inclusive, safe, resilient and sustainable' (United Nations 2022). In the *New Urban Agenda* (United Nations 2017) adopted at the United Nations Conference on Housing and Sustainable Urban Development in Quito, Ecuador, in October 2016, the world leaders made the following key commitments: (i) 'Provide basic services for all citizens'; (ii) 'Ensure that all citizens have access to equal opportunities and face no discrimination'; (iii) 'Promote measures that support cleaner cities'; (iv) 'Strengthen resilience in cities to reduce the risk and the impact of disasters'; (v) 'Take action to address climate change by reducing their greenhouse gas emissions'; (vi) 'Fully respect the rights of refugees, migrants and internally displaced persons regardless of their migration status'; (vii) 'Improve connectivity and support innovative and green initiatives'; and (viii) 'Promote safe, accessible and green public spaces' (United Nations 2016).

All of this entails improving the planning, governance and management of the urban commons and the various urban services and infrastructures including safe drinking water supply, improved sanitation and wastewater management, solid waste management, control of air pollution and air quality management, public and open spaces, housing and other urban amenities. In recent years, the idea of developing smart cities has been discussed and proposed by scholars and practitioners as a pragmatic solution towards building smart urban economies (Vinod Kumar and Dahiya 2017) and addressing the emergent urban planning and development challenges.

The 43 chapters presented in this edited volume engage with these questions through empirical case studies from around the world. The implementation and growth of smart cities as engines of innovation—with long-term effects on productivity, liveability and the sustainability of particular initiatives—are explained in this book's theoretical framework. It critically examines how combining regulatory governance and private agency can foster technological innovation in smart city initiatives. In-depth analysis of the typologies of smart city approaches has been conducted. Thus, this rich collection of papers presents a comprehensive framework for understanding smart cities with focus on the current and upcoming challenges related to technological innovation, disaster resilience, ecological considerations, social issues and urban governance.

The structure of the book reflects the interconnection between theories and practice. Part I of the book introduces the readers to the diversity and challenges of the urban commons and their regeneration. Part II focuses on the current and future conditions of urban growth, agglomeration, and urban infrastructure and services. Part III of the book thematically engages with the worsening climate crisis, urban health and solid waste management. Part IV examines the ecological perspectives, advanced technology and social impact related to smart buildings, ecosystem services and future smart cities. Part V includes chapters that discuss urban governance, smart solutions and sustainable cities as well as the COVID-19 pandemic.

All in all, this edited volume examines and raises various issues of critical importance that challenge the process of sustainable urbanisation in the twenty-first century. In doing so, it identifies and discusses the essential elements: the urban commons and the urban environment.

I would like to congratulate the young group of editors for their excellent initiative and sincere efforts in putting together this important volume. The preparation of this book has benefitted from the rich insights gained by the editors and contributing authors from the critical analysis of the governance of urban commons and related issues through the case study approach. This book promises to serve as an important resource for readers of various academic disciplines interested in urban planning and sustainability in the current age of Anthropocene.

Bharat Dahiya
Director, Research Center for Sustainable Development
and Innovation, School of Global Studies
Thammasat University
Bangkok, Thailand

References

Dahiya B (2000) Managing the urban local commons: conflicts and governance in Valasaravakkam Town in South India. In: Proceedings of conference: ‘environmental resources: conflict, cooperation and governance’, held at Development and Project Planning Centre, University of Bradford, Bradford, United Kingdom

Dahiya B (2012a) 21st Century Asian cities: unique transformation, unprecedented challenges. Glob Asia 7(1):96–104 (ISSN: 1976-068X)

Dahiya B (2012b) Cities in Asia, 2012: demographics, economics, poverty, environment and governance. Cities 29(Supplement 2):S44–S61. https://doi.org/10.1016/j.cities.2012.06.013

Dahiya B (2014) Southeast Asia and Sustainable Urbanization. Global Asia 9(3):84–91 (ISSN: 1976-068X)

Dahiya B, Das A (2020) New urban agenda in Asia-Pacific: governance for sustainable and inclusive cities. In: Dahiya B, Das A (eds) New urban agenda in Asia-Pacific. In: Advances in 21st century human settlements. Springer, Singapore, pp 3–36. https://doi.org/10.1007/978-981-13-6709-0_1

Das A, Dahiya B (2020) Towards inclusive urban governance and planning: emerging trends and future trajectories. In: Dahiya B, Das A (eds) New urban agenda in Asia-Pacific. Advances in 21st century human settlements. Springer, Singapore, pp 353–384. https://doi.org/10.1007/978-981-13-6709-0_13

Foster SR, Iaione C (2015) The city as a commons. Yale Law Policy Rev 34(2):281–349. http://www.jstor.org/stable/43920369

Haase D, Guneralp B, Dahiya B, Bai X, Elmqvist T (2018) Global urbanization: perspectives and trends. In: Elmqvist T, Bai X, Frantzeskaki N, Griffith C, Maddox D, McPhearson T, Parnell S, Romero-Lankao P, Simon D, Watkins M (eds) Urban planet: knowledge towards sustainable cities. Cambridge University Press, Cambridge, pp 19–44. https://doi.org/10.1017/9781316647554.003

Kumar TMV, Dahiya B (2017) Smart economy in smart cities. In: Kumar TMV (ed) Smart economy in smart cities—international collaborative research: Ottawa, St. Louis, Stuttgart, Bologna, Cape Town, Nairobi, Dakar, Lagos, New Delhi, Varanasi, Vijayawada, Kozhikode, Hong Kong. Springer, Singapore, pp 3–76. https://doi.org/10.1007/978-981-10-1610-3_1

Ostrom E (1990) Governing the commons: the evolution of institutions for collective action. Cambridge University Press

Ramos J, Ede S, Bauwens M, Wong JG (eds) (2021) Cosmo-local reader. futures lab. https://clreader.net

United Nations (2015) Transforming our World: The 2030 agenda for sustainable development, A/RES/70/1. https://sustainabledevelopment.un.org/post2015/transformingourworld/publication. Accessed 26 Nov 2022

United Nations (2016) The new urban agenda: key commitments. United Nations. https://www.un.org/sustainabledevelopment/blog/2016/10/newurbanagenda/

United Nations (2017) The new urban agenda, A/RES/71/256, Habitat III and United Nations

United Nations (2022) Sustainable development goal 11: make cities and human settlements inclusive, safe, resilient and sustainable. https://sustainabledevelopment.un.org/sdg11. Accessed 26 Nov 2022

Preface

Cityscapes are created by city planning, city planners and the people who live in those cities. Every city has a integrated network of the residential places, urban infrastructure, transport networks and green spaces. Rapid urbanisation has become a global trend in the present scenario, with half of the world's population relocating to urban centres. By 2050, it is projected that cities will house 66 percent of the global population. As a result, existing urban environments will inevitably be significantly expanded, necessitating the creation of new ones. Urban areas cover only 2% of the overall earth's total but consume more than 75% of the world's natural resources. Based on the United Nations Environment Programme (UNEP), material consumption in cities will be double by 2050 in comparison to 2010. The future cities will be exposed to diverse challenges out of which climate change is the major factor that needs immediate attention.

The massive increase in population has put pressure on countries to regulate and manage urban resources. Cities offer the most opportunities, act as catalysts for social change, foster innovation, have a well-connected infrastructure, and quickly adapt and scale-up technology. However, these cities face challenges such as dealing with urban waste, conserving fossil fuels, enhancing affordable and responsive healthcare systems, aging infrastructure, air pollution, providing efficient traffic control, and ensuring transparency in governance. One possible solution the planners and scientists across the world has reached a consensus on is the concept of: the smart city: the most effective solution in the present context.

A smart city strives to be 'smarter', more sustainable, efficient, equitable and liveable. There are numerous definitions of a smart city in the literature, some of which are complex. Their diversity varies from what aspects a city must include being considered smart, what resources it must employ, what characteristics it must display and the smart city's targets, intention and scope. While the concept is progressively being used in various sectors, the wide range of viewpoints within smart city definitions has caused confusion among urban policymakers working to establish public policies to enable the transition to smarter cities. This transition is regarded as critical by policymakers, as evidenced by the establishment of the 11th UN Sustainable Development Goal (SDG), which aims to make cities inclusive, safe, resilient and sustainable. Since smart cities have become more influential, the ambiguity in their scope becomes increasingly alarming and will impact the creation of public benefit and value. As a result of the correlation between the 11th SDG and smart cities, this book fills a significant literature gap regarding how far the scope of sustainability is addressed in smart city definitions and what role it plays. This conceptual clarity is critical not only for the development of scholarship and practice but also for the decision-making processes of public policymakers.

The rapid increase in urban population and the resulting increase in resource consumption will inevitably present cities with a slew of new challenges. This fact emphasises the significance of shifting paradigms in how cities operate in sustainability. Previous research highlights the importance of determining the scale on which a system's sustainability is measured. Attaining global sustainability necessitates different actions than achieving urban sustainability. In terms of urban sustainability, there is no single best-established definition. Nonetheless, a set of characteristics of urban sustainability is commonly used. These include intergenerational equity, intragenerational equity, environmental conservation, significant reductions in the use of non-renewable resources, sustainable economy and diversity, community autonomy, citizen wellbeing and satisfaction of basic human needs.

These attributes incorporate the three pillars of sustainability: environmental, economic and social, where environmental factors refer to the ecological dimension and include the conservation of the natural environment (flora and fauna) and natural resources, as well as an economy based on energy production. The social dimension has equity, community autonomy, citizen wellbeing and satisfaction of basic human needs, whereas the economic dimension includes the economic viability and diversity of urban areas. In the context of this study, a sustainable urban environment achieves economic vitality, social equity, conservation of the natural environment and its resources, and quality of life. Urban sustainability appears to be a recurring theme in smart city literature, but to what extent is the concept embedded in smart city understanding, and how comprehensively is it addressed is the question that needs to be addressed.

These concerns gave rise to the innovative, technologically based and environmentally friendly urban spaces known as Sustainable Smart City (SSC). The SSC uses technology to monitor its community and provide sustainable and affordable urban space solutions. To support applications and services in urban areas, the successful deployment of SSCs necessitates a stable, secure, interoperable and dependable telecommunication network. Recent advancements in the Internet of Things (IoT) and Blockchain technology are expected to drive and support the growth of SSCs. This book presents an overview of the elements of SSCs, as well as an overview of their adaptation by cities around the world and future trends.

This book provides a critical theoretical framework for understanding the implementation and development of smart cities as innovation drivers, with long-term effects on productivity, livability and the sustainability of specific initiatives. This framework is based on an empirical analysis of 21 case studies, which include pioneer projects from various regions. It investigates how successful smart city initiatives foster technological innovation by combining regulatory governance and private agency. The typologies of smart city-making approaches are thoroughly examined. This book presents the holistic approach of smart cities, which start from current issue and challenges, advanced technological development, disaster mitigation, ecological perspective, social issue and urban governance.

The book is organised into 5 major parts, which reflect interconnection between theories and practice. Part I will explain the introduction which reflect the diversity and challenges of the urban commons and its regeneration. Part II will cover the current and future situation of urban growth, agglomeration and urban infrastructure. This part will include Rethinking Urban Sprawl: Moving Towards Sustainable Cities, Drivers of urban growth and infrastructure, Urban Land Use dynamics and Urban Sprawl and Urban Infrastructure Sustainability and Resilience. Part III describes Climate Crisis, Urban Health and Waste Management. This part will include Climate Change and Health Impacts in Urban Areas, Green Spaces: An Invaluable Resource for Delivering Sustainable Urban Health, Health and wellbeing and Quality of Life in the changing urban environment, Urban Climate and Pollution-Case Study, Sustainable Urban Waste Management and urban sustainability and Global Warming and urban heat Island. Part IV will cover the ecological perspectives, advanced technology and social impact for SSC (i.e. Smart Building, Ecosystem Services, Society and Future Smart Cities). This part includes Urban Ecosystem Services, Environmental Planning, and city Management, Artificial intelligence and Urban Hazards and Societal impact, and using geospatial application and Urban/Smart City Energy Conservation-Case study. Part V will cover Urban Governance, Smart Solutions and Sustainable Cities. It will include good governance, especially e-Governance and citizen participation, Urban Governance, Space and policy planning to achieve sustainability, Smart City Planning and Management and Internet of Things (IoT), Advances in smart roads for future smart cities, Sustainable City planning, Innovation, and Management, Future Strategy for Sustainable Smart Cities and Lessons from the Pandemic: The Future of Smart Cities.

This book is intended for researchers, scholars, geographers and engineers working in sustainability governance, environmental governance and urban planning. This book will be helpful to postgraduate students in courses on urban planning, urban engineering, environmental management, climate change governance, and transformation and social change processes. The audience for this book is potentially very large in both academics and informed lay audience. In latter mainly thought leaders, policymakers in government agencies and industry and other professional. Also, we envision that the book will have relatively broad public appeal among those who are concerned about how to implement SDG.

Paschim Medinipur, West Bengal, India — Uday Chatterjee
Nadia, West Bengal, India — Nairwita Bandyopadhyay
Jakarta, Indonesia — Martiwi Diah Setiawati
Mumbai, Maharastra, India — Soma Sarkar

Acknowledgments

This book has been inspired by the tremendous effort made by academia, engineering scientists, city planner, policymakers and grassroots activists worldwide who are working very hard to achieve sustainable urban environments. We express our heartfelt gratitude to the excellent chapter authors for their contributions to this book. We also acknowledge the hard work of the anonymous reviewers for their constructive criticism and suggestion, which has helped improve the research and book quality. As lifelong learners, we are grateful for the incredible support from our colleagues, students, parents, family members, teachers and collaborators in easing the efforts we have put in day in and day out while editing this book so that it may add value and contribute positively to the knowledge of sustainable urban development. Last but not least, we would like to acknowledge the continuous assistance of our publisher and its publishing editor, Springer.

Contents

Editors and Contributors

About the Editors

Dr. Uday Chatterjee is an Assistant Professor at the Department of Geography, Bhatter College, Dantan, Paschim Medinipur, West Bengal, India, and Applied Geographer with a Post-Graduate in Applied Geography at Utkal University and Doctoral Degrees in Applied Geography at Ravenshaw University, Cuttack, Odisha, India. He has contributed various research papers published in various reputed national and international journals and edited book volumes. He has authored jointly edited books entitled Harmony with *Nature: Illusions and Elusions from Geographer's Perspective in the 21st Century*, and *Land Reclamation and Restoration Strategies for Sustainable Development* (November 2021, Edition: 1st, Publisher: Elsevier, Editor: Dr. Gouri Sankar Bhunia, Dr. Uday Chatterjee, Dr. Anil Kashyap, Dr. Pravat Kumar Shit • ISBN: 9780128238950 (https://www.elsevier.com/books/land-reclamation-and-restoration-strategies-for-sustainable-development/bhunia/978-0-12-823895-0). He has also conducted (Convener) one Faculty Development Programme on 'Modern methods of teaching and advanced research methods' sponsored by Indian Council of Social Science Research (ICSSR), Govt. of India. His areas of research interest cover Urban Planning, Social and Human geography, Applied Geomorphology, Hazards and Disasters, Environmental Issues, Land Use and Rural Development. His research work has been funded by the West Bengal Pollution

Control Board (WBPCB) Government of West Bengal, India. He has served as a reviewer for many International journals. Currently, Dr. Uday Chatterjee is the lead editor of Special Issue (S.I.) of *Urbanism, Smart Cities and Modelling, GeoJournal*, Springer.

Dr. Nairwita Bandyopadhyay is presently working as Head of the Department and Assistant Professor of Geography at Haringhata Mahavidyalaya affiliated to University of Kalyani. She holds a Ph.D. Geography from Department of Geography, Delhi School of Economics, University of Delhi. Her thesis was titled '*Drought Impact Assessment and Analysis of Drought Policy in Gujarat*'. She holds a M. Phil. in Geography (First Class with Distinction) and M.A. in Geography (First Class) with special papers in Remote Sensing and GIS, Disaster Management, Environmental Impact Assessment from University of Delhi in Geography. She was awarded the N. P. Aiyyar Young Geographers Award at 38th Indian Geography Conference of National Association of Geographers in India (NAGI) IN 2016 and the Best paper award for 'Monitoring Vegetative Drought Dynamics with drought Indices in Gujarat'. She has published in reputed international peer-reviewed journals like Elsevier, Natural Hazards, GIS Science and Remote Sensing, Springer, Routledge with more than 100 citations. She has contributed to book chapters and authored a book. She has participated in International seminars and has presented papers at Germany, Spain, Greece and China. Participated in training programs conducted by NASA, NIDM under ministry of Home Affairs, Government of India and World Bank.

Dr. Martiwi Diah Setiawati is currently a research fellow at the Research Center for Oceanography, National Research and Innovation Agency (BRIN)-previously known as Indonesia Institute of Sciences (LIPI). She obtained her Bachelor's degree in marine science and technology from IPB University, Indonesia, in 2009. In 2012, she got a Master of Science in Udayana University, Indonesia, and a Master of Engineering in Yamaguchi University, Japan, under a double degree program. She received her Doctoral Degree in Environmental Science and Engineering from Yamaguchi University, Japan, in 2015. From 2016 until March 2021, she joined the Integrated Research System for Sustainability Sciences (IR3S) (now known as Institute for Future Initiatives-IFI), The University of Tokyo as a project researcher under the Climate Change Adaptation Initiative Project in Indonesia. This project collaborates between the Ministry of Environment Japan and the Ministry of National Development Planning of the Republic of Indonesia (BAPPENAS) to mainstream climate change adaptation into a local development plan. As an environmental scientist, she is interested in remote sensing and GIS application to multiple environmental conditions, including habitat studies, disaster mitigation, climate change impact assessment, and adaptation. Her previous research projects cover the integrated climate assessment—risks, uncertainties, and society and developing models to predict future health risks posed by changes in climate, land use and population. She has published nearly 20 papers in various international and local journals and proceedings.

Soma Sarkar is a Ph.D. scholar in the School of Development Studies at Tata Institute of Social Sciences, Mumbai, and a recipient of the Dr. Ambedkar Doctoral fellowship by DAIC, Government of India. Her ongoing doctoral research seeks to provide an in-depth understanding of urban water crises and governance mechanisms in India with a case study of Shimla. Soma has a Master's degree in geography with the University Gold Medal for Academic Excellence from Sikkim University, and an M.Phil. in Development Studies from TISS, Mumbai, where she explored the spatialities of water in a caste society like India. She has also completed a certificate course on the Global Food, Energy, and Water

Nexus which was jointly offered by Cornell University, USA and Tata Institute of Social Sciences, Mumbai, and aimed at engaging students from the US, China and India to chart a Sustainable Future. Soma has presented her research at many international conferences and has also been engaged in a number of research projects on WASH, Forest Resource Rights and Governance Mapping and Green Economy. Her broad research interests include environmental governance and policy, political ecologies of water, climate change, intersectionality and Himalayan ecology.

Contributors

Yewande Adewunmi School of Construction Economics and Management, University of Witwatersrand, Johannesburg, South Africa

I. Wayan Sandi Adnyana Centre for Environmental Research (PPLH), Udayana University, Denpasar-Bali, Indonesia

Apoorv Agrawal Department of Urban and Regional Planning, School of Planning and Architecture Bhopal, Bhopal, Madhya Pradesh, India

R. Akhil Department of Geography, Himalayan University, Itanagar, Arunachal Pradesh, India

Tahmina Akter Department of Geography and Environmental Studies, University of Chittagong, Chattogram, Bangladesh

Md. Rashedul Alam Department of Government and Politics, Jahangirnagar University, Dhaka, Bangladesh

Athena Anwar Research Center for Climate and Atmosphere, National Research and Innovation Agency of Indonesia, Bandung, Indonesia

Abd. Rahman As-syakur Centre for Environmental Research (PPLH), Udayana University, Denpasar-Bali, Indonesia

Tri Atmaja Department of Urban Engineering, Graduate School of Engineering, The University of Tokyo, Tokyo, Japan

Vibhore Bakshi School of Planning and Architecture, Bhopal, India

Parama Raychaudhuri Bannerji Department of Geography, Naba Barrackpore Prafulla Chandra Mahavidyalaya, Kolkata, India

Nilay Kanti Barman Department of Geography, Midnapore College (Autonomous), Midnapore, India

Prosenjit Barman Department of Geography, Central University of Punjab, Bhatinda, Punjab, India

Anindya Basu Department of Geography, Diamond Harbour Women's University, Sarisha, West Bengal, India

Tanmoy Basu Department of Geography, Katwa College, Purba Barddhaman, West Bengal, India

Adrija Bhattacharjee Department of Geography, Diamond Harbour Women's University, Sarisha, West Bengal, India

Sujayita Bhattacharjee Post-Doctoral Candidate, International Institute for Population Sciences (IIPS), Mumbai, Maharashtra, India

Gouri Sankar Bhunia Department of Geography, Nalini Prabha Dev Roy College, Bilaspur, Chhattisgarh, India

Arindam Biswas Department of Architecture and Planning, Indian Institute of Technology (IIT) Roorkee, Roorkee, Uttarakhand, India

Trinity Borgohain Government Model College, Kaziranga, Golaghat, Assam, India

Lina Bose Department of Humanities and Social Sciences, Indian Institute of Technology Kharagpur, Kharagpur, West Bengal, India

Soumen Brahma Department of Geography, Nalini Prabha Dev Roy College, Bilaspur, Chhattisgarh, India

Savaş Çağlak Ministry of Education, Amasya City, Turkey

Waluyo Eko Cahyono Research Center for Climate and Atmosphere, National Research and Innovation Agency of Indonesia, Bandung, Indonesia

Subrata Chattopadhyay Department of Architecture and Regional Planning, Indian Institute of Technology, Kharagpur, West Bengal, India

Shalini Chaudhary Rekhi Centre of Excellence for the Science of Happiness, IIT Kharagpur, Kharagpur, West Bengal, India

Gillie Cheelo Department of Urban and Regional Planning, Copperbelt University, Kitwe, Zambia

Roy Alexander Chileshe Department of Urban and Regional Planning, Copperbelt University, Kitwe, Zambia

Sushmita Choudhary Department of Architecture and Regional Planning, Indian Institute of Technology, Kharagpur, West Bengal, India

Anuradha Choudry Department of Humanities and Social Sciences, IIT Kharagpur, Kharagpur, West Bengal, India

Purnima Kumari Chowdhury Department of Architecture and Regional Planning, Indian Institute of Technology (IIT), Kharagpur, West Bengal, India

Rima Das Department of Geography, Bhangar Mahavidyalaya, South 24 Parganas, West Bengal, India

Sandipan Das Symbiosis Institute of Geo-Informatics, Symbiosis International (Deemed University), Pune, Maharashtra, India

Aditya Dhanuka Department of Civil Engineering, Government College of Engineering, Jalgaon, Maharashtra, India

P. Dhanya Tamil Nadu Agriculture University, Coimbatore, India

Madhubarna Dhar Department of Humanities and Social Sciences, Indian Institute of Technology Kharagpur, Kharagpur, India

Meenakshi Dhote Department of Environmental Planning, School of Planning and Architecture, New Delhi, India

Megersa Dinka Department of Civil Engineering Science, University of Johannesburg, Johannesburg, South Africa

Sanu Dolui Department of Geography, The University of Burdwan, Burdwan, West Bengal, India

Kensuke Fukushi Institute for Future Initiative (IFI), The University of Tokyo, Tokyo, Japan

Amlan Ghosh Symbiosis Institute of Geo-Informatics, Symbiosis International (Deemed University), Pune, Maharashtra, India

Namrata Ghosh Public System Group, Indian Institute of Management (IIM), Ahmedabad, Gujarat, India

Dessy Gusnita Research Center for Climate and Atmosphere, National Research and Innovation Agency of Indonesia, Bandung, Indonesia

Mark Ethan Harrison University of Tennessee, Knoxville, TN, USA

A. S. M. Imrul Kayes Unnayan Prochesta, Satkhira, Bangladesh

Sumaia Islam Urban Management and Development, Institute for Housing and Urban Development Studies, Erasmus University Rotterdam, Rotterdam, Netherlands

Jagrati Jain RV College of Architecture, Bengaluru, India

Niraj Jain Department of Real Estate Studies, Copperbelt University, Kitwe, Zambia

G. Jayapal Department of Geography, Kannur University, Kannur, Kerala, India

K. Jayarajan Department of Geography Government College Chittur, University of Calicut, Kozhikode, India

Cudjoe Justice Department of Geography and Resource Development, University of Ghana, Legon, Accra, Ghana

Tatik Kartika Research Center for Remote Sensing, National Research and Innovation Agency of Indonesia, Cibinong, Indonesia

Leena Khadke Department of Civil Engineering, Indian Institute of Technology (IIT) Bombay, Mumbai, Maharashtra, India

Prawira Yudha Kombara Research Center for Climate and Atmosphere, National Research and Innovation Agency of Indonesia, Bandung, Indonesia

Derya Evrim Koç Sakarya University, Faculty of Humanities and Social Sciences, Department of Geography, Esentepe, Sakarya, Türkiye

Paulose N. Kuriakose Department of Urban and Regional Planning, School of Planning and Architecture, Bhopal, Madhya Pradesh, India

Kiyo Kurisu Department of Urban Engineering, Graduate School of Engineering, The University of Tokyo, Tokyo, Japan

Nand Lal Kushwaha Division of Agricultural Engineering, ICAR–Indian Agriculture Research Institute, New Delhi, India

John Manyimadin Kusimi Department of Geography and Resource Development, University of Ghana, Legon, Accra, Ghana

Lilias Makashini Department of Real Estate Studies, The Copperbelt University, Kitwe, Zambia

Sukir Maryanto Department of Geophysics, Brawijaya University, Malang, Indonesia

Biraj Kanti Mondal Department of Geography, Netaji Subhas Open University, Kolkata, India

Manishree Mondal Department of Geography, Midnapore College (Autonomous), Midnapore, India

Laily Mukaromah National Research and Innovation Agency (BRIN), Purwodadi Botanic Garden, Pasuruan-East Java, Indonesia

Sanchari Mukhopadhyay Center for the Study of Regional Development, School of Social Science, Jawaharlal Nehru University, New Delhi, India

Ephraim Kabunda Munshifwa Department of Real Estate Studies, Copperbelt University, Kitwe, Zambia

Anthony Mushinge Department of Real Estate Studies, Copperbelt University, Kitwe, Zambia

Sk. Mustak Department of Geography, Central University of Punjab, Bhatinda, Punjab, India

Prakash Nagesh Centre for Transportation and Logistics, Indian Institute of Management (IIM), Ahmedabad, Gujarat, India

Markus Neppl Department of Architecture, Karlsruhe Institute of Technology, Karlsruhe, Baden-Württemberg, Germany

Nurjannah Department of Statistics, Brawijaya University, Malang, Indonesia

Joan Nyika Department of Civil Engineering Science, University of Johannesburg, Johannesburg, South Africa

Takahiro Osawa Center for Research and Application of Satellite Remote Sensing, Yamaguchi University, Ube-Yamaguchi, Japan

Deb Prakash Pahari Department of Geography, The University of Burdwan, Bardhaman, West Bengal, India

Manju Pandey Government Mata Shabari, Navin Girl's College, Bilaspur, Chattishgarh, India

Archana Patnaik Department of Humanities and Social Sciences, Indian Institute of Technology Kharagpur, Kharagpur, India

Meenakshi Pawar Department of Environmental Planning, School of Planning and Architecture, New Delhi, India

T. K. Prasad Department of Geography, Kannur University, Kannur, Kerala, India

Angga Yolanda Putra Directorate of Laboratory Management, Space and Atmosphere Observation Pontianak, North Pontianak, Indonesia

Zhu Qian Faculty of Environment, School of Planning, University of Waterloo, Waterloo, Canada

Nurul Sri Rahatiningtyas Department of Geography, University of Indonesia, Depok City, Indonesia

Fahmi Rahmatia Research Center for Climate and Atmosphere, National Research and Innovation Agency of Indonesia, Bandung, Indonesia

Shweta Rani Department of Geography, Dyal Singh College, University of Delhi, New Delhi, India

Nikita Ranjan Department of Architecture and Planning, Indian Institute of Technology Roorkee, Roorkee, Uttarakhand, India

Kazi Jihadur Rashid Remote Sensing Division, Center for Environmental and Geographic Information Services, Dhaka, Bangladesh

Nur Faizah Romadona Department of Microbiology, Indonesia University of Education, Bandung, Indonesia

Sushma Sahai Department of Geography, Loreto College (University of Calcutta), Kolkata, West Bengal, India

Herry Santosa Department of Architecture, Brawijaya University, Malang, Indonesia

Heru Santoso Research Center for Climate and Atmosphere, National Research and Innovation Agency of Indonesia, Bandung, Indonesia

Wilin Julian Sari Research Center for Climate and Atmosphere, National Research and Innovation Agency of Indonesia, Bandung, Indonesia

Sumana Sarkar Department of Geography, The University of Burdwan, Burdwan, West Bengal, India

Udit Sarkar Data and Management Unit, Ministry of Housing and Urban Affairs (MoHUA), Government of India, New Delhi, Delhi, India

Suresh Selvaraj SreeSankaracharya University of Sanskrit, Kalady, India

Saroj Senapati Department of Geography, Atal Bihari Vajpayee Viswavidyalaya, Bilaspur, Chhattisgarh, India

Amrita Sen Department of Humanities and Social Sciences, Indian Institute of Technology Kharagpur, Kharagpur, India

Sucharita Sen Center for the Study of Regional Development, School of Social Science, Jawaharlal Nehru University, New Delhi, India

Vullapu Sai Sesidhar Department of Planning, School of Planning and Architecture, Vijayawada, Andhra Pradesh, India

Martiwi Diah Setiawati Research Center for Oceanography, National Research and Innovation Agency (BRIN), Jakarta, Indonesia

Wiwiek Setyawati Research Center for Climate and Atmosphere, National Research and Innovation Agency of Indonesia, Bandung, Indonesia

Amir Shakibamanesh Faculty of Architecture and Urban Studies, Tehran Art University, Tehran, Iran

Osmar Shalih National Disaster Management Authority (BNPB-RI), Bogor, Indonesia

Madhuri Sharma Department of Geography and Sustainability, University of Tennessee, Knoxville, TN, USA

K. P. Shimod Department of Geography, Kannur University, Kannur, Kerala, India

Vibhu Singh School of Planning and Architecture New Delhi, New Delhi, India

Sudarshana Sinha Department of Humanities and Social Sciences, Indian Institute of Technology Kharagpur, Kharagpur, West Bengal, India

Aman Srivastava Formerly, Centre for Technology Alternatives for Rural Areas (CTARA), Indian Institute of Technology (IIT) Bombay, Mumbai, Maharashtra, India

Sujarwo Department of Agribusiness, Brawijaya University, Malang, Indonesia

Sumaryati Research Center for Climate and Atmosphere, National Research and Innovation Agency of Indonesia, Bandung, Indonesia

I. Nyoman Sunarta Tourism Faculty, Udayana University, Denpasar-Bali, Indonesia

Yuliana Susilowati Research Center for Climate and Atmosphere, National Research and Innovation Agency of Indonesia, Bandung, Indonesia

Ayon Kumar Tarafdar Department of Planning, School of Planning and Architecture, Vijayawada, Andhra Pradesh, India

Anil S. Thakur Independent Researcher, Urban Planner, Designer and Architect, Melbourne, Australia

Katibe Aslı Tunçat Sakarya University, Faculty of Humanities and Social Sciences, Department of Geography, Esentepe, Sakarya, Türkiye

Beyza Ustaoğlu Sakarya University, Faculty of Humanities and Social Sciences, Department of Geography, Esentepe, Sakarya, Türkiye

Omid Veisi Faculty of Architecture and Urban Studies, Tehran Art University, Tehran, Iran

V. Vineethkumar Department of Physics, Government College Kasaragod, Kasaragod, Kerala, India

Md. Yachin Islam Graduate School of Bioresources, Mie University, Tsu City, Mie Prefecture, Japan

Adipandang Yudono Department of Urban and Regional Planning, Brawijaya University, Malang, Indonesia

Idah Ethel Zulu Department of Urban and Regional Planning, Copperbelt University, Kitwe, Zambia

Part I
Introduction

Chapter 1
Global Narratives of Knowledge and Innovation-Based Development

Vibhore Bakshi and Arindam Biswas

Abstract The composite of knowledge and innovation play a vital role in the economic and spatial restructuring of the city. The chapter examines the research that includes need identification with emerging global discourses of knowledge and spatial development. The assessment of the critical parameters for knowledge and innovation from a global and Indian perspective. The evaluation of knowledge-based indicators for Karnataka along with sustainable development goals. This chapter has four sections. The first section discusses the global cases for knowledge-based development and growth. The examination of expenditure on research and development as gross domestic product percentage for India is only 0.64 in juxtaposition to Israel and South Korea which has a higher proportion of 4.95 and 4.80% dedicated to innovation and research. The second section discusses India's existing condition and proposed approaches to embark upon knowledge-based growth and development. This assessment includes the 'global innovation indices' and NITI Aayog's knowledge-based development parameters. The third section addresses the SDGs and innovation policies from notable Indian states. The chapter particularly focuses on Karnataka Vision 2030 since it has obtained the best score in NITI Aayog's ranking for innovation 2020. Lastly, some recommendations for knowledge-based development, demystifying the approaches from international and national cases, are included at the end of chapter.

Keywords Knowledge and innovation · Knowledge-based development and growth · Global innovation indices · NITI Aayog's · Knowledge indices · Innovative policies · Karnataka Vision 2030

V. Bakshi (✉)
School of Planning and Architecture, Bhopal 462030, India
e-mail: vibhore.bakshi@spabhopal.ac.in

A. Biswas
Department of Architecture and Planning, IIT Roorkee, Uttarakhand, India
e-mail: arindam.biswas@ar.iitr.ac.in

U. Chatterjee et al. (eds.), *Urban Commons, Future Smart Cities and Sustainability*, Springer Geography, https://doi.org/10.1007/978-3-031-24767-5_1

Introduction

The broader understanding of history and emergence of Knowledge-based clusters can be identified from paradigms of 'Theory of Creative Destruction' in 1940s by Joseph Schumpeter, Core Peripheral model by John Friedman in 1966, Michael porter's 1988 concept of cluster development, Manuel Castells and Peter Hall's principles of development of Knowledge clusters in 1994, Saxenian's networked approach for a region, network of global cities by Sasskia Sassen in 2001 and Richard Florida's philosophy of creative class in 2005. The advent of industries in 1950s around US and many europeon cities, causal implications on the cities was evident, migration to industries extensive region promoted spread effect; on contrary to the areas which lacked the prospects of development from where migration happened led to backwash effect (Mydral, 1957). The emergence of the approach of knowledge diversification can be witnessed from the model of Silicon Valley and Ottawa in the early 1950s, to knowledge specialisation around 1990s for Helinski and Cambridge. The attributes for Knowledge firm and environment sought to include factor inputs like public policies, market dynamics and supporting industries (Huggins 2008). The knowledge-based urban development framework depicts socio-cultural development, enviro-urban development, institutional development and economic development (Yigitcanlar 2011). The knowledge cluster proposition represents two approaches for knowledge-based development, i.e. regional approach and cluster development approach (Isaksen 2004). The knowledge development includes vibrant business climate, quality of life and economic prosperity. The cluster development approach depicts the role of organisation, governance and financing (Asheim et al. 2005). The knowledge proposition inculcates talent pool, education, technology, market, business network, capital, connectivity and incubation centres. Many cities, as emerge from the literature reflects on the essential role of knowledge in nation building, however few cities of Italy ponders us to think, how knowledge plays a vital role, when pandemic situation arises (Salvatore et al. 1950). The Knowledge theories have evolved over a period of time; the changing paradigms of knowledge is witnessed by the different countries across the globe.

The process of knowledge creation and entrepreneurship requires innovation that can contribute in making an effective regional innovation policy (Asheim et al. 2005). The five key elements are industrial knowledge bases, different territorial competence bases, the distributed knowledge base, the importance of creative knowledge environments and different institutional frameworks. In Neo liberal era, spatial restructuring process is predetermined by the industrial location and mobility linkages from residential clusters of the workers to industrial estates, this leads to emergence of gentrification (Easton et al. 2020). The economic recession around the 2000s has disrupted the growth of knowledge-based and technological industries (Anne 2021). The case of Silicon Valley, Cambridge, Ottawa and Helinski ought to emerge globally through new networks fostering economic policy and firm networking (Huggins 2008). The local development strategy for innovation districts focuses on policy realms for urban and spatial aspects of the knowledge economy. As emerges from literature, Barcelona, Boston, Chattanooga, Detroit, Medellin, Montreal, Philadelphia, Rotterdam and Sydney are few visionary cities that tend to follow footsteps towards innovation district. The conceptualisation of the innovation district induces regenerative measures for underperforming settlements into major knowledge centres (Yigitcanlar and Velibeyoglu 2008). The knowledge theories address the sectoral facets associated with spatial cluster development (Porter 1996).

The emerging theories (Table 1.1) of knowledge development showcase the principles of creative destruction, spatial dynamics of core and periphery, cluster development, regional advantage, technology, digital and network cities, creativity, knowledge networking and framework for knowledge-based urban development.

Global Cities: Prospects of Knowledge-Based Development

The regionalisation process in Cologne adopts the regional clustering techniques with a framework of successful policy implementation. Singapore's approach for a knowledge-based economy describes ICT, innovation, entrepreneurship, business reorganisation, process of globalisation, government–industry partnership and effective implementation of policies. The applicability of the various knowledge paradigms is relatable to the case of London. The city of London has witnessed major spatial expansion in Knowledge-based industries in the peripheral boroughs around 1970s and 1980s, availability of peripheral land at cheaper price has fostered the Knowledge-based industries growth in juxtaposition to the slower pace growth of retail and leisure industries (Cottineau and Arcaute 2020). Cyberaja has emerged as a knowledge city by strengthening the knowledge networks through urban planning interventions by the administration in Peninsular Malaysia. The process of knowledge development in Cyberaja township started in 1997. The intent of developing Cyberaja as information and communication technology (ICT) hub focuses on the principle of Tacit knowledge. Cyberaja depicts an ideal case of influential spatial planning and knowledge-based cluster development. Furthermore, the proximity of ICT clusters has extensively contributed in restructuring process (Ramli 2012). The pillars of Knowledge creation, innovation and entrepreneurship are evident from Sweden. The strategies adopted in Sweden's case highlight the role and responsibilities of different institutions for nourishment of knowledge networks (Asheim et al. 2005). The innovation in Sweden can be assessed through the framework of the Triple Helix model, i.e. private, government and institution. The four-stage process can be envisaged in the development process of Sweden for promoting knowledge-based urban development—inception, implementation, consolidation and renewal. Triple Helix approach adopts innovation for business, government and academic factors. The extent of harnessing entrepreneurship skill sets in the universities with the process of creating incubation centres are the baby steps for promoting innovation. The emergence of revolution in automobile industries in 1940s and 1950s can be witnessed from the the developments by Henry Ford, where innovation took over

Table 1.1 Knowledge theories and propagators

Serial No	Knowledge theories	Year	Propagators	Concept
1	Theory of creative destruction	1942	Joseph Schumpeter	Capitalism replaced by innovation, regional innovation contributes to economic growth, more productivity and increasing wealth
2	Core peripheral model	1962	John Freidman	Spatial focus on the equal distribution of resources, includes economic, political and cultural sectors
3	Concept of cluster development	1966	Michael Porter	Economic activities are agglomerated in clusters, bind by social groups, industrial knowledge clusters depend up on education, information, research and technical support to a regional economy
4	Concept of technopolis, space of flows	1994	Manuel Castells and Peter Halls	Knowledge is technology driven. It depends up on proximity to research centres. Innovation and economic prosperity are major determinants of Knowledge
5	Regional advantage	1995	Anna Lee Saxenian	The importance of regional advantage, examples of Silicon Valley, emerging knowledge clusters reshaped the regional clusters in USA
6	Network cities and globalisation	2001	Sasskia Sassen	The global economic network, information flow and technological advancements can foster the regional development, sought to be seen in Tokyo, London and New York

(continued)

Table 1.1 (continued)

Serial No	Knowledge theories	Year	Propagators	Concept
7	Creative class	2005	Richard Florida	Regional policy depends up on creative professionals, creative industries, the multiple occupations in creative industry generates more wealth, the approach describes Chicago's creative class
8	Knowledge framework of urban development	2013	Yigicanlar	Sectoral facets of society, economy, institutions contribute to knowledge
9	BCI global	2020	Business Continuity Institute	Includes talent pool, education, technology, market business network, capital, connectivity and incubation centres

the capitalism, and the replacement of goods by better cost effective technology was evident (Schumpeter 1939, 1954). The approach to examine knowledge-based urban development from the domains of economy, society, management and technology is clearly evident in Austin, Barcelona, Helsinki, Melbourne, and Singapore. The capital city of Norway, Oslo, depicts very close interaction between consulting companies and important customers. The activities of clients and consultants are project-based and involve lots of coalition-building and face-to-face contact which is facilitated by knowledge sharing when players colocate. The industrial district model of Oslo highlights the interaction between the local software firms and suppliers (Isaksen 2004). The boost in economic prosperity of Brisbane can be attributed to shifting production from industrial and mass manufacturing to knowledge-intensive goods and services production through competitiveness, sustainability and urban development. It incorporates creative environment, administrative environment, business environment, natural and built environments (Yigitcanlar and Velibeyoglu 2008). The strategy for smart, sustainable and knowledge-based development in Brazil ascertains qualitative analysis through surveys and interviews with key experts and stakeholders' socio-cultural development, economic development, spatial development and institutional development (Sabatini et al. 2020). The urban and rural redevelopment process in France, UK and USA depicts the phenomenon of gentrification caused by increasing migration; the facilitation for housing migrants around knowledge-based industries is reflected in the industrial policies of EU and USA. The process of gentrification is evident in Chittagong, Bangladesh, induced by better employment opportunities and migration through urban development principles of social development, economic development and lesser real-estate prices (Morrison and Bevilacqua 2019). However, there are few issues observed in Chinese cities like inequality of income wage slabs, income polarisation, lack of skilled-based technological change and fading network connections with premier institutions in the development of knowledge clusters that act as major hurdles towards inclusive urban development. In the past few years, knowledge-based economic development has further contributed to crony capitalism, and the rapid increase in urbanisation has contributed to widening income inequality. The ladder toward urban development has given rise to the creative disciplines and policy restructuring process for enabling knowledge-based urban development. The growth of tertiary sectors results in the widening gap between the wages of skilled labour in China (Liu et al. 2019). The efforts for making Melbourne a knowledge city focus on robust economic performance in knowledge-intensive sector, innovation and entrepreneurialism, availability of skilled labour, enabling infrastructure for knowledge dissemination, global ties, emergence of disruptive technology and high degree of livability. In Los Angeles, the process of innovation, entrepreneurship, academic institutions, business firms and potential investors converge to enable efficient vibrant and conducive entrepreneurial network (Graf, 2016). In Japanese cities, the role of global supply chain in Research and Development sector is identified as potential contributor in promoting knowledge and innovation (Huang et al. 2021).

Research Framework

In the previous section of the chapter, many approaches are demystified that collates a broader understanding of knowledge enabling mechanism from a global perspective. However, to understand the current situation of India in knowledge and Innovation, there are few questions to embark on the research chapter as mentioned below in Table 1.2. The emerging research need for knowledge and innovation can be identified for Indian cities from the attributes like global percentage share estimates by NITI Aayog in research and development sector for India which is just 0.68 percentage of overall country's GDP. UNDP, global innovation report card 2021, reveals that India is a moderate performer since it lags in the attributes of preliminary education, higher education, ICT, economy, enabling environment in comparison to the overall average.

The outcome of the research chapter focuses on the global and Indian perspectives of enabling knowledge and innovation-based framework perhaps it highlights Karnataka as a state model that can be adopted for other states in India.

Estimates for Global Research and Development

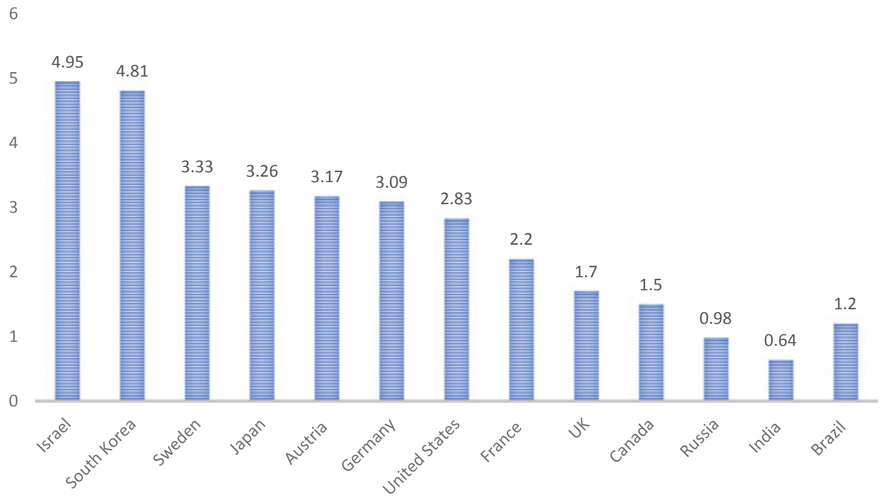
Research and development relentlessly drives the innovation and act as an engine to the IT sectors. This section of chapter tries to adopt a method of examining the reasons for, why few nations have invested more in the research and development industries, learnings and takeaways from the nations. Furthermore, understanding

Table 1.2 Research questions and objectives

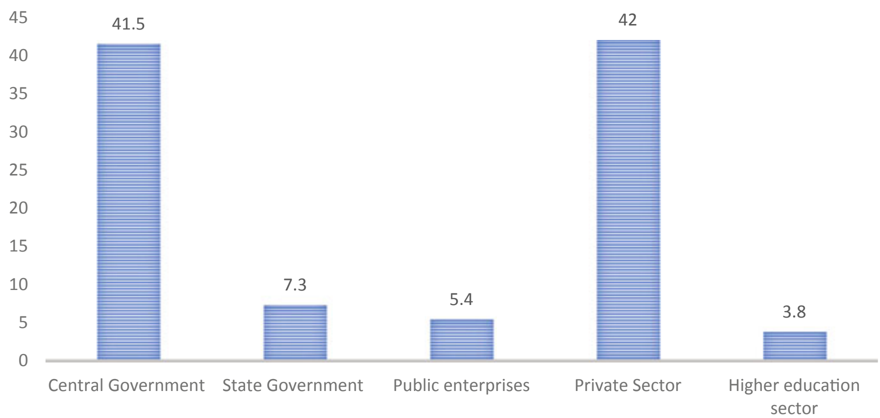
Serial No	Research questions	Objectives of the research	Datasets
1	What approaches can be adopted for fostering innovation and knowledge in Indian cities ?	Identification of theories of knowledge and innovation (Table 1.2) Assessment of existing frameworks for knowledge development across the globe	Approaches adopted in Cologne, Singapore, London, Cyberaja, Sweden, Austria, Barcelona, Melbourne, USA, UK and Brazil through literature
2	What is the current situation of India in knowledge and innovation?	Assessment of India from GDP, R&D investment percentage, from the lens of global and Indian indices and overall assessment of knowledge and innovation parameters Graphs 1.1, 1.2, 1.3 and 1.4 and Table 1.3	Estimates of global R&D, innovation initiatives in India, approach for innovation, NITI Aayog Index 2021, UNDP Global Knowledge Framework 2021, Bloomberg Index 2020
3	What is the existing mechanism for knowledge and Innovation dissemination in Karnataka since it has obtained best rankings in NITI Aayog report 2021?	Assessment of Karnataka's initiatives for Knowledge output through policy measures and the overall comparison of state's SDG indicators Fig. 1.1 and Table 1.4, Graphs 1.5 and 1.6	Karnataka's Vision 2030, Economic Survey for Karnataka 2021, IBEF report 2018

the dynamics, policy regimes of different nations, the major research question in the whole process is 'How the investments in Research sectors have transformed the city from the agrarian society to the major wealth generators', Why such contributions are lesser in the developing economies, what changes can be thereof thought off to strengthen the knowledge and innovation sectors. In this section of the chapter, the assessment of different countries is done as shown in Graph 1.4.

The (OECD, 2021) estimates depict the marginal increase in R&D expenditure, as percentage of gross domestic product increased from 2.4% in 2018 to 2.5% in 2019. The year 2017 and 2018 were marked by higher spendings on R&D sectors since there was a stagnation between 2013 and 2016. Israel and Korea are the top performers among OECD countries. Regions tend to witness spatial growth propelled

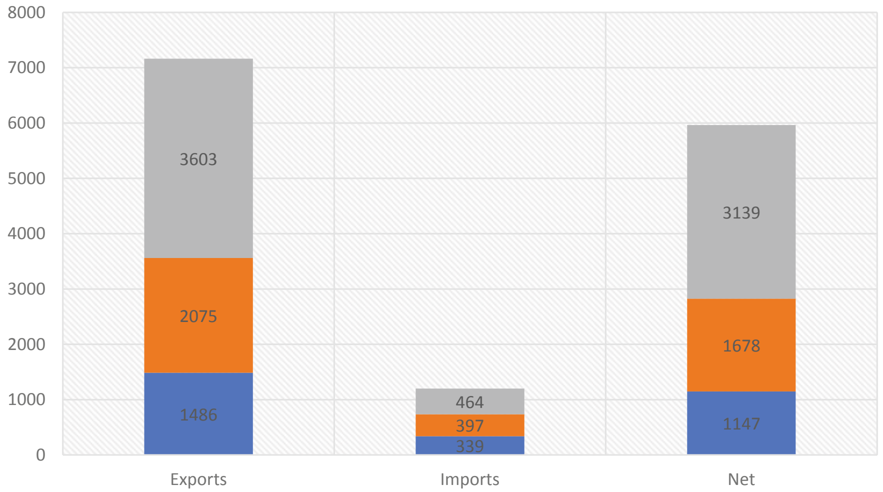


Graph 1.1 R&D expenditure (% of GDP). *Source* Niti Aayog Report (2020)

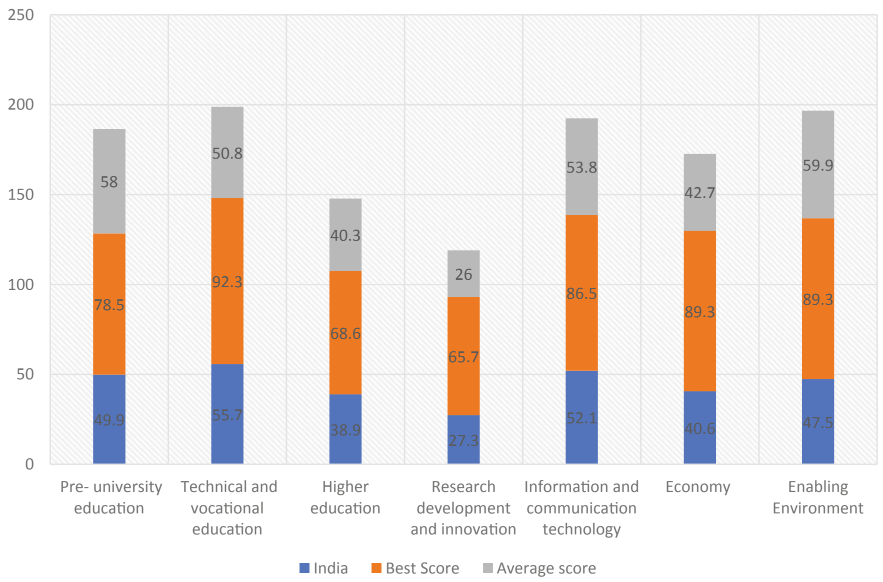


Graph 1.2 India's key players in R&D ecosystem. *Source* R&D ecosystem, India, 2019

by industrial locations, and population agglomerates around industries intensive regions, where the process starts with knowledge specialization followed by knowledge diversification in next subsequent stages (OECD, 2009). NITI Aayog, 2020 rankings for India reveal that R&D expenditure percentage in India leapfrogs around 0.64 in comparison to Israel and South Korea who are the top performers due to more contribution in R&D, varying from 4 to 5 percentage of overall, followed by the other nations.



Graph 1.3 Export, import and net trade in US dollars in R &D sector (2015, 2016 and 2017) 2015 2016 2017 . *Source* RBI Datasets, India, 2019



Graph 1.4 Global knowledge scores. *Source* UNDP Report: Global Knowledge Index 2021

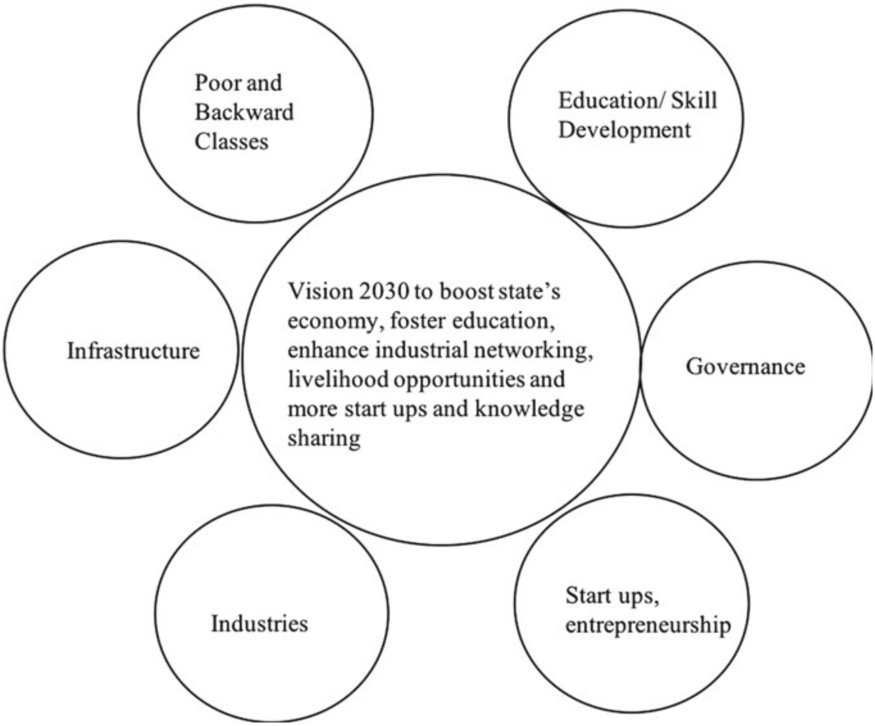
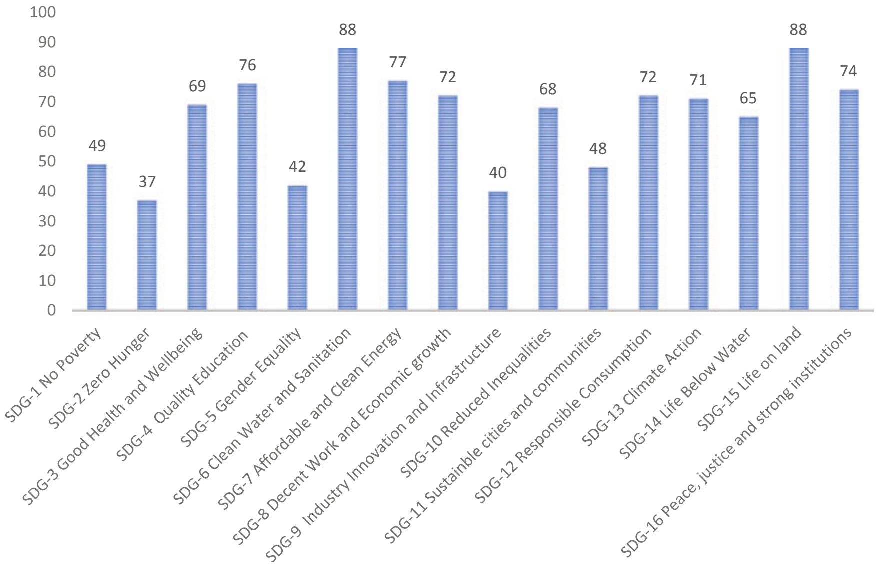


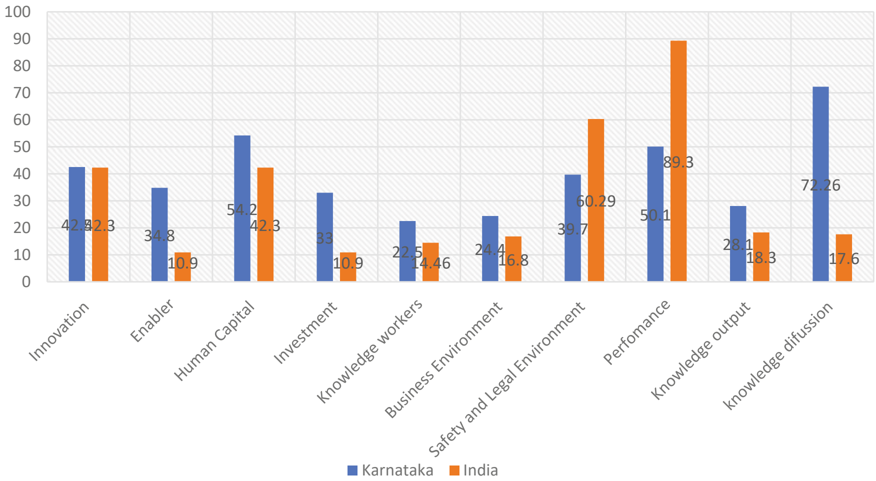
Fig. 1.1 Karnataka's Vision 2030: knowledge economy. *Source* Economic Survey of Karnataka, 2020

Innovation Initiatives in Developed Economies

Israel's high-tech sectors have contributed immensely in innovation, and the paradigm shift in technological sectors, with the government collaboration, has contributed to the emergence of Israel as one of the Silicon Valleys of the world (Trajtenberg 2001). The process of reevaluation and reassessment of the policies at periodic levels, the government initiatives for strengthening research and development sector dates back from 1968, the ministry of trade and commerce established office of the chief scientist (OCS) was set up in the initial years for subsidising the research and development projects undertaken by private firms. Moreover, Magnet Program was introduced by the government of Israel in 1990s to integrate the academic institutions and academic centres. To boost entrepreneurship, and welcome new ideas, the government introduced 'incubators program'. Later on, BIRD program, Israel-US Bi-national Industrial Research and Development Foundation (BIRD) came into formation in early 1980s to provide a support infrastructure for research and development activities. Israel leads in the intellectual property rights, i.e. the number of registered patents globally.



Graph 1.5 Karnataka sustainable development goals. *Source* Economic Survey 2021



Graph 1.6 Karnataka's innovation scores in comparison to India's average score. *Source* NITI Aayog 2021

The importance of intellectual property rights in dissemination of knowledge and innovation can be very well examined, from the Israel's model. The tremendous expenditure on research and development has resulted in the drastic transformation of Korea from agricultural economy in 1960s to technology driven land in later 2000s.

The interplay between government, academic institutions and the private companies has contributed immensely to the economic development. The large industrial conglomerates of family business led to the industrial advancements. The period of 1960s was also marked by the prestigious institutions, more knowledge exchange (Jung 2013). The Korean government established the Korean institute of Science and Technology in 1966 and made it operational in 1969. The institution played a significant role; it led to the technological advancements in the sectors of automobiles, machinery, electronics, metal steel and other industries. Few other initiatives were undertaken by the government of Korea around 1970s, like establishment of Korea institute of machinery and materials, Korean chemical research institutions and Korean institute of ship building. The government relied on the huge potential of human resource for research and development sector. The model of South Korea is sought to be highlighted from the economic growth paradigms of Romer (1990), Aghion (1992) and others, that focuses on the principles of more available resources like human resource in terms of engineers and scientists for research and development will contribute to the economic growth.

Within Europe, Sweden is the country, which has highest expenditures on R&D. The value of expenditure on R&D has doubled in last 25 years. The substantial expenditure of R&D in Sweden has boosted telecommunication sector, electronic sector and computing infrastructure. The Sweden has extensively invested in R&D sector as seen in Graph 1.4. It is intriguing to analyse the attributes of R&D sectors; automotive industry has contributed to more than 25 percentage of R&D expenditure in Sweden. Furthermore, information communication and technology also contributes to the major share in computer services. Sweden is described as one of the most prospering countries of European union since the process of R&D depicts the adoption of innovation measures in creating a niche in electronic market and attracting international investors. The regional innovation scorecard 2007–2019 released by European Commission highlights the emergence of Sweden as a leader especially in terms of increasing proportionate scores of research and development expenditure from 0.68 to 0.90 (R&D statistics 2019).

Innovation Initiatives in India

India is considered as one of the world's largest economies; therefore, there is a need to shift from net consumer of knowledge to net producer. The Vision 2022 for India needs to attract more investments in research and development. Investment in R&D sector is crucial for maintaining the global position of India as a knowledge economy. The gross expenditure on R&D has consistently increased in last few years. It has increased three folds from Rs. 24,117 crores in 2004 to almost Rs. 104,864 crores in 2016 (R&D Ecosystem report 2019). The share of India's R&D sector is illustrated in Graph 1.2.

Graph 1.2 showcases the major key player in research and development process is central government. Furthermore, the overall contribution of state government and universities which act as the major key players for R&D have lower consolidated shares than central government and private player individually. There is a need for more investments in higher education sector to foster knowledge ties across the globe. From the previous section of the chapter, it is analysed that academic institutions play a vital role in knowledge dissemination and economic restructuring of the cities. Secondly, India's global share in R& D expenditure is 2.8% equivalent to USD 48.1 billion. Among BRICS countries, India's expenditure is lowest at 0.63% of GDP as evident in Graph 1.1. Although, the share of GDP expenditure on R&D leapfrogs around 0.63%, the expenditure on R&D has increased from Rs 57,908 crores in 2015–2016 to Rs. 73,720 crores in 2017–2018 (Ministry of Statistics 2017).

To reassert the importance of higher education sector in R&D sector, there is an urgent need to examine the revenue propelled by intellectual property. The intellectual property datasets relate to the copyrights, patents, publications and royalty. The RBI datasets depict that the R&D exports have drastically increased from USD 1486 million in 2015–2016 to USD 3603 million in 2017–2018, whereas imports have significantly increased from USD 339 million to USD 464 million in 2017–2018 as shown in Graph 1.3.

The datasets pertaining to intellectual property, i.e. royalties, copyright and licence fees, highlight the immediate need to increase the revenue share from the exports of the intellectual assets which still stands at 732 million USD in year 2017–2018, followed by 568 million USD and 489 million USD in year 2015–16 and 2016–17, respectively. Moreover, the intellectual property expenditure for imports stands at a much higher proportions in comparison to imports. The expenditure from intellectual assets has increased from 4891 million USD to 5720 million USD and further to 6877 5720 million USD in year 2016–17 and 2017–2018 (DIPP datasets 2018).

Approach for Innovation

The approach for innovation enables policymakers and other stakeholders to assess the footsteps of development through knowledge-based principles. There are various assessment tools designed for evaluation of a country's innovation. These innovation indices sought to consider attributes for identification of the certain areas where the countries are lacking and where the countries are progressing. To assess the parameters of innovation, few indicators of innovation are taken into consideration.

1. UNDP, Global Knowledge Index 2021
2. NITI Aayog, Innovation Report 2020
3. Bloomberg Innovation Index 2021.

UNDP, Global Knowledge Index 2021

The global knowledge index, which was developed in 1917 by UNDP and released every year, identifies seven parameters for assessment of the knowledge framework for the countries. These seven parameters are pre-university education, technical and vocational education and training, higher education, research, development and innovation, information and communications technology, economy and the general enabling environment. The index undertakes the multi-disciplinary approach of knowledge development. The concept depicts the interlinkage with knowledge societies and knowledge economies limiting itself to education and technology (UNDP 2021). Global Knowledge Index is constituted by multi-dimensional knowledge attributes pertaining to economic and social development. The approach adopted for knowledge-based innovation deciphers the diagnostic approach with a multi-facet principle of human development and knowledge sharing linking it with sustainable development goals Agenda 2030. The application of global knowledge index covers 138 countries and overall 199 comprehensive indicators, serving as important tool sets for urban planners, policymakers for inducing better knowledge centres. The Global Knowledge Index Report 2020 elaborates parameters highlighting pre-university education, technical and vocational education and training, higher education, research development and innovation, information and communication technology, economy and general enabling environment. attributes. While Norway sought to secure first position in the general enabling environment. Out of 138 countries, India ranks at 75 in the global knowledge index.

The global knowledge index depicts India as a moderate performer overall, and it ranks second in 24 countries with medium human development.

The examining of the sectoral indices for India identifies the attributes globally ranked universities, export of creative goods, i.e. trade scenario, the tertiary composition from science and technology, engineering and mathematics, protection of minority investors, best scientific journals; however, improvement is required in enrolment in vocational training programs, labour degree of freedom, labour participation from female to male, enrolment in globally ranked universities. The assessment of the parameters for the knowledge index indicates that Switzerland secures the first position with a score of 73.6. The examination of sectoral indices for knowledge reveals that Finland secures the first position in the parameter of pre-university education followed by Hongkong. For the aspect of technological and vocational training and information communication and technology, it is seen that the USA secures the first position with a score of 92.3. Switzerland obtains highest marks of 68.6 and 65.7 in research development and innovation and thus securing first position in the domain of higher education. Singapore obtains the highest score of 76.6, securing first position for economic attributes. It is sought to examine that scores for India for attributes like pre-university education, higher education, information and communication technology are lesser than the global average. The master planning approach and the innovation district planning approach with an efficient policy framework together can lead to better prospects for the future. With rise in urbanisation, and demographic dividend comprising a young population, India has a huge potential to contribute to the knowledge sector, thus increasing the scores in knowledge indicators and securing a better position globally.

Bloomberg Innovation Index 2021

The Bloomberg Innovation Index 2021, released in Feb 2021, focuses on seven equally weighted metrics. The indicators for Bloomberg innovation inculcates indicators of research and development, more production and the knowledge agglomerations for high-tech companies. Seven European countries have ranked in the top ten rankings. South Korea has ranked first. The disruption in the health sector amidst coronavirus sought to promote innovation worldwide. Many countries have adopted digital innovation mechanisms to fight the virus. South Korea's first position depicts the innovation and efficient conducive working environment, major economic contribution in research and development sector and more budgetary fund allocation for business transition to digital economy. Prospering manufacturing units with digital technology sought to be analysed from Singapore's economic growth; furthermore, the eminent educational institutions have transformed the fabric of Singapore in emerging innovative and knowledge centre. While few cities like Germany lack of skilled labour and adequate strategies have disrupted the innovation process. Intellectual property rights have been a major hurdle in the growth process of the USA and China in the path of innovation. The developing Asian countries like India have ranked extensively in the top 50, for the first time in the last seven years. The indicators for Bloomberg innovation index highlight research and development, spendings of government thus contribution to GDP, manufacturing value contribution per capita, post-secondary education enrolments, Ph.D. enrolment and patents per million population.

NITI Aayog, Innovation Report 2020

The innovation report released by NITI Aayog in 2020 amidst COVID highlights the key principles of social and economic development. NITI Aayog innovation index ranks Karnataka in top position among the major states in India, while Maharashtra occupies the second place followed by Tamil Nadu. The vision of India sought to be called a 5 US dollar trillion economy is linked with the innovation led approach. (NITI Aayog 2020) It is evident that amidst the pandemic, economic growth has been disrupted in different lockdown phases across not only in India but also across the globe. The innovation strategies inducing knowledge-based development is the need of the hour. India should capitalise on the young manpower and knowledge-based facets of urban and regional planning. The advent of programs by the ministry like 'Make in India' and 'Atmanirbhar Bharat' sought to envisi on the economic development process in India. India's innovation report describes the comprehensive assessment of innovation capabilities of 28 Indian states and 9 union territories. The Indian innovation index focuses on two aspects of enablers and performance. It depicts seven key indicators for assessment of innovation capabilities in terms of underperforming and over performing for different states in India. Innovation scores are calculated by taking the average of five indicators of enablers and two indicators of performance. The five indicators undertaken for enablers are human capital, investment, knowledge workers, business environment, safety and legal environment; furthermore, performance indicators are knowledge output and knowledge diffusion.

Human capital relates to the education attainment and the research capabilities of individuals, research and development potential of the states, enrolment in Ph.D., enrolment in engineering and technology, pupil teacher ratio, schools with ICT infrastructure. The pillar of human capital questions the role of education in innovation capabilities. Investment in innovation depicts the expenditure on research and development, expenditure on science and technology, FDI flows and venture capitals. The attribute of knowledge workers depicts employment of individuals in highly skilled professions which can contribute to innovation. The next enabler indicator is business environment which considers ease of doing business rankings and technological advancements. The indicator relates to the conducive environment for innovation and work. Safety and legal environment sought to regulate and enforce the open procedures for promoting knowledge and innovation. The performance indicators embarks on knowledge output and further entails on the extensive contribution of research and development in transforming Indian cities in to knowledge capitals. The knowledge output comprises of intellectual assets (number of patents, copyrights, trademark and research articles published), whereas knowledge diffusion includes outreach of knowledge at various levels. This involves the interdependencies between academic institution, industries and the government (Yigitcanlar and Velibeyoglu 2008).

The average score of innovation indicators for Indian states is 23.4, on the range of scale where 0 depicts the worst scenario and 100 best scenario. The enabler scores for Indian states is 29, and performance score is sought to be 17.9. The detailed assessment depicts that the major contributors for innovation are safety and legal environment (60) and human capital (42.3), whereas the investment score (10.9) highlights the immediate need for improvement. The robust cybersecurity system and India's ranking (23) in UN's global cybersecurity index in 2017 highlight the immense contribution of ICT sector in economy, the increase in the manpower and job opportunities post-neoliberalisation, rapid expansion of IT sectors, software parks, rise in premier engineering institutions sought to provide a good score, whereas the low employability in knowledge sector in developed countries like India becomes a huge hurdle in knowledge diffusion and knowledge output which reflects the human capital is not contributing much in research and development, sought to be examined from lower investments on venture capital and research sector.

The NITI Aayog report on Indian innovation depicts that there is a positive correlation between the gross state domestic product and innovation, while it has few exceptions like Goa has less innovation score with more economic contribution because of the flourishing tourism sector. The Karnataka innovation score for the attributes depicts a GSDP contribution of 1.53 lakh per capita with efficiency ratio of 1.44; however, the state ranks first in innovation with overall score of 42.5, average score of the enabler and performance indicators. The enabler indicator is contributed by human capital (54.27), investment (33.01), business environment (24.43), safety and legal environment (39.75). The performance indicator includes parameters like knowledge diffusion (72.26) and knowledge output (28.13). The assessment of performance scores describes a fragmented picture for knowledge diffusion and Knowledge output in India in comparision to South Korea, Japan and Sweden, which have outshined in these indicators. There is a need to have more Ph.D. enrollments in India, the registration of higher institutions to professional bodies is a challenge, with a facilitation of ICT infrastructure. There is a need to invest more on higher education, since it will trigger knowledge-intensive employment. The participation of NGOs involved in knowledge sector is declining in India, therefore what attractive mechanisms can attract NGOs in Knowledge intensive sectors needs to be relooked through policy regimes, capacity building and community mobilisation. Business environment needs to be fostered by improving Ease of doing business ranking (42.86) and facilitation of more incubation centres for better knowledge needs. The chapter identifies Karnataka's State model as best case for examination for convergence of policies to boost knowledge and innovation, which are discussed in the later stage of chapter. Karnataka is performing well in terms of Knowledge diffusion (50.19) that relates to ICT export (100) which have increased sharply with advent of IT and software policies, around the period of economic liberalisation post-1990s. Another bigger challenge in knowledge diffusion through high and medium industries (9.12). Knowledge output (28.13) highlights the scope to further improve on grassroot innovations, patents, start-ups, innovation industries.

The (Table 1.3) knowledge and innovation parameters are extracted from global and Indian indices. The matrix identifies the areas of interventions for improving the overall process of knowledge-based urban development furthermore, it depicts the best case studies from sectoral point of views as discussed in UNDP, Global Knowledge Index 2021, NITI Aayog, Innovation Report 2020 and Bloomberg Innovation Index 2021.

Vision 2030: Government of Karnataka and SDGs

The strategies and action plans for achieving sustainable development goals 2030, a document prepared by the state department of Karnataka, highlight the visionary points in line with the state's vision for SDGs 2030. The indicators include sectoral aspects, social, economical and environmental dimensions of development. However, the report on vision 2030 assesses the 17 SDGs in detail. This research takes into consideration the critical parameters from the knowledge innovation indices at the country level and state level. The assessment of knowledge innovation indicators takes into consideration SDG 4 (quality education), SDG 8 (decent work and economic growth) and SDG 9 (industry, innovation and infrastructure). Vision 2030

Table 1.3 Knowledge and innovation parameters

Serial No	Parameters	Indicator	Need to focus	Best case models
1	Pre-university education, technical and vocational education, research development and innovation, ICT and economic environment	UNDP, Global Knowledge Index (2021) India ranks 74 out of 138 countries	Pre-university education, higher education remains a bigger challenge since dropouts are more in rural areas Research development infrastructure investments ICT enabling framework Need for enabling environment, since ease of doing rankings is a challenge	Switzerland scores the best in overall position, highest for research and development Norway secured first position for general enabling environment Finland efforts for facilitation of social infrastructure are best for pre-university education Digitalisation through policy, accessibility to big data in USA has resulted in improved rankings for ICT Singapore economic environment and policies are role model for other countries since it has secured the best position
2	Research and development, high-tech companies, conducive work environment, secondary education enrolments, economic contribution in education, Ph.D. enrolments and patents	Bloomberg Innovation Index (2021) India ranks 74 out of 138 countries	More research and incubation centres are required in India Digital technology adoption is a big challenge Rising number of Education dropouts	South Korea's first position depicts the innovation and efficient conducive working environment, major economic contribution in research and development Singapore has efficiently transformed due to eminent institutions and knowledge industries

(continued)

Table 1.3 (continued)

Serial No	Parameters	Indicator	Need to focus	Best case models
3	Enabler indicators: human capital, investment, knowledge workers, business environment, safety and legal environment	NITI Aayog Innovation Report 2020 for Indian States Karnataka ranks first in innovation	Enrolment numbers in Ph.D. Number of education institutions with NAAC accreditation. Schools with ICT infrastructure Higher education expenditure Knowledge-intensive employment in NGOs needs to be improvised Business environment rankings needs to be at a better position More incubation centres are required Knowledge diffusion through high and medium industries Improvisation in rankings of innovation, patents and start-ups	Economic activities are agglomerated in clusters, bind by social groups, industrial knowledge clusters depend up on education, information, research and technical support to a regional economy

Source Niti Aayog, 2020, Bloomberg, 2021, UNDP, 2021

specifically for SDG 4 focuses on reducing the dropout to zero from 26.18% in 2019 by creating awareness.

However, Karnataka's efforts for achieving the innovation rank-1 are witnessed from the relative comparison of sustainable development goals, (Graph 1.5), the gender equality, industry innovation and infrastructure, sustainable cities and communities which still remain a big challenge, despite of software and hardware statutory provisions which Karnataka underwent in 1980s and majorly triggered in 1990s (NASSCOM).

The vision 2030 Fig. 1.1 highlights the attributes pertaining to economic generation. Governance depicts the democratic participation of community, encourages transparency and more accountability. Furthermore, it focus on enriching the role of Bangalore's leadership in science and technology through knowledge-based industries. For poor and backward class, it focuses on increasing the incomes for rural areas through knowledge-intensive allied activities. This process is sought to reduce the social fragmentation between different classes of society. From very early phases of development, Karnataka has focused on Education and skill development as important pillars of knowledge and wealth generation, and have pioneered many schemes for reducing the school dropouts and engaging more number of students in the education impartment. State depicts the model case of proliferation of quality and accessible education to all. In rural areas of Karnataka, the school dropouts have significantly dropped to zero, and these records are maintained by the village education register under Right to Education. Amidst pandemic, Technology Assisted Learning Program (TALP) is sought to ensure 100% participation of children in imparting education on the principles of quality education to all socio-economic segments of society.

There is a need to facilitate more computer literacy initiatives to strengthen the digital gap and further expansion of digital education initiatives from pre-primary education to post-graduate educational programs. Karnataka still holds the legacy of prestigious institutions which is discussed in the later part of the paper. Karnataka as a state may emerge as one of the global knowledge, education and research hubs by 2025. The vision 2030 envisages to develop model schools in each Gram Panchayat, since it has already attained zero dropout. However, there is a need to facilitate a coherent role of NGOs, social help groups and private organisations to foster education at a state level. To embark on SDG 8, decent work and economic growth, there is a need to foster occupations that generate better wages and enhance the livability of citizens with prospering, economic growth. SDG 8 envisions on need to promote social infrastructure in health education and skills through public private partnership by attracting humongous investments. There is a need for conducive work environments for knowledge workers and MSME industries, to diffuse polarisation of wages, promoting equitable distribution of wages, from the perspective of Knowledge diversification. Karnataka ranks in topmost states of India in terms of employment; however, the vision 2030 on the aegis of Atma Nirbhar scheme focuses on reducing the unemployment rate less than 1% by 2030. Eradication of labour inequalities, child labour and encouragement of conducive work environment constitute as the primary ingredients for the vision of the SDGs by UN Habitat and the State Government of Karnataka, furthermore, fostering entrepreneurship, accounting the informal employment and boosting MSME's in knowledge production. To foster knowledge networks across the country, there are central government initiatives like start-up India, Skill India, Prime Minister's employment generation program, Pradhan Mantri Kaushal Vikas Yojana. Karnataka state-level policy initiative under the aegis of Chief Minister's Koushalya Karnataka Yojana, Chief Minister's Karnataka livelihood scheme, Rajiv Gandhi Yojana have transformed the livelihood opportunities of locals, state has witnessed occupational shifts from traditional occupations to creative profession in search of earning better. Start-up policy has propelled the start-ups and entrepreneurs to innovate and contribute to the economy of the state. Bangalore has emerged as the hub for start-up culture (UNH Report 2020). There is a need to necessitate huge investments in the services sector for increasing the gross state share per capita share of Rs. 210,877 (MOSPI 2020) as it ranks seventh in the country among different states, developing more innovative and knowledge-based industries and organising more investors to meet up. NITI Aayog 2018 datasets highlight accessibility of rural area inhabitants through roads under the aegis of Pradhan Mantri Gram Sadak Yojana; moreover, the mobile connections per 100 individuals in rural areas and urban areas appear to be one of the best for the state of Karnataka. The number of Internet users (44.32) is also more than the Indian average of 33.47, which sought to promote industrial innovation viz digitalisation. In regard to Global Start-up Ecosystem Ranking Report 2015, Bengaluru is the only Indian city to be ranked within the best twenty start-up cities across the world. To accomplish SDG 9, the government of Karnataka envisages to possess a leadership position in software and information technology-enabled services, biotechnology, nanotechnology and light engineering industry by 2025, paving the way for the state to achieve SDG 9 by 2030.

Graph 1.6 depicts the position of Karnataka in 'Knowledge dissemination process' through various attributes. The vision of Karnataka government is to foster the innovative capabilities. The huge investments in software and hardware, IT industries have extensively contributed to human capital and investments, which other states in India are still spearheading towards. The Karnataka represents the ideal case to examine the attributes in much details, the strategies, policies and attributes related to better scores can be a model for other Indian states; however, there is a need to focus on safety and legal environment for business.

Karnataka's Economic Initiatives to Foster Knowledge Ties

In the previous sections of the chapter, we have discussed the reasons for Karnataka's best innovation rankings. The state has emerged as one of the best investment destinations for investors. To improve the scorings for industry, innovation and infrastructure (Graph 1.3), New Industrial Policy 2020–2025 emphasises on the innovation parameters that will thrive the state's growth. Karnataka is pioneer in aerospace exports, software and hardware production. The statutes, the policies, statutes and location for Karnataka favour more foreign direct investment, availability of cheap labour, excellent accessibility and connectivity for the investors. The state contributes to 8% of overall foreign direct investment for India. The state has emerged home for tremendous population of 12 lakh software professionals, furthermore contributing to 31 lakh more jobs (Economic Statistics 2021). The Karnataka start-up policy 2015–2020 has registered 10,000 people thus contributing to USD 48 million. Karnataka start-up cell is sought to approve the licences for start-ups, incubators, investors, etc. Karnataka alone accounts for one third of electronics and computer software exports.

The advantages for Karnataka for promoting efficient business and improving knowledge ties include firstly good law and order situation prevailing in Karnataka which is conducive to foreign direct investments. Secondly, abundant availability of highly skilled manpower. Thirdly, Karnataka ranks among the top five industrially developed states in India. Furthermore, the state provides excellent logistic support and connectivity to the investors. All these points have extensively resulted in emergence of state as one of the biggest and fast expanding markets in the country since Karnataka has attracted FDI of USD 38,410 million from 2007–08 to 2020–21 (up to Nov 2020) constituting 8% of all India FDI.

The policies and initiatives to foster knowledge ties are evident from Table 1.4. The Karnataka Start-up Policy 2015 has extensively propelled the start-up culture in Karnataka and has boosted the innovation process, whereas the industrial policy 2014 has attracted huge investments across the globe, which has eventually resulted in the

Table 1.4 Karnataka's Policy Initiatives for Innovation and economic growth

Serial No	Policies for innovation	Intent for innovation
1.	Karnataka Start Up Policy-2015	Encouragement of start-ups in the State, Establishment of 25 innovative Technology Solutions in the State, Envisages to create 0.6 million direct as well as 1.2 million indirect jobs in Technology sector
2.	Industrial Policy 2014	To make Karnataka, the most preferred investment destination through inclusive, sustainable and balanced growth
3.	ESDM- Electronics systems Design and Manufacturing Policy, 2014	Generation of 240,000 new jobs, one fourth of India's Phd and more patent fillings in Karnataka, Investments in sector like Telecommunications, Defence, Medical, Industrial, Automotive, Consumer Products, applications and components. To Foster economic growth of ESDM to US $ 400 billion by the year 2020 and job generation over 28 million
4.	ICT Policy, 2011	Karnataka's pioneer role in outsourcing service for ICT. To retain the Karnataka's position in terms of largest skilled workforce in India for IT services. Products and R&D. To enable Karnataka to be the most preferred destination for MSMEs (Micro small and medium enterprises)
5.	SEZ Policy, 2009	Facilitation and establishment of SEZs at the same time safeguarding the environment and the interest of land owners

Source Economic Survey, 2021, IBEF report 2018

Karnataka's emergence as the top ranker in knowledge and innovation rankings by Ministry of Urban Development. Although it is discussed that the software policies have extensively contributed in restructuring process of urban planning, the ESDM 2014 is visionary in terms of job employment.

Role of Software Policies in Reshaping the State's Economy

The role of IT industries and software parks for Karnataka in global investments have been ground-breaking amidst 1990s liberalisation process in comparison to other states of India. Furthermore, it is intriguing to explore the spatial temporal dimensions of growth and innovation since the emergence of academic institutions and electronic cities have contributed immensely to the knowledge-based spatial growth. The research chapter also explores the possibilities of spatial expansion enlisted in the Master Plan of Bangalore and the way forward in development fostering innovation.

The software industries started flourishing in the mid-1980s with the advent of computer policy 1984. The rise in export of computer softwares and later technologies to abroad was evident in the early 1990s. The growth of software technology parks scheme facilitated a sharp increase in offsite services from on-site services. The global recognition share of offshore services has increased sharply post-IT reforms and policy amendments. Computer policy in 1984 initiated restructuring for software industries in a better way for increasing software exports globally with a vision to enhance global competitiveness. Although, on the contrary to this, the Department of Electronics (DOE) felt that provisions under the software policy were too rigid and cumbersome, the idea of self-dependent and global recognition was falling apart (Sridharan 2011). The digital revolution ought to be envisaged from the railway system computerisation administered by Rajiv Gandhi furthermore marked by the creation of Centre of the Development of Telematics (C-DoT), digital technology. The 1984 and 1986 software reforms for fostering economic growth for the country deciphers mere increase in gross domestic product (Sen 1994). The hike in software exports and global recognition were experienced in the 1990s around the neoliberalisation process. The introduction of Texas instruments in 1986 led to a flexible approach in the software development process and questioned the statute. For further expansion of software markets, the software technology park scheme was introduced by the Department of Electronics in the 1990s. Later on, 1991 the Software Technology Parks demanded for an autonomous power to avoid the government hindrance in the process of expansion of the software market all across the globe. The money devaluation post-economic liberalisation in 1991 attracted foreign investors. The removal of barriers in import of IT equipment and peripherals further led to the emergence of an export-oriented market for softwares in India. The Department of Electronics significantly contributed in reforming software statutes further followed by the efforts of National Association of Software and Service Companies (NASSCOM).

With the advent of 1984 policy changes in software, the global market allowed the local workforce in lesser wages in comparison to the prevalent wages in the USA. The availability of unemployed engineer youth was massive. The situation was marked as an opportunity for the English-speaking engineer in the country around the early 1990s. In this way, Bangalore has emerged as one of the unicorns for knowledge developments in India. In the next stages of research, the attempt to study the impact of Bangalore urban expansion in regard to the advent of IT and software parks will be analysed in detail since it has contributed extensively in the economic growth of Karnataka as a state, in terms of attracting huge investments and fostering knowledge networks.

Conclusion

The roadmap of India's innovation and knowledge development needs to identify the existing lacunas in the current innovation frameworks for efficient and effective knowledge dissemination. The convergence of approaches from the model of Cologne, Singapore, London, Cyberaja, Sweden, Austria, Barcelona, Melbourne, USA, UK and Brazil is lesson for India's economic growth. The integration of academic institutions with research and industry and network ties needs to be relooked. The current education system for higher studies needs to be fostered as India since the global rankings is not satisfactory in its representation for UNDP Global Knowledge Index, 2021. More school dropouts in rural areas, lack of investments and business enabling environment are the major concerns, more investment in R&D sector is required as can be learned from the models of South Korea and Singapore. The involvement of NGOs in imparting knowledge and promoting innovation is lacking in India as stated in NITI Aayog report, 2021. The ladder towards boosting knowledge economy for Indian states is challenging but not impossible, perhaps the contribution of policies and state's vision for boosting innovation and knowledge economy in Karnataka is an eye opener for other states of India. The research chapter has made an attempt to demystify Karnataka's model to be replicated for Indian cities in addition to the cross-learnings from global cases as discussed. The vision 2030 for Karnataka focuses on industries, facilitation of start-up culture, education and skill development as thrust sectors. The efficient policy implementation framework not only depicts the state's vision but also tries to analyse the knowledge attributes from the lens of global agenda of sustainable development goals. Amidst, neoliberal era the advent of software and hardware industries has emerged as knowledge industries in Karnataka where Bangalore has an immense contribution. The economic state policies for India must reflect on mechanisms to attract huge investments, enhancing human capital, more knowledge occupation and conducive business environment; however, India is emerging as one of the blooming economies; on this 75th Independence Day address, India has surpassed UK's economy and has become fifth largest economy of the world. The enhancement of above indicators through policy measures and effective implementation framework will leapfrog India's position to a better place in knowledge and economic rankings from global perspective.

References

Anne F (2021) Business insider: what caused the great recession? Understanding the key factors that led to one of the worst economic downturns in US history

Asheim B, Coenen L, Vang J, Moodyson J (2005) Regional innovation system policy: a knowledge-based approach, Centre for Innovation, Research and Competence in the Learning Economy (CIRCLE) Lund University, Paper no. 2005/13, http://www.circle.lu.se/publications. ISSN 1654-3149

Bhattacharjee S (2019) Comprehending the gentrification of a suburb: the case of Mulund, Mumbai, Springer Nature BV, GeoJournal. https://doi.org/10.1007/s10708-019-10067-5(01)

Botti A (2013) Making a sustainable neighbourhood: gentrification and urban regeneration in Glasgow, Edinburgh School of Architecture and Landscape Architecture, University of Edinburgh, pp 1–12

Business R&D in Western Sweden: 2020, Business Region Goteborg

Cottineau C, Arcaute E (2020) The nested structure of urban business clusters. Appl Netw Sci 1–8:10–20. Springer Open. https://doi.org/10.1007/s41109-019-0246-9

Crescenzi R, Alexander J (2016) Innovation in Russia: the territorial dimension. Econ Geogr. https://doi.org/10.1080/00130095.2016.1208532

Dutta PV, Nagarajan KH (2005) Spatial inequality among Indian villages do initial conditions matter? CPRC-IIPA Working Paper No. 29, pp 5–12

Easton S, Lees L, Hubbard P, Tate N (2020) Measuring and mapping displacement: the problem of quantification in the battle against gentrification. Urban Stud 57(2):286–306. https://doi.org/10.1177/0042098019851953

Etzkowitz H, Klofsten M (2005) The innovating region: toward a theory of knowledge-based regional development, R&D Management 35, 3, 5. Blackwell Publishing Ltd, pp 243–255

Edquist C, McKelvey M (1998) High R&D intensity without high tech products: a Swedish paradox? Innov Technol Dev 6:132–135

Fidrmuc J (2002) Migration and regional adjustment to asymmetric shocks in transition economies, William Davidson Institute, Working Paper 441, pp 1–8

Fuller S, Vosko FL (2007) Temporary employment and social inequality in Canada: exploring intersections of gender, race and immigration status. Springer Science, Soc Indic Res, vol 88, pp 31–50. https://doi.org/10.1007/s11205-007-9201-8

Global Knowledge Index Report: 2020, UNDP

Graf M (2016) Exploring sources of innovation in the knowledge-based economy the case of Los Angeles, Published by the RAND Corporation, Santa Monica, Calif Dissertation, pp 11–35

Hariharan A, Biswas A (2020a) Global recognition of India's knowledge-based industry evolution through empirical analysis. J Knowl Econ https://doi.org/10.1007/s13132-020-00673-x

Hariharan A, Biswas A (2020b) A critical review of the Indian knowledge-based industry location policy against its theoretical arguments. Reg Sci Policy Pract 12:431–454. https://doi.org/10.1111/rsp3.12257

Hariharan A, Biswas A (2020c) A temporal review of global recognition of India's knowledge-based industry through an institutional viewpoint. Reg Sci Policy Pract 2020:1–18. https://doi.org/10.1111/rsp3.12310

Huang CM, Lioun MH, Iwaki Y (2021) The impact of R&D and innovation on global supply chain transition: GTAP analysis on Japan's public R&D investment. J Soc Econ Dev (Suppl 3):447–S467 (Springer Nature). https://doi.org/10.1007/s40847-020-00113-1

Huggins R (2008) The evolution of knowledge clusters: progress and policy, economic development quarterly, vol 22, no 4. Sage Publications, pp 277–289. https://doi.org/10.1177/0891242408323196

India Innovation Report (2020) Niti Aayog, Government of India, Parliament Street, New Delhi, 110001

Isaksen A (2004) Knowledge-based clusters and urban location: the clustering of software consultancy in Oslo. Urban Stud 41(5/6):1157–1174. https://doi.org/10.1080/00420980410001675797

Jung J, Mah J (2013) R&D policies of Korea and their implications for developing countries. In: Science, technology & society. SAGE Publications, pp 165–188. https://doi.org/10.1177/0971721813489435

Liu CY, Zhiyong HF, Jeong J (2019) Towards inclusive urban development? New knowledge/creative economy and wage inequality in major Chinese cities. Elsevier Cities J. https://doi.org/10.1016/j.cities.2019.06.016

Morisson A, Bevilacqua C (2019) Balancing gentrification in the knowledge economy: the case of Chattanooga's innovation district. Urban Res Pract 12(4):472–492. https://doi.org/10.1080/17535069.2018.1472799

Myrdal G (1957) Economic theory and underdeveloped regions. Duckworth, London
OECD (2021) OECD main science and technology indicators. R&D Highlights in the March 2021 Publication, OECD Directorate for Science, Technology and Innovation. www.oecd.org/sti/msti2021.pdf
OECD (2009) How regions grow: trend and analysis. OECD Publisher, Paris
Oshima K (1973) Research and development and economic growth in Japan. In: Williams BR (ed) Science and technology in economic growth © International Economic Association, vol 12, pp 310–312
Patra S (2014) Knowledge production by Indian Biotechnology Parks. Asian Biotechnol Dev Rev 16(10:69–87 (Research and Information System for Developing Countries)
Ramli N (2012) Creating knowledge-based clusters through urban development: a study of Cyberaja, MSC Malaysia. Dissertation, pp 15–25
Research and Development statistics: 2019–2020, Government of India, Ministry of Science & Technology, Department of Science & Technology R & D Expenditure Ecosystem: Current Status & Wayforward: 2019, Government of India, pp 30–70
Riccardo C, Jaax A (2016) Innovation in Russia: the territorial dimension, economic geography. https://doi.org/10.1080/00130095.2016.1208532
Sabatini J, Yigitcalnar T, Schreiner T, Sotto D, Inkinen T (2020) Strategizing smart, sustainable, and knowledge-based development of cities: insights from Florianópolis, Brazil. Sustainability 2020 12:8859. https://doi.org/10.3390/su12218859
Salvatore A, Linzalone R, Felicetti AM (1950) Knowledge management in pandemics. A critical literature review. In: Knowledge management research & practice. https://doi.org/10.1080/14778238.2020.1801364
Sanyal B (2018) A planners planner: John Friedmann's quest for a general theory of planning. J Am Plann Assoc 84(2):179–191. https://doi.org/10.1080/01944363.2018.1427616
Schumpeter JA (1950) Capitalism, socialism and democracy, 3rd edn. Allen and Unwin, London
Schumpeter JA (1954) History of economic analysis. Oxford University Press, New York
Schumpeter JA (1939) Business cycles: a theoretical, historical and statistical analysis of capitalist processes. Macmillan, New York
Spišáková D, Emília BG, Spišák E (2021) Assessment of research and development financing based on the strategies in EU: Case of Sweden, Slovakia and Romania. Sustainability 13(15):8628. https://doi.org/10.3390/su13158628
Sridharan N (2011) Spatial inequality and the politics of urban expansion. Environ Urbanization ASIA 2(2):187–204 (SAGE Publications). https://doi.org/10.1177/097542531100200204
Trajtenberg M (2001) Innovation policy in the knowledge-based economy: R&D Policy in Israel: an overview and reassessment. In: Feldman MP et al (eds). Kluwer Academic Publisher, pp 410–440
Yigitcalnar T (2011) Knowledge-based urban development redefined: from theory to practice knowledge-based development of cities. Int J Knowl Based Dev 2(4):340–356. https://doi.org/10.1504/IJKBD.2011.044343
Yigitcanlar T, Velibeyoglu K (2008) Knowledge-based urban development: the local economic development path of Brisbane, Australia, Local Economy, vol 23, no 3, pp 195–207. https://doi.org/10.1080/02690940802197358

Chapter 2
Recreational Centres as Urban Commons: Potential and Barriers to Regeneration in Zambia

Lilias Makashini, Ephraim Kabunda Munshifwa, and Yewande Adewunmi

Abstract The wellbeing of people centres on the value of their families and jobs; hence, they exert effort on issues directly impacting these two sections. However, this focus has led to the decline of social cohesion. Thus, cities must incorporate space outside work and home if they are to promote healthy societal life. Commercial and public space fails to foster togetherness due to market logic forces and the illegality of citizens to maintain neglected spaces. Therefore, this calls for inclusive participation of citizens in managing shared goods and services or urban commons. Despite the diversity of commons, only parks and greenery are used to describe those of a recreational nature. This chapter advocates for the use of recreational centres as urban commons in communities that experience deterioration, due to their potential to bring about regeneration. Using degenerated recreational centres in Zambia, this research adopts a qualitative approach to investigate the potential and determine the barriers constraining the regeneration of these facilities. The chapter found that although recreational centres are valuable, their management is hampered by a lack of institutional support and poor policy enforcement. Management of recreational centres as urban commons must thus be policy-driven for successful community regeneration.

Keywords Urban commons · Third place · Recreational centres · Regeneration · Zambia

L. Makashini (✉) · E. K. Munshifwa
Department of Real Estate Studies, The Copperbelt University, Kitwe, Zambia
e-mail: lilias.masiba@cbu.ac.zm

E. K. Munshifwa
e-mail: ephraim.munshifwa@cbu.ac.zm

Y. Adewunmi
School of Construction Economics and Management, University of Witwatersrand, Johannesburg, South Africa
e-mail: yewande.adewunmi@wits.ac.za

U. Chatterjee et al. (eds.), *Urban Commons, Future Smart Cities and Sustainability*, Springer Geography, https://doi.org/10.1007/978-3-031-24767-5_2

Introduction

In conceptualising urban spaces and assets as urban commons, most scholars refer to 'urban green commons' such as lakes, parks and gardens (Ostrom 2015; Foster and Iaione 2020; Feinberg et al. 2021). McGuirk (2015) and Ostrom (2015) however suggested up-scaling commoning beyond 'gardening' and using it to address societal challenges like housing, poverty and energy use. Urban infrastructure such as broadband, roads and housing are therefore, being submitted as urban commons (Foster and Iaione 2020; Vazquez 2022). Additionally, urban commons have the potential to regenerate communities that have experienced deterioration of the social, economic and physical environments. Commoning practices develop resilience of the community by offering access to services and activities focused on public space and abandoned or misused buildings (Carlone et al. 2022). This chapter thus advocates for the use of recreation centres as urban commons in communities that have experienced deterioration of the social, economic and physical environments.

Oldenburg and Brissett (1982) stated that people invest time and energy in issues that enhance their home and work life due to the value placed on these two sections. They posited that people are reluctant to participate in those activities that do not promote these two parts of life, which results in the decline of the sense of community. Bingham-Hall (2016) thus suggests the need for incorporating a range of public spaces or 'third places' outside of home and work. It is believed that this will develop social cohesion and a robust societal life which is vital for a healthy community (Feinberg et al. 2021). However, commercial and public spaces fail to foster this togetherness due to market logic forces that exclude and segregate those unable to afford their use (Bingham-Hall 2016). The concept of urban commons has thus evolved due to the importance of this third place in people's lives and the need to revitalise communities.

According to Dellenbaugh et al. (2015:10), *the urban commons are about collectively appropriating and regulating the shared concerns of the everyday*. Boydell and Searle (2014:324) added that such management includes *equitable use, access and sustainability* aspects. Nemeth (2009) further defines a commons as a place for social interaction and developing personalities through unstructured connections. Therefore, these publicly accessible places or commons are critical for lively and sustainable communities. Peter and Meyer (2022) also recommend that commoning is critical to the agenda of developing smart cities. Smart cities are defined as the use of technology and innovative approaches to the provision of community services and urban development (Zheng et al. 2019; Lee et al. 2022). The European Commission (n.d.) adds that a smart city goes beyond the use of technology for developing better urban spaces to include smarter transport, water, energy and waste disposal and safer and inclusive public spaces. Thus, urban commons fit well into the creation of smart cities, as they encourage citizen participation and restructure governance of local resources, in an effort to improve the quality of life for the communities (Batagan 2011; Mundada and Mukkamala 2020; Peter and Meyer 2022). Kohn (2004), however, cautioned against the use of 'commons' as the term could have elitist and discriminatory connotations. This is because in referring to commons derived from the term community, one must belong to the said community by association or residence in order to enjoy joint use, access or management. Borch and Kornberger (2015) also added, based on their definition of commons as a resource to be shared by a group of people, that the group must be clearly clarified.

Nevertheless, the alternative term 'public', often meaning open, accessible or owned by the state, also has its limitations, as not every public place is accessible such as military institutions. Harvey (2011) adds that even some seemingly open-access commons are controlled and privately managed. Vazquez (2022) further states that very few commons can function independently and uses the term 'hybrids'. This signifies the relationship established by the commons with the state or market in obtaining financial assistance and legal protection. Thus, McGinnis (2001:3) describes commons *as not just public spaces that accommodate a variety of social activities and where people gather but also provide a sense of identity, belonging, connectedness, fun, tradition, stories and a source of memories.*

Mazzuco (2016) observed a striking amount of underused and misused public spaces, which has further contributed to the diminishing sense of community and public life. Similar observations were made by Camerin (2021) about former military sites, which were large tracts of land. Without proper strategies for their management, these public spaces or urban commons become dilapidated and neglected. Nevertheless, it has been agreed by researchers that they have the potential to trigger community resilience to manage economic, social and environmental crises through capacity building, provision of affordable space and the opportunity for civic participation and self-governance. Profit-driven regeneration of these spaces often contends with resistance by communities presented by many protests and thus calls for policy-driven regeneration and the development of regulations for shared-care of urban commons (Dellenbaugh et al. 2015). However, crucial legal gaps have been identified in managing cities, specifically urban commons. Boydell and Searle (2014:338) explored the diversity of rights, obligations and restrictions that can apply to urban commons and concluded that urban spaces comprise *a range of potential uses with a corresponding range of perceived use rights.* These, if not well managed, can be a source of struggle and conflict regarding ownership and control of resources. For example, in Bologna (Italy), it was illegal for citizens to improve or maintain public spaces and abandoned buildings that directly impacted their lives (Cities of Service 2018). This was mitigated by developing the Regulation on Public Collaboration between Citizens and the City for the care and regeneration of urban commons. The regulation allows citizens and private organisations to sign collaborative pacts with the city to improve public space, green areas and abandoned buildings.

Similarly, Park et al. (2020) also stated that cities are tightly controlled by regulations and policies, which stifle creativity and people's actions. In their research in Seoul, South Korea, poor tenants, homeless people and street vendors who were excluded from the urban process by gentrification and displacement squatted on idle railroad land owned by the Korea Rail Network Authority (KRNA) as a protest. This triggered the emergence of urban commons as havens in that the displaced people were able to find solace and a communal solution to their predicament of homelessness. Hence, there is a need for systemic restructuring of commoning practices to produce a revitalised urban society, with urban commons considered a vital resource for urban development.

Kohn (2004) and Borch and Kornberger (2015) also pointed out that public spaces are not devalued or exhausted by their use, and the more people access and utilise them, the more their value increases. Hence, Efroymson et al. (2009) called for their preservation, especially those very popular in the community. For instance, the old Berlin Airport in Tempelhof, which closed in 2008, was reopened in 2010 as a recreation facility named the Tempelhof Field. Residents voted to use it as it was, rejecting any form of construction. The place currently comprises community gardens, dog parks, picnic areas and sports facilities, while the two landing strips are used by cyclists, skaters, joggers and walkers, and attract over three million visitors every year (Vazquez 2022). Thus, as Orum and Neal (2010) conclude, the more foot count there is to a facility, the more profound and intense the sense of community. And the opposite consequently is that the less traffic to these spaces, the less the sense of community becomes.

Like Mazzuco's (2016) observation about underused and misused public spaces, the World Bank (2016) suggested that every city has underutilised areas often due to urban development patterns. These underused areas can be individual buildings or whole communities with social, economic and physical attributes, leading to what scholars term urban decay (Hyra and Rugh 2016; Hwang and Woo 2020). Indicators include boarded-up buildings, derelict properties, closed businesses and high crime and unemployment rates (Udeh and Okeke 2018). This urban decay is caused by deindustrialisation, wars and reduction in economic activities and is known to cause environmental degradation from pollution, the decline of values of neighbouring properties, and being havens for crime (Wilson 2012; Elrahman 2016). These dilapidated spaces, also known as brownfields, need to be regenerated to make them useable. The regeneration process aims to restore the community's attractiveness through innovative efforts. Once regenerated, the community can enjoy a cleaner environment and overall improvement in residents' quality of life near and around the facilities.

For successful regeneration to occur, the community must be allowed to participate at every stage of the process to enable empowerment, skills transfer and self-governance. This building of competencies in the community allows them to control the process and, subsequently, their lives. Regeneration processes inundated with bureaucratic practices do not result in environmentally sensitive, economically viable and socially acceptable communities, so coresponsibility or a blend of top-down and bottom-up approaches is being advocated (Bartke and Schwarze 2015; Vazquez 2022). Vazquez (2022) believes these foster the communal spirit and are more egalitarian. The 'Making Space in Dalston' Project is a success story of this top-down/bottom-up approach to regenerating a community. In the early 1990s, Dalston (UK) had plunged into one of the worst economic, social and environmental crises due to deindustrialisation and the oil crisis (Vazquez 2022). Having been gentrified within the 2004 London Plan as an area of preferential regeneration, the project began as a top-down process. However, without previous consultations with the community, the developers designed excessive building heights and densities and reduced the percentage of affordable housing from 50 to 13%. This infuriated the residents of Dalston and thus resulted in the adoption of the more transparent bottom-up approach. Consultants J & L Gibbons and Muf Architecture/Art created a methodology to embrace the two approaches based on three fundamental principles: 1—Valuing what was there; 2—nurturing the possible and 3—defining what was missing. The project went beyond considering only listed buildings but included abandoned facilities, murals and signs as assets. The project was fragmented into 76 micro-interventions and phased into flexible stages resulting in the completion of the project in 12 months, a feat inconceivable in urbanism processes. Another achievement of the project is the yearly plan of events that take place in Gillett Square (one of its facilities), which include: African street markets, skating competitions, artistic performances, children's festivals, jazz concerts, musical parades and carnivals, electronic music workshops, charity events, courses and workshops, summer schools, photography festivals and the celebration of independence days of countries like Jamaica or Senegal (Vazquez 2022:175). The project proved how public space regeneration could be achieved through small but precise interventions, using limited resources and by the goodwill and voluntarism of both residents and professionals.

This chapter, therefore, advocates for the use of recreation centres as urban commons in communities that have experienced social, economic and physical deterioration due to their potential to bring about regeneration. It explores the opportunities presented by recreation centres for communities to be mobilised, empowered and enriched through their participation and the barriers that could hinder the regeneration of the dilapidated public facilities.

Rationale of the Study

Urban commons are a global phenomenon; thus, their management is a worldwide concern. Iaione (2015) identifies two factors that determine urban spaces and services' crises. One factor is the deficit and decline of public spaces, and the second is citizens' gradual loss of interest in public spaces. These two factors can be observed in most of the Copperbelt Province of Zambia's recreation centres. Due to the impact of privatisation of the mining industry in the country, leading to the gap in the management of recreation centres that belonged to the mines, most of them lie in ruins with no proper strategy, resources or management. Regenerating them would lead to positive effects of recreation, thereby improving the community's health and general quality of life. Therefore, there is need to embrace diverse modern methods to operate urban spaces in general and more specifically the recreation centres. Examples of grassroots projects that support collective participation in and ownership of urban space exist under the banner of urban commons (Bingham-Hall 2016). Thus, public spaces can become a resource for urban development when transformed into urban commons

(Mazzuco 2016). Therefore, this chapter aims to investigate considering recreation centres as a resource for regeneration by embracing them as urban commons.

A Brief History of Zambian Recreation Centres and the Subsequent Degeneration

The Zambian story is not complete without mentioning the mining of copper, an activity that has been critical to the country's existence. Although mining exploration began long before the arrival of European prospectors in the early 1900s, the first official mine was established in 1927 in a town called Luanshya (ICMM 2014). For several years after that, many mines were opened in various towns of the Copperbelt Province, which borders the Democratic Republic of Congo (see Fig. 2.1).

Although the mines were in private hands, they provided many public services and goods to meet the community's social needs (Mutale 2004). After independence from colonial rule in 1964, the Zambian Government began restructuring the economy by nationalising various foreign-owned firms, including the mines. This resulted in establishing the parastatal, the Zambia Consolidated Copper Mines (ZCCM), which regarded the different mines as divisions, and continued with the provision of social services and goods for the mine employees and their communities. Services included subsidised housing, education, health, waste management and recreation services (Fraser and Lungu 2006). Regarding recreation services, a host of centres were constructed in all mining townships and suburbs to provide various sporting activities and recreation amenities to benefit the whole community. However, the nationalisation process was poorly timed as copper prices on the international market slumped, resulting in the country borrowing heavily to maintain the operations of the mines and social responsibilities (Fraser and Lungu 2006). In the early 1990s, the country undertook a Structural Adjustment Program which included the reprivatisation of the mining sector, leading to the sale of assets as mining packages. The Development Agreements signed by investors allowed them to decide which assets to take on, leaving the community services and most social assets like schools, health facilities and recreation centres to be adopted by government, sold to individuals or given off as trusts (Rothchild and Sons Ltd 1998). The government did not emphasise ownership and management of the social services, and thus, it was not an obligation. This movement from ZCCM to private ownership created a vacuum in the management of most recreation centres, and thus, most are now in a deplorable state.

In agreement with Iaione (2015) factors of crises, it is evident that the recreation centres in the Copperbelt Province have suffered from decline as well as the loss of interest by the citizenry of the communities where they are located. The current state does not support the provision of social and recreation services, and thus, there is a need to identify ways to revamp them.

Fig. 2.1 Copperbelt Province of Zambia. *Source* https://commons.wikimedia.org/wiki/File:Zambia_Copperbelt_Province_Districts.svg. Date accessed, 12 July 2022

Methodology

This chapter investigates the possibility of using recreation centres as urban commons to regenerate communities battling social, economic and physical degeneration. To achieve this, the following questions are addressed:

- What characteristics of the recreation centres make them suitable options for consideration as urban commons?
- What benefits can be derived from using the recreation centres as urban commons?
- What challenges need to be addressed to ensure sustainable regeneration?

In addressing the above questions, the chapter adopted a qualitative approach and thus included qualitative data collection and analysis techniques. Data was collected using interviews and focus group discussions. A quintain of four recreation centres in

Table 2.1 Recreation centres forming the study quintain

Focus Group Discussion Number	Recreation Centre	Town	Date held	No of attendants
FGD1	Nkana Main Recreation Centre	Kitwe	28/10/2021	4
FGD2	Chamboli Football Ground	Kitwe	08/12/2021	11
FGD3	Bufuke Clubhouse	Mufulira	20/01/2022	5
FGD4	Mufulira Main Recreation Centre	Mufulira	04/02/2022	4

Source Authors, 2022

two towns, Kitwe and Mufulira, was developed so that results and conclusions can be compared and contrasted for robustness and comprehensive inferences (Ridder 2017; Yin 2018). Kitwe was considered because it was central to the country's urbanisation process and hosts a variety of recreation centres in many townships, while Mufulira was selected because it had a high number of sports councils and membership representing various clubs (Horizon 1963; Mutale 2004). The Nkana Main Recreation Centre and the Chamboli Football Ground in Kitwe, and the Mufulira Main Recreation Centre and Bufuke Club in Mufulira were selected as case studies to form the quintain.

Four Focus Group Discussions were held at each of the four recreation centres. Attendants were from various walks of life, including churches, schools, non-governmental organisations dealing with sports and the recreation centre managers. Details are presented in Table 2.1.

Interviews were conducted with people managing the recreation centres under review and other key stakeholders. Other stakeholders included in the study were government representatives under the Ministry of Youth, Sport and Arts, a former ZCCM employee who had been responsible for social services, and those managing recreation centres constructed outside the mining industry. This was done to gain insights into the sports and recreation sector and lessons on its functions and operation structures. Details about the interviewees and information required are presented in Table 2.2.

Results and Discussion

This chapter discusses urban commons using Kitwe and Mufulira recreation centres constructed and managed by the mining companies and the parastatal ZCCM. As mentioned earlier, the gap caused by the privatisation process has resulted in their deplorable state, as seen in the pictures below. The Nkana Main and Mufulira Main Recreation Centres have got some sections in a better status because some sports disciplines have sponsorship from the Mopani Copper Mines Plc. (MCM), an investor

Table 2.2 Details of interviews conducted

Interviewee	Designation and information required	Town	Date held
A	Former ZCCM Social Services Employee—operations of the mines regarding the provision of social services	Kitwe	07/10/2019
B	Lecturer at the Copperbelt University—has researched the impact of privatisation	Kitwe	17/02/2020
C	Club Manager for Nkana Main Recreation Centre–current management and operations	Kitwe	08/09/2020
D	Club Manager for Diggers Rugby Club—current management and operations	Kitwe	08/09/2020
E	Manager for Bufuke Club—current management and operations	Mufulira	23/12/2020
F	Mopani Primary School Headteacher for Swimming Pool—current management and operations	Mufulira	23/12/2020
G	Club Manager for Squash Club—current management and operations	Mufulira	23/12/2020
H and I	Club Manager and Grounds Manager for Leopards Cage Rugby Club—current management and operations	Mufulira	23/12/2020
J	Provincial Youth Development Coordinator at the Ministry of Youth Sport and Arts—government plans and programs for sports and recreation in the Copperbelt Province	Ndola	07/04/2021
K	Provincial Sports Coordinator at the Ministry of Youth Sport and Arts—government plans and programs for sports and recreation in the Copperbelt Province	Ndola	19/04/2021
L	Chief Executive Officer at the Olympic Youth Development Centre (OYDC)—current recreational services being offered; management strategies; plans and innovative ideas	Lusaka	03/05/2021
M and N	Manager and Accountant for Zamsure Sports Complex—current recreational services being offered; management strategies; plans and innovative ideas	Lusaka	04/05/2021
O	Club Manager for Bank of Zambia Sports Recreation Centre—current recreational services being offered; management strategies; plans and innovative ideas	Lusaka	04/05/2021
P	Supervisor/Caretaker for Fallsway Arena (Former BP Sports Complex)—current recreational services being offered; management strategies; plans and innovative ideas	Lusaka	07/05/2021
Q	Assistant Director, Department of Housing and Social Services, Kitwe City Council—municipality's community development operations, plans and challenges regarding sport and recreation	Kitwe	22/09/2021
R	Community Development Officer, Department of Housing and Social Services, Mufulira Municipal Council—municipality's community development operations, plans and challenges regarding sport and recreation	Mufulira	13/01/2022

Source Authors, 2022

Fig. 2.2 **a–d** Nkana Main Recreation Centre (Kitwe) showing the main clubhouse, bowling clubhouse, bowling pitch and diggers rugby club pitch

which acquired part of the mines in Kitwe and Mufulira. The rugby clubs and the swimming pool in Mufulira get grants from MCM to pay employees and for everyday operations. However, the rest of the facilities do not receive any funding and are thus dilapidated. Figures 2.2, 2.3, 2.4 and 2.5 show the four facilities that form the quintain.

Suitable Characteristics of Recreation Centres

Several characteristics of the recreation centres make them suitable options for consideration as urban commons. A few are noted in the following section.

Management structures

The four recreation centres had various management structures in place.

- The Nkana Main Recreation Club (Kitwe) is divided into four sections, each with its management and operating systems. The first section, called Nkana Mine Recreation Centre, is managed by former mine employees who had registered a company and operate a third (1/3) of the main recreation centre building. They manage the beer garden, three bar areas and three halls currently rented out to

Fig. 2.3 **a–d** Chamboli Football Grounds (locally known as Mogadishu) (Kitwe) showing the clubhouse, change rooms, football pitch and volleyball courts

churches. They have a Board in place that oversees the centre's functions and makes the necessary decisions for its continued existence. The second section, also a third of the main recreation centre building, is owned by Nkana Business Ventures, which support the Nkana Football Club. Due to the poor state of their building section, no activities occur. The Antioch Bible Church uses the third and last section of the main recreation centre building. They took on the indoor and outdoor basketball courts and converted them to support the functions of the church. The fourth section of the recreation centre is the Diggers Rugby Club which the Mopani Copper Mines Plc. supports. It is managed by an Executive Committee who make decisions regarding the club's operations.

- Chamboli Football Ground (Kitwe) does not have a formal management structure. No one has complete ownership of the facility, so volunteers of various community groups organise activities when the opportunity arises. A Police Post was established to deter further vandalism as a decision by the community.
- Mufulira Main Recreation Centre (Mufulira) has various management structures that manage the separate services or sports disciplines. The Cricket Club currently has no official owners and is not operational. It is derelict and closed up with no activities taking place. MCM is currently managing the swimming pool through the Mopani Primary School. It gets funding from MCM for big capital projects such as refurbishing the pool pump house and salaries for the full-time employees.

Fig. 2.4 **a**–**d** Mufulira Main Recreation Centre (Mufulira) showing the cricket clubhouse, squash clubhouse, swimming pool and Leopard's Cage Rugby Club Pitch

Fig. 2.5 **a**–**d** Bufuke Club (Mufulira) showing the club house front and back, football pitch and camp house

The Squash Club is managed by a group of volunteers who have formed a board. The board is responsible for financing and general management of the club. The Leopard's Cage Rugby Club is managed by MCM, who finances the club's operations.

- Bufuke Club is managed by a committee of volunteers from the Butondo Community who have formed a board. They are caretakers of the facility and are safeguarding the place from vandalism.

Scholars refer to combined or collective management as a characteristic of urban commons (Shah and Garg 2017; Feinberg et al. 2021). Stakeholders as interest groups or individuals hold varying rights to these spaces, managing accessibility, use and daily operations. The recreation centres under review had stakeholders coming together in various decision-making roles and capacities to ensure the facilities have a structure (as shown in Fig. 2.6). Even Chamboli Football Ground which did not necessarily have a designated management structure had the community coming together to make decisions for and on behalf of the facility. The various organisations sometimes come together to decide what happens, for instance, in the case of the establishment of the Police Post. Thus, the recreation centres all qualify and meet the criteria to be considered urban commons due to the suitable common management structures in place.

Public space

This characteristic denotes being open and accessible to community people (Shah and Garg 2017; Vazquez 2022). All four recreation centres are accessible to the community with services such as restaurants and bars. However, services such as using the rugby pitches and squash courts are the preserve of players of the resident teams at the clubs because they pay membership or subscription fees which grant them exclusive use. The Chamboli Football Ground is the only recreation centre that allows any football team to use the premises free of charge, even though it has a resident football team. This is because the resident football team, Zanama Football

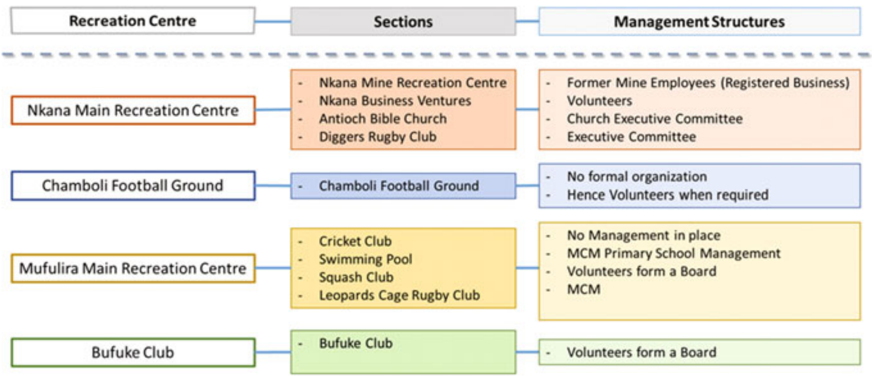


Fig. 2.6 Management structures that exist at the four recreation centres. *Source* Authors, 2022

Club, is currently not performing well in the national league, so the football ground is open and available to anyone wishing to use it. The Nkana Main Recreation Centre section, owned by former mine employees, has tried to encourage patrons to become members so that they can pay subscription fees. However, because of the poor state of the facility, people are not interested in being paid up members and thus use the facility for refreshments.

Underused and misused public space

A key feature of grassroots projects and the urban commons is that they are established in underused and misused public spaces. All four recreation centres are currently being underused and misused. The Nkana Main Recreation Centre in Kitwe was once the headquarters of various sports activities organised by the mines, and so many of them had offices in the main recreation centre building, including the bowling, cricket and rugby clubs. However, comparing it to the current use, the halls that had been previously used for darts, bingo, ballroom dancing, snooker and weightlifting, to mention a few, are currently either closed up or rented out to churches. Even the basketball courts are being misused as they operate only as the Antioch Bible Church. Various local groups are using the Chamboli Football Ground pitch, but the clubhouse and change rooms are not being used because they have been severely vandalised. Further, even though the football pitch is used regularly, people use it as a shortcut, so the grass is completely destroyed. A similar situation exists in Mufulira, where the Mufulira Main Recreation Centre has only the squash club courts and rugby club pitch and bars being used, while the rest of the facilities are not operational. At the time of the study, the swimming pool did not have water and had not been used for over a year as it had been under renovation. At Bufuke Club, the football pitch is operational as it is the home of the Butondo Western Tigers Football Club, as well as the indoor and outdoor bars. However, the club camp house and halls are rented out to churches.

Provide the opportunity for recreation

McGinnis (2001) and Feinberg et al. (2021) describe urban commons as spaces that provide fun and recreation opportunities. Even in their current dilapidated state, the four recreation centres are providing recreation services to the surrounding communities. Apart from the various sports disciplines available such as football, rugby, pool and squash, the facilities offer refreshments to patrons. This makes the recreation centres places that can still attract community members seeking these services.

The characteristics of the four recreation centres that make them suitable for consideration as urban commons are summarised and shown in Fig. 2.7.

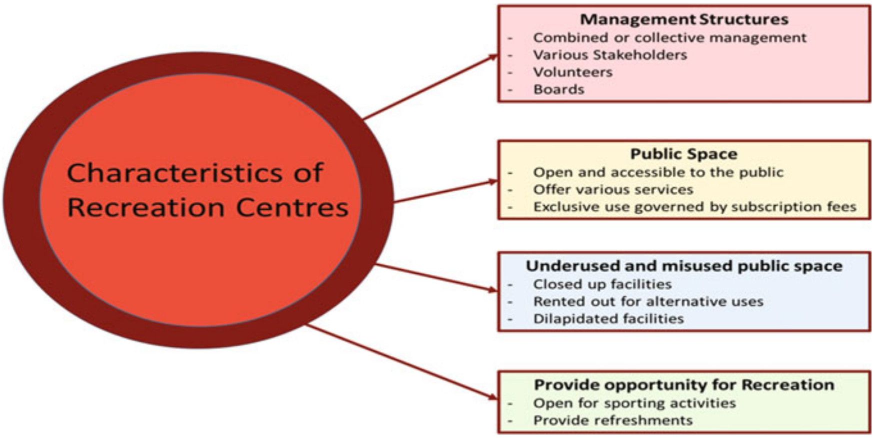


Fig. 2.7 Characteristics of recreation centres that make them suitable for consideration as urban commons. *Source* Authors, 2022

Benefits of Using Recreation Centres as Urban Commons

Feinberg et al. (2021) suggest that urban commons benefit individuals and the community. The people interviewed and those who attended the focus group discussions were asked whether the recreation centres benefited the community, and they all agreed to this.

Potential to increase value by use

Interviewee O bemoaned that the sport and recreation industry is struggling because too few people are using recreation facilities and said that there is need for deliberate steps to be taken to increase the number of people accessing the facilities. One of the post-privatisation recreation centres visited, Fallsway Arena in Lusaka, is running a football academy sponsored by the Super Sport United Football Club based on South Africa. The caretaker revealed that it seemed too simple to be successful when the program began. However, he confessed that now people pay the $100 monthly subscription consistently, while some even pay 3, 6 and even 12 months in advance.

Similarly, the Olympic Youth Development Centre (OYDC) in Lusaka, another post-privatisation facility visited, records overwhelming participation in the services provided. Established as a centre to prepare national sports teams for the Olympic Games, it offers over 20 sporting disciplines and hence receives close to 800 youths per week, participating in organised sports leagues. This supports the observation by Kohn (2004) and Efroymson et al. (2009) who stated that the more public spaces are used, the more valuable they become to society.

Local economic development

It was pointed out in FGD4 that having an active facility would encourage vendors of snacks and refreshments, and these sales would help families in the community gain some finances. Another attendant suggested that the recreation centres could host fundraising ventures for outside organisations such as the church. Activities such as fetes, galas and festivals at these facilities could encourage the community to use them more often. The Mufulira Main Recreation Centre, Leopard's Cage Rugby Club currently runs a team regalia shop as a source of extra income. Other shops can also be opened, promoting activity and increasing traffic to these facilities. This is in line with the extra activities added to improve the operations at the Tempelhof Field and Dalston Project mentioned earlier.

Skills and health enhancement

One interesting activity found at the Mufulira Main Recreation Centre, Leopard's Cage Rugby Club is the running of a tailoring school and shop. This was established to ensure all the Leopardesses (the female rugby team) have a skill even as they play rugby. The skill is believed to help the team get more economic support apart from the allowances they receive. The tailoring school is also open to the general community so more young people can get economically empowered.

Interviewee J pointed out that *'our towns are turning into concrete forests because we are disregarding recreation facilities… the number of people doing exercises is improving, but there is no space in communities'*. This implies that people realised the need to exercise, but this is discouraging without the space to do so. Thus, having these recreation centres functioning well should result in a healthier community.

Sense of pride and identity

Morrison (2016) describes pride as the belief in one's contribution towards a phenomenon or event, even abstractly. This is exemplified in fans of sports teams and celebrities or the patriotic feelings of birth and association. The recreation centres contribute to community pride and identity due to the famous sportsmen and women who have roots there. Bufuke Club, for example, has produced footballers such as Beston Chambeshi and Felix Katongo, who have represented the country by playing in the Zambia National Football Team. Community members thus feel pride when they relate with the recreation centre, knowing that it has contributed to the identity of national team players.

Additionally, an attendant of FGD2 expressed strong sentiment about the Chamboli Football Ground and those wishing to claim ownership of the recreation facility. It was revealed that an unscrupulous local political leader sold the facility to an upcoming church, which resulted in heated protests from the community. '*This ground is personal and sentimental to the community, so no one can come and claim it. We are willing to fight for this ground, and anyone who tries to use underhanded methods can die'*. This shows that community members hold very strong feelings about these public spaces and thus are willing to do whatever it takes to protect and value them.

The benefits of recreation centres as urban commons are summarised in Fig. 2.8.

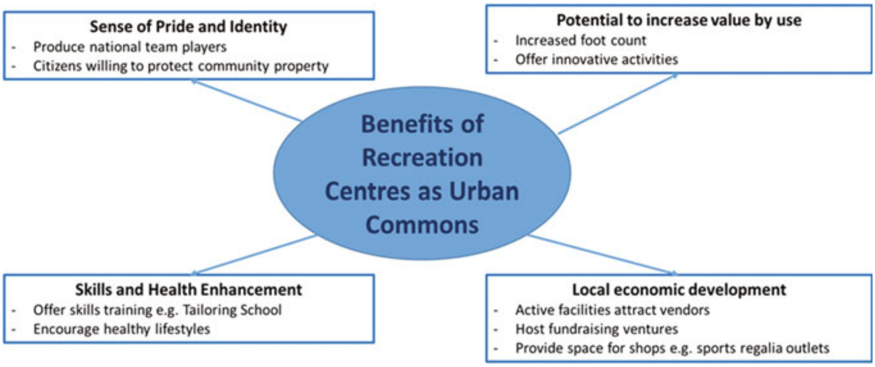


Fig. 2.8 Benefits of recreation centres as urban commons. *Source* Authors, 2022

Challenges Hindering Sustainable Regeneration

Although the recreation centres have great potential to benefit the communities where they are located, a number of challenges may hinder their sustainable regeneration. The critical challenges identified are presented below.

Mindset of community

The mindset of the community was unanimously agreed as the key impediment to sustainable regeneration. Interviewee B stated that '*communities were spoilt because the mines took care of everything…some people cannot even cut their grass unless the Government comes in*'. Interviewee I added that '*our attitude is bad as locals. We don't have community and responsibility pride. We leave taps open and don't flush toilets all because there is a worker who will come to clean up after us*'. To enjoy the benefits identified in Fig. 2.8, the community must take responsibility and manage the facilities as they should. One of the attendants of FGD3 said, '*where ignorance is bliss, tis folly to be wise*' about the challenges he encountered as a community leader trying to get people involved in activities that would benefit them. He further added that it was challenging attempting to change the mindset of people as most thought of benefiting themselves only. However, the community played a crucial role in maintaining the character and essence of Tempelhof Field and Dalston. Thus, the community is vital for any regeneration to be achievable because if the community cannot be entrusted with this task, it would be a futile undertaking.

Poor support by local businesses

Interviewee I pointed out that '*the financial muscle of the community is deficient. People are struggling to put food on their tables, so they can't contribute resources*'. This implies that the community needs to obtain outside resources to provide and maintain social services and goods. However, as mentioned earlier, the Development Agreements signed by the investors who purchased the mines, gave them the liberty to choose which assets to buy. Thus, they do not have the impetus to support local social services. Interviewees A and B affirmed that no law or policy exists to compel investors to look into social infrastructure. 'E*ven from a Corporate Social Responsibility (CSR) point of view, they are at liberty to agree or not. If you compel, it ceases to be CSR as CSR is a voluntary action for the public good',* as pointed out by Interviewee B. This leaves the communities in a vulnerable situation, as they can only access what services are offered by the new investors regardless of their needs.

Additionally, the mines were the biggest employer on the Copperbelt Province, directly and indirectly through contractors and suppliers of various goods and services. Mutale (2004) explains that in the early 1970s, about 32% of employees in Kitwe were employed by Nkana Division under the ZCCM. However, the new mine owners employ less than a quarter of the previous number, causing many local businesses to close down because they relied on the income from mine employees. Many townships are still experiencing the impact of the reduced income as few businesses are operational, and those that are functional are barely surviving.

Politics and Political interference

Politics can be said to be two sides of the same coin as they have been known to bring people together and be a source of conflict in many communities. It was revealed during the focus group discussions that campaigns towards general elections often resulted in large crowds gathering to hear what was being promised by the aspiring candidates. However, these gatherings would also result in conflicts among those supporting opposing political parties. These conflicts can potentially prevent communities from working together to achieve a common goal. Therefore, it is essential to ensure that those from opposing political parties can set aside their differences to benefit the whole community. For instance, an attendant at FGD4 said, '*we had conflicts at the recreation club where one member came from a political party and the other from an opposing party. We told them to keep politics outside the club because it is for the community and not a specific party*. Such interventions would then ensure the community can progress and work together to achieve desired outcomes.

It was further divulged that some political leaders cause conflicts in the community by frustrating those wishing to serve. An attendant at FGD2 pointed out that '*the politicians have contributed to reducing the trust in the community. When someone comes to help, they think they are there to de-campaign them, so they will intimidate and frustrate the person so much that they will leave the community*. Thus, the relationship with local politicians will have to be handled dexterously to curb political interference and to ensure that they support any efforts by the community and those from outside wishing to help.

The critical challenges that may hinder sustainable regeneration of the recreation centres are shown in Fig. 2.9.

Fig. 2.9 Challenges hindering the sustainable regeneration of recreation centres. *Source* Authors, 2022

Zambian Recreation Centres as Urban Commons and Future Smart Cities

Urban decay has been described as an unavoidable stage in the life cycle of cities and so degeneration will at some point occur (Fink 2019). This decline is evident in the current state of some of the third places in Zambia. The closed-up businesses, boarded-up buildings and vandalism experienced at the recreation centres, are an indication that there is need for intervention by key stakeholders of the communities where they are located. In order to enjoy the benefits that these facilities provide, despite having the right characteristics, the challenges that have been identified need to be managed. This will lead to successful and sustainable regeneration. Adopting small but precise interventions and the sufficient use of resources, combined with citizen empowerment and self-governance, smart cities will become a reality. This will be as a result of the ripple effect of smarter technologies, safer environments, and the improved socio-economic status of the facilities, spilling over into the communities where they are located. The link between the recreation centres as urban commons and smart cities is presented using the problem and solution tree shown in Fig. 2.10. The problem and solution tree is used because of its ability to identify problems and their causes and effects, as well as presenting the opportunity to convert these into the ideal state or the solution being proposed (Snowdon et al. 2008; Madu et al. 2018; ACGC 2021).

Recommendations

In order to adopt recreation centres as urban commons and for sustainable regeneration to occur, the following are recommended.

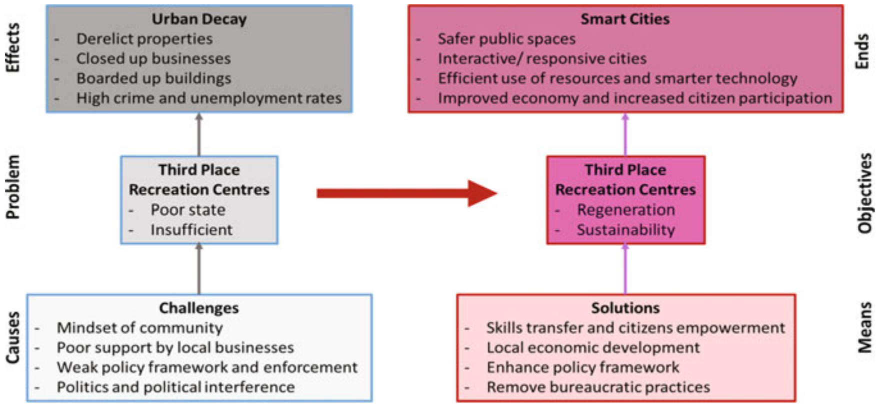


Fig. 2.10 Link between recreation centres as urban commons or third places and smart cities. *Source* Authors, 2022

Mindset change

A critical observation of one attendant of FGD4 was the need for the solution to begin from within. He said, ' *we have gone out to ask for sponsorship and have been asked how much we raised ourselves. So we need to have our effort*'. This shows that the community must champion any chance of regeneration, and they must lead the process. A similar sentiment was made in FGD2 where an attendant said, '*if someone needs to help us as a community, we need to show that we are doing something ourselves, and then the person comes to top up*'. Interviewee A added, '*there was a need for a cultural shift from a laissez-faire attitude to one that can bring results'*. Thus, people need to have more responsibility and ownership pride in their community and its assets, and the desire to protect them. Interviewee B added that '*morality levels must be raised to trust people to do things for others'*. There is a need, therefore, to continue engaging the community on the importance of their participation in community affairs if the regeneration of derelict environments is to succeed.

The mindset change can also be brought about by sensitisation by local leaders. Interviewee A suggested that '*Ward Councilors can bring about a positive change instead of surrounding themselves with cadres chanting slogans'*. An attendant of FGD1 also added that '*implementation is supposed to come from leaders*'. Therefore, local leaders from various backgrounds and organisations play a critical role in ensuring that the community is adequately sensitised about the value of managing public and community places.

Create hybrid commons

Interviewee J suggested that '*the sports and recreation industry was part of the lifeline for development and thus needed to be taken with the seriousness it deserves. All key stakeholders, including Central Government and all Local Authorities, need to find* *new solutions to the current state of recreation so that it can enhance the lives of our people'*. Thus, the suggestion of hybrid commons, as proposed by Vazquez (2022), is a welcome one. Collaboration of the government, private sector and community could lead to successful regeneration projects, as seen from the Dalston Project. Camerin (2021) also added that developing regulations and policies that legalise commoning are the tools needed as innovative solutions to using empty and underused spaces.

Remove political bureaucracy

As observed from the Bologna story, removing political bureaucracy opens up opportunities for communities to take control of projects that impact them. One of the attendants of FGD3 pointed out that '*the recent pronouncement by the President of Zambia, denouncing cadreism will prevent bullying by those in power*'. This will encourage those who desire to serve and improve their societies, knowing that local political leaders will not harass them. An attendant of FGD1 added the importance of trust in leaders, if people are to be willing to participate in community activities. He said, '*when there is no trust in leaders because the leaders they put trust in did not do what they expected to do or speak for the community, the people will not do anything*'. Thus, with trust in leaders, especially those from political spheres, the community can also be expected to play their part.

Conclusion

Undoubtedly, people need space outside work and home to unwind, relax and interact with others in their community. Without this third place, societies are experiencing a diminishing sense of community. Profit-based third places are segregative, allowing only a select few to access, use and manage them. The alternative of these is public spaces that are often underused and misused, contributing to the shrinking community life. Thus, the argument for urban commons cannot be over-emphasised. Urban commons provide space for the promotion of public health, recreation, community building and various local meetings. Benfield (2017) also suggested making better use of existing spaces to curb sprawling. This can be done by reinventing old and dilapidated facilities that may be present within communities. Hence, there is a need, to consider urban commons as more than just green spaces such as parks and water bodies, but as essential tools to respond to societal problems such as poverty, dereliction and homelessness. Studies have shown the ability of various infrastructures as urban commons to bring about the regeneration of communities, and so this chapter considered degenerated recreation centres on the Copperbelt Province of Zambia. Embarking on deliberate regeneration strategies at the recreation centres could result in interactive and responsive facilities with smarter technologies, sufficient use of resources and sustainability practices, which are the objectives of smart cities. Smart cities cannot be achieved without the transformative approach that includes urban commons and the restructured governance of local resources. Although the recreation centres considered in this chapter meet the requirements of urban commons, the mindset of the people in the communities, political interference, a weak policy framework and poor support from local businesses, were identified as challenges that need to be addressed if regeneration is to occur. With the increased use of these recreation centres and consequently their value, communities can simultaneously increase in prosperity, in terms of economic and social characteristics. This chapter, therefore, suggests increased sensitisation and engagement of all relevant key stakeholders and the removal of bureaucratic processes to create healthier and more sustainable and smart cities.

Acknowledgements The authors wish to acknowledge the Copperbelt University—Africa Centre of Excellence for Sustainable Mining (CBU-ACESM), Kitwe, Zambia, for sponsoring this work.

References

ACGC (2021) Problem and solution trees: tools for creating change in your school or community. Alberta Council for Global Cooperation, Alberta

Bartke S, Schwarze R (2015) No perfect tools: tradeoffs of sustainability principles and user requirements in designing support tools for land use decision between greenfields and brownfields. J Environ Manage 153(2015):11–24

Batagan L (2011) Smart Cities and sustainability models. Informatica Economica 15(3):80–97

Benfield K (2017) Sustainability and the urban commons. Part 1 of 2. Smart Cities Dive. https://www.smartcitiesdive.com/ex/sustainablecitiescollective/sustainability-and-urban-commons-part-1-2/164666/. Date accessed: 07 July 2022

Bingham-Hall J (2016) Future of cities: communing and collective approaches to urban space. Theatrum Mundi, LSE Cities. London School of Economics and Political Science

Borch C, Kornberger M (2015) Urban commons: rethinking the city. Routledge, Oxon

Boydell S, Searle G (2014) Understanding property rights in the contemporary urban commons. Urban Policy Res 32(3):323–340. https://doi.org/10.1080/08111146.2014.901909

Camerin F (2021) Regenerating former military sites in Italy. The dichotomy between 'profit-driven spaces' and urban commons. Global Jurist 21(3):497–523

Carlone T, Gatta F, Leonardi C, Vassallo C (2022) Regenerate the urban space as a common/generate commons through urban space: a reflection on the comparison of urban commoning tools in France and Italy. City, Teritory Archit 9(21). https://doi.org/10.1186/s40410-022-00157-2. Hal-03376148v2

Cities of Service (2018) Co-creating urban commons. Engaged cities award case study, Bologna, Italy

Dellenbaugh M, Kip M, Bieniok M, Muller A, Schwegmann M (eds) (2015) Urban commons: moving beyond state and market. Bauwelt Fundamente 154, Basel

Efroymson D, Ha TTKT, Ha PT (2009) Public spaces: how they humanize cities. HealthBridge–WBBTrust, Dhaka

Elrahman AA (2016) Redevelopment aspects for brownfields sites in Egypt. Proc Environ Sci 34:25–35

European Commission (n.d.) Smart Cities. City initiatives, pp 1–6. https://ec.europa.eu/info/eu-regional-and-urban-development/tp[ics/cities-and-urban-development/city-initiatives/smart-cities_de. Date accessed 07 July 2022

Feinberg A, Ghorbani A, Herder P (2021) Diversity and challenges of the urban commons: a comprehensive review. Int J Commons 15(1):1–20. https://doi.org/10.5334/ijc.1033

Fink C (2019) Understanding cities through their life cycles. Planetizen. https://www.planetizen.com/news/2019/06/104858-understanding-cities-through-their-life-cycles. Date accessed: 17 Mar 2021

Foster SR, Iaione C (2020) Urban commons. Oxford Bibliographies Urban Stud. https://doi.org/10.1093/OBO/9780190922481-0015

Fraser A, Lungu J (2006) For whom the windfalls? Winners and losers in the privatization of Zambia's Copper Mines. Catholic Centre for Justice, Development and Peace

Harvey D (2011) The future of the commons. Reflections. Radical Hist Rev 109:101–107. https://doi.org/10.1215/01636545-200-017

Horizon Magazine (1963) The Copperbelt—a centre for sport. Roan Selection Trust, January 1963

Hwang U, Woo M (2020) Analysis of inter-relationships between urban decline and urban sprawl in city regions of South Korea. Sustainability 12(1656):1–23. https://doi.org/10.3390/su12041656

Hyra D, Rugh JS (2016) The US great recession: exploring its association with black neighbourhood rise, decline and recovery. Urban Geogr. https://doi.org/10.1080/02723638.2015.1103994

Iaione C (2015) Governing the urban commons. Italian J Public Law 7(1):170–221

ICMM (2014) Enhancing mining's contribution to the Zambian economy and society. Mining: partnerships for development report, April 2014. International Council on Mining and Metals

Kohn M (2004) Brave new neighbourhoods. The privatization of public space. Routledge, New York

Lee J, Babcock J, Pham TS, Bui TH, Kang M (2022) Smart Cities as a social transition towards inclusive development through technology: a tale of four Smart Cities. Int J Urban Sci 1–26. https://doi.org/10.1080/12265934.2022.2074076

Madu IL, Adesope OM, Ogueri E (2018) Application of problem tree analysis in solving poverty related issues. Global Approaches Extension Pract (GAEP) 13(1):62–71

Mazzucco SC (2016) Repurposing underused public spaces into urban commons. An active participatory urban regeneration model for Gospel Oak, London, UK

McGinnis K (2001) Great commons of the world. Yes! Magazine. Available at http://www.yesmagazine.org/issues/reclaiming-the-commons/great-commons-of-the-world. Date accessed, 6 June 2022

McGuirk J (2015) Urban commons have radical potential—its not just about community gardens. Resilient Cities. The Guardian. https://www.theguardian.com/cities/2015/jun/15/urban-common-radical-community-garden. Date accessed: 10 Mar 2022

Morrison PS (2016) Pride in the city. Region J ERSA 3(2):103–124. https://doi.org/10.18335/region.v3i2.130

Mundada M, Mukkamala RR (2020) Smart Cities for sustainability—an analytical perspective. In: Conference Paper presented at the 2020, Fourth world conference on smart trends in systems, security and sustainability (World S4). Institute of Electrical and Electronics Engineers (IEEE), pp 770–775

Mutale E (2004) The management of urban development in Zambia. Ashgate, Aldershot

Nemeth J (2009) Defining a public: the management of privately owned public space. Urban Stud 46(11):2463–2490. https://doi.org/10.1177/0042098009342903

Oldenburg R, Brissett D (1982) The third place. Qual Sociol 5(4):265–284

Orum AM, Neal ZP (2010) Common ground? Readings and reflections on public space. Routledge, New York

Ostrom E (2015) Governing the commons. The evolution of institutions for collective action. Cambridge University Press, New York

Park IK, Shin J, Kim JE (2020) Urban commons as a haven for the excluded: an experience of creating a commons in Seoul, South Korea. Int J Commons 14(1):508–524. https://doi.org/10.5334/ijc.1038

Peter C, Meyer C (2022) Organising for the Smart African City: leveraging the urban commons for exerting the right to the city. In: Organisation studies, pp 1–22. https://doi.org/10.1177/01708406221089609

Ridder HG (2017) The theory contribution of case study research designs. Bus Res 2017(10):281–305

Rothchild and Sons Ltd (1998) Achieving the successful sale of the Nkana, Nchanga and Konkola Assets

Shah A, Garg A (2017) Urban commons service generation, delivery and management: a conceptual framework. Ecol Econ 135:280–287. https://doi.org/10.1016/j.ecolecon.2016.12.017

Snowdon W, Schultz J, Swinburn B (2008) Problem and solution trees: a practical approach for identifying potential interventions to improve population nutrition. Health Promot Int 23(4):345–353. https://doi.org/10.1093/heapro/dan027

Udeh CA, Okeke FO (2018) Urban regeneration—eradicating urban decay for improved human settlement. J Environ Manage Safety 9(1):49–54

Vazquez CG (2022) Cities after crisis. Reinventing neighbourhood design from the ground up. Routledge, New York

Wilson RL (2012) Dealing with abandoned and dilapidated buildings: strategies for saving, maintaining and enhancing our downtown architectural assets. Community Design Solutions. Reprinted from Uptown December. Municipal Association of South Carolina

World Bank (2016) How eight cities succeeded in rejuvenating their urban land. Press release. https://www.worldbank.org/en/news/press-release/2016/07/13/How-eight-cities-succeeded-in-rejuvenating-their-urban-land. Date accessed 13 Apr 2021

Yin RK (2018) Case study research and applications: design and methods, 6th edn. Sage Publications, Los Angeles

Zhen L, Kwok WM, Aquaro V, Qi X (2019) digital government, smart cities and sustainable development. ICEGOV, 3–5 Apr, Association for Computing Machinery, Melbourne, Australia, pp 291–301

Chapter 3
Political Common(ing) in a Smart City

Shalini Chaudhary and Anuradha Choudry

Abstract The concept of *commons* has been investigated in academia through multiple disciplinary lenses. This chapter explores the concept of commons, attempting a thematic categorisation along those disciplinary lines. The themes thus derived include—availability, accessibility, conflicts, rights and innovation. Thereupon, a framework is drawn to develop a supra-concept of political commons relevant to our study of governance in smart cities. Smart cities are essentially state projects aimed at living better and governing smarter. Their default initiation from the state quarters stipulates placing commons within a political context—one pertaining to the public sphere and its activities. Conceptual explication of political commons then outlines its measurable *'SOFT'* characteristics that relate to the interests of the *subjects* (people) with an implicit *objective* of a politico-democratic functioning, between interoperable *forces* of state/market/society, and using technological and social processes as *tools*. The chapter uses community media as an example for empirically rooting this concept. The utility of political commons as a conceptual framework is, thus, suggested in its ability to direct *identification* of newer and relevant commons, provoke theorisation (*ideation*) around them and create pathways for their active application/commoning (*instrumentality*) in pursuit of sustainable urban futures informed by democratic principles and practices.

Keywords Commons · Political Commons · Political Commoning · Smart City Governance · Democratic Governance · Community Media

---

S. Chaudhary (✉)
Rekhi Centre of Excellence for the Science of Happiness, IIT Kharagpur, Kharagpur, West Bengal 721302, India
e-mail: shalinichaudhary1707@gmail.com

A. Choudry
Department of Humanities and Social Sciences, IIT Kharagpur, Kharagpur, West Bengal 721302, India

U. Chatterjee et al. (eds.), *Urban Commons, Future Smart Cities and Sustainability*, Springer Geography, https://doi.org/10.1007/978-3-031-24767-5_3

Introduction

Perusing the pieces of political art since before the emergence of modern nation states, one notices a pattern of public life depicted through them. A thematic distinction is accorded to the cities, vis-à-vis other social geographies, in terms of the exclusive portrayal of people meeting, engaging, and deliberating. A sense of ‘people power’ undergirds these depictions despite the encoded socio-political hierarchies between the characters. Be it the 1791 ‘Oath of the Tennis Court’ by Jacques-Louis David that captured the political scene of the city of Versailles leading up to the French Revolution or Raphael Sanzio’s sixteenth-century masterpiece ‘The School of Athens’ that showed Plato and Aristotle dialoguing amidst a crowd in the city of Athens. Cities have historically been the locus of political acts and activities, while most critical political ventures and astonishments of power have also had a city at their focus.

In recent history, however, the city has diversified its portfolio due to reasons attributable to—the paradigmatic eventuality of spatial and temporal growth of human societies (Redfield and Singer 1954; Soja 2011), anthropo-ecological dynamics (Moran 2019), accommodation of complex governance architecture, disrupting/constructive forces of globalisation and development, or assimilative response to human technological innovations. This has resulted in cities becoming repositories of development narratives around human societies. In the process, however, the fundamental political function of a city polity—that of meeting, engaging, and deliberating through ancillary acts of policy-making, economic exchanges, social gatherings, or religious events—has undergone a radical change. From the austere, in-person, locale-centricity of pre-modern cities to the digital, multi-layered, global orientation of smart cities, the political functions within them too require platform and procedural upgradation. Contrastingly, what has remained a constant feature is the denomination of certain spaces as ‘commons’, vis-à-vis their shared ownership or use by the city commune and its necessity for a healthy and sustainable city life.

Smart cities are essentially political/state projects assigned with the *telos* of living better and governing smarter. Their default initiation from the state quarters is a result of both its financial scale and multi-sectoral leverages that demand permission, coordination, and support from the state. Exploring commons in a smart city, therefore, stipulates placing it within a political context. Here, *political* does not entail discussing the function of power, though that is certainly an implicit element. Political, for the purpose of this chapter, pertains to the public sphere and its activities.

The authors are aware that this chapter does not conform to the general ingenuity with which testable models and frameworks are elsewhere presented in this book, and therefore fear putting it forth as an odd addition to the list. What it seeks to contribute, however, is a direction in the form of a ‘sensitising concept’ (explained by Herbert Blumer in his 1954 essay ‘What is wrong with social theory?’)—*political commons*. By developing a skeleton of political commons in terms of its definition and characteristics, this chapter intends to set the stage for more nuanced research on urban commons in smart cities. In the next section, we first attempt the thematic categorisation of commons as a concept based on an overview of the literature from different disciplines. Five major themes are derived out of this exercise, namely—the *availability* of common as a resource (short term and long term), their *accessibility* to groups and individuals, *conflicts* that ensue out of commons, *rights* associated with the usage and control over them, and *innovations* that introduce new commons or transform the dynamics around existing ones. In the subsequent section, governance in smart cities is studied to help the political placement of the concept of commons and understand commoning as an intrinsic part of governing. After this literature-based conceptual derivation, four common ('*SOFT*') characteristics underlying these themes are then identified, forming the basis of the concept of political commons.

In the last section, the concept of political common is explored through an example of community media. The justification for taking this media-medium as an adjunct empirical category to our central conceptual enquiry into political commons is embedded in the purposive nature of this media and the emerging governance

Table 3.1 Works on 'commons' in literature: a thematic categorisation (Source: Literature survey by the authors)

Fields	Focal points	Related works	Theme
Economic and Ecological History, Human Geography	Resource scarcity, resource exploitation, sustainability	Garrett Hardin's 1968 seminal work *The Tragedy of the Commons;* Cox (1985)	**Availability** (long term and short term)
Economics	Macro (property, ownership, markets, contracts, enclosures); Micro (shared use, game theory, free rider problem)	Property rights regimes and resource management (Feeny et al. 1990) Common-pool resources (Ostrom 2000); Labour Resource (Harvey 2010)	**Accessibility** (individual and group)
Psychology	Social traps, commons dilemma, etc.	Edney (1978), Messick and McClleland (1983), Fox (1985)	**Conflicts**
Politics, Institutions and Governance	National (property rights), International (jurisdictions, inter-state conflicts, global governance)	Governing the Commons (Ostrom 1990); Adaptive governance (Dietz et al. 2003); Others include Benkler (2003b), Thompson (2000) and Armitage (2008)	**Rights**
Society and Technology Studies	Ease of access, exploitation, exploration; Problem-solving paradigms	**Knowledge** Commons (Hess and Ostrom 2007) **Information** Commons (Beagle 1999) **Innovation** Commons (Allen and Potts (2016) and Potts (2018); **Digital** Commons; **Creative** Commons (Bollier 2003)	**Innovation**

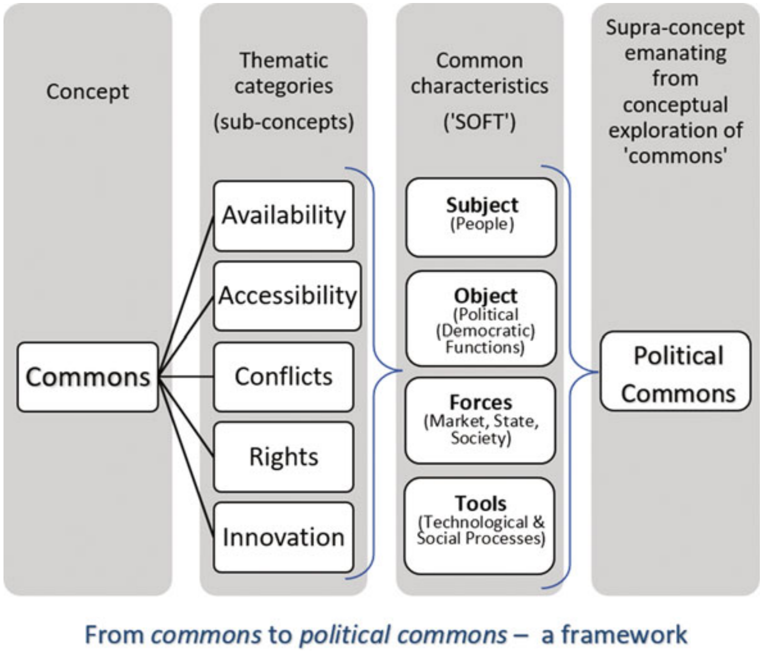


Fig. 3.1 An outline of the conceptual derivation of the concept of political commons (Source: Authors)

demands of a smart city. Community media, or the alternative media to the mainstream one, quasi-institutionalises the fundamental democratic functions of a city that we discussed earlier, i.e. engagement and deliberation in a public space or through a public platform. Furthermore, the smart city context provides a challenging socio-technological landscape which seeks to disrupt these 'ordinary' democratic acts of meeting, engaging, and deliberating. Community media, therefore, provides for a relevant example that interweaves the basic premise of a common and its governance ina smart city. It builds upon the 'common' character of its platform—i.e. relating to public, with a democratic objective of promoting people's participation, interplay of state/market/societal forces, and operating through social and technological processes—to explore the possibilities of an informed civic engagement. Community media, thus, lends a measurable element to the process of political commoning in a smart city.

The chapter seeks to indulge the issues immediately beyond the materiality of commons in the context of smart cities to include the ideational recalibration of commons in the light of emerging trends and demands on cities' governance. The authors do not wish to introduce the reader to any new paradigm or a measuring scale for commons. Any such extravagant claim would be a deeply farcical and self-defeating exercise given the existing corpus of rich academic analysis in the field that extensively covers the connected issues, otherwise very narrowly discussed

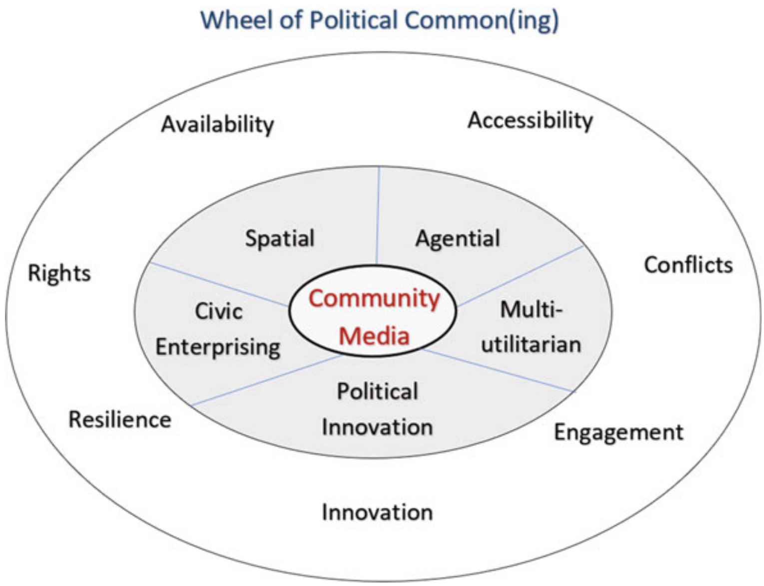


Fig. 3.2 Wheel of Political Common(ing): a roadmap for inclusive governance in smart cities (Source: Authors)

here. It deals with the literature on three independent yet interconnected concepts of commons, smart city governance, and community media. A common underlying factor is their rudimentary association with people and public life, making the acts of engaging with any of these as deeply political. We attempt to connect the dots of the pre-existing 'frame of analysis' of the commons across different disciplines and subdisciplines (primarily—media studies, political theory, community, and smart city governance) and simultaneously highlight the similar people/public-centric principles and practices across domains.

Reading Commons: A Literature Survey Through the Lens of Public/Political

> *Each commons has distinctive dynamics based on its participants, history, cultural values, the nature of the resource, and so forth.*
>
> (Bollier 2007)

A universally applicable definition of the term commons has been jettisoned as a difficult project given the 'fluctuating and fluid' nature of the forces, ideas, and institutions that underlie the emergence of commons (Holder and Flessas 2008). When seen as a 'school of thought' or 'frame of analysis', any idea of commons points to the two structural aspects—social situatedness and relation vis-à-vis market or state (Bollier 2007). Mapping the progress in conceptual development of the term 'commons' from natural commons to social or immaterial commons, and to the most recent post-dualistic dimensionality imparted to the term through recent studies, Bresnihan (2015) notes that 'commons is not land or knowledge but a way these, and more, are combined, used and cared for by and through a collective that is not only human but also nonhuman'. Bollier (2007), in one of his important works on commons, examines it as a 'third force in political life', exemplifying its constant tussle with the market and the state forces. He also cautions us against the need to universalise or box the commons into tangible groups.

In the more updated conceptualisations of commons, their socio-political relevance is extensively discussed. Holder and Flessas (2008) observe that 'the idea of 'the commons' can work as a signifier—of resistance, community, collective action and common values'. Commons also allow participation in socio-cultural and political discourses and the actualisation of vocal agency (Benkler 2003a, b). The contemporary forces and challenges of social life, therefore, necessitate the politicised meanings of commons and warn against the dangers of de-politicisation by capitalist forces (Bianchi 2018). Discussing the commons in the plausible post-political condition, Varvarousis et al. (2020) make a point,

> *(o)ur argument is not that the commons in our study are revolutionary 'hotspots' or panaceas that will unhinge the neoliberal logic, but rather that they merit attention for the politicisation potentialities in terms of subjectivities and social fabric…*

In fact, beyond the traditional domestic/local mapping of commons relation, the multi-levelness of the commons through technologically and politically entrenched global linkages has also been explored (Berkes 2008). Furthermore, in galloping the cross-disciplinary environments, the newer issues and avenues for commons and commoning have also been discussed in the literature (Hess 2008; Holder and Flessas 2008; McCarthy 2005).

In this section, a multi-disciplinary conceptual derivation of the term *commons* is secured based on the engagement with corresponding texts in ecology, history, geography, economics, politics and governance, and technology studies. It is hoped that the concept of political common methodologically achieved from this endeavour, in the later section, holds generic relevance for transdisciplinary application without succumbing to the problem of 'conceptual stretching'. Based on the exploration of the concept of 'commons' from different fields of study, Table 3.1 stipulates five broad themes (also discussed below) dominating the concept. This thematic categorisation is a simplistic textual attempt to make sense of complex theoretical and empirical research across different fields and opted to facilitate the broader understanding of the 'commons' in general.

1. **Availability**—The object of 'common' here is taken as an exhaustible resource. Given its relevance for the basic sustenance of human life, its availability has become an issue of concern.
2. **Accessibility**—This relates to the predominantly market-centric or/and quasi-market relation building between the resources and dependent communities. The

accessibility is decoded, assumed, contested, dispersed, and managed through market mechanisms of property ownership, contract making, enclosing, resource-pooling, etc.

3. **Conflicts**—The implicit discord generated from the limitedness and liminality of the common has also been extensively researched. It broadly relates to the issue of interests (selfish or communal) and existence (individual or social) in public life.
4. **Rights**—It pertains to the politico-institutional placement of the common. The active managerial role of the state, in addition to or together with the community and market, becomes a central concern.
5. **Innovation**—It accounts for the in-flux developments that are at times socially driven or politically determined, and at other times technologically stimulated or market run.

These themes are not exclusive of each other; instead, a deep interconnection between the three major forces of any human society—namely, community, market and state—dominates these, albeit to varying degrees.

Governing Smart Cities: As a Democratic Polity

> *Part of what makes democracy work is the sense that it is necessarily about contesting and changing the ways in which citizens communicate with power over different distances, how they oppose it, and how they try to hold it accountable. Democracy is about the re-invention of these relations in changing situations in different geopolitical contexts.*
>
> (Low 2009)

Smart cities have essentially changed the urban scape of human societies around the globe. There is a functional urgency to transform the old into 'sustainably' new, black into 'ecological' green and traditional, and archaic into expeditiously modern, all this while maintaining the principles of inclusivity, accountability, and sustainability. A smart city is defined as '*the utilization of ICT and innovation by cities (new, existing or districts), as a means to sustain in economic, social and environmental terms and to address several challenges dealing with six dimensions (people, economy, governance, mobility, environment and living)*' (Anthopoulos 2017). The role of government in smart cities is also being rethought and re-adjusted given the high-tech realities of the smart urban spaces. The governments are forced to explore the participatory digital mechanics of decision-making, public services, and principles of good governance (Rodríguez-Bolívar 2016).

Governing

Smart city governance is comprehensively defined as a '*form of smart governance, enabling and allocating decision-making rights to stakeholders (in particular citizens) to participate in effective and efficient decision-making processes to improve the quality of life in cities*' (Pereira et al. 2018). In their holistic framework of assessment on smart city governance, Castelnovo et al. (2016) also discuss 'public value generation' as one of the major dimensions. It deals with the social goals and long-term impacts of smart governance projects and interventions, specifically with respect to wellbeing and social inclusion. They discuss the 'codesign(ing) and coproduction by stakeholders and social innovation(s)' implicit in the process of value generation in the public domain. The concept of smart cities has also been theoretically and empirically linked with the quality of human life. Besides the components of sustainability and smartness, the aspect of 'social cohesion' also holds universal relevance (Arroub et al. 2016).

Despite the overbearing technological character ofsmart cities and their obsessive reference in most academic and business accounts as 'socio-technical systems', their acknowledgement as 'people-centric paradigms' is a functional characterisation that sees people as 'smart users' with human (sharing information) and digital (aggregation of sensorial information using digital devices) components (Delmastro et al. 2016). In the systems analysis of smart cities consisting of multiple subsystems, human beings are seen as active agents 'involved in shaping the behaviour of each urban subsystem and the system as a whole' (Razaghi and Finger 2018). In this analysis, they act as 'prosumers' of services in the cities. To extend this argument further, citizens function in both *corporeal* and *meta-corporeal* forms in contemporary 'smart societies'. In the corporeal form, the visible political acts of engaging and deliberating are done. In the meta-corporeal forms, their effective participation in the public sphere is enhanced by their interaction with social technologies. This enhancement may be symbolic or real, depending on the policy output reflecting those tech-assisted socio-political interactions.

However, the governance efforts in a smart city are not devoid of risks to the 'smarting' project and society at large. Shayan et al. (2020) delineate a rich list of risks to smart cities, of which 'social risks' are of value for our analysis here. These include mistrust of the technological interventions, limited citizen participation, ICT-induced digital disabilities, divide, and inequalities between citizens and vis-à-vis market forces and states. To understand the link between urban sustainability of the ICT-enabled smart governance modularitites, a study conducted by Tomor et al. (2019) noted the importance of a 'context-sensitive framework'. One major observation made in the study was that despite the availability and accessibility of the general public to the digital services provided by the government, the citizen-state interaction predominantly relates to a 'one-way information supply'. Digital engagement and empowerment, in this case, do not effectively result in deliberation. In a similar vein, a study conducted on the EUROCITIES network and exploring the concept of 'creative citizenship' found that though these embolden the dynamics of information transparency in the democratic set-up, these ‘do not generate virtual environments favouring fluid interaction between local governments and citizens’ (Rodríguez-Bolívar 2018). ICT cannot, therefore, be assumed as a sufficient condition, ‘(f)or a city to become a “smart city” it needs full engagement of its government and its citizens’ (Rodríguez-Bolívar 2015). Moreover, the compounded nature of emerging urban problems points to the need for not only increased participation within the cities but also a feature of networking and learning between cities, thereby highlighting the need for regional and global integration (Bai et al. 2010). Nam and Pardo (2011) elaborate on the innovation in smart cities in technological (tools-based), organisational (use-based), and policy (problem/solution-based) terms.

This, however, also points to the need for social innovation using the available mechanisms of power and politics available in smart cities, commoning being one of them. The community participation and political functions possible through the spaces and ideas of smart cities can give birth to democratic practices even in the intensely capitalistic and politically enclosed environments of smart cities across the world. Empirically speaking, considering that the idea of smart cities is associated with capital, technology, and people, it is imperative to account for the centrality of cross-cultural and inter-governmental (vertical and horizontal) learning and exchanges for future sustainability.

Commoning

> *To devise common spaces means something much more than to succeed in re-appropriating small pieces of still available open space. It means…to discover the power to create new, ambiguous, possibly contradictory, but always open institutions of commoning. Space, actual physical space, but also metaphorical, imaginary space, becomes not only the ground that is necessary in order to see those institutions function, but also the space that shapes institutions of commoning and is shaped by them.*
>
> (Stavrides 2015)

Recent works on the concept provide an interesting reading of commons by focusing on the agential role assigned to the communities—from passive ‘spectators’ to the active ‘sparring partners’ with the state and markets (Leitheiser et al. 2021). In other tangible conceptualisations, commoning is seen as ‘engag(ing) with grassroot communities’ (Teli et al. 2020) or having close association with the emergence of local social movements (Susser 2017). Gibson-Graham et al. (2016) discuss the post-capitalist transformative commoning strategies beyond the ‘capitalocentric discourse’—whereby commons are considered as a type of property and ‘the coming community of commoners’ is seen as an exclusive response mechanism. They take into account the ‘more-than-human’ components of commoning, classifying commoners as all-encompassing ‘assemblages’ of human and non-human, animate and inanimate, market and social, and governmental and institutional. Nightingale (2019), while providing a political ecology critique from a feminist perspective, give a radical reconceptualisation of commoning to make it more ‘durable’. She focuses on 'doing commoning' and 'becoming in common' as symbolising continuous performance and efforts based on the understanding of the emergence of commons as an 'exercise of power' itself.

These developments, theoretical and empirical, do not necessarily suggest that the process of commoning would inevitably lead to a healthy and unidirectional trend of making the city spaces participative, responsive, and democratic. Low (2009) argues that there are risks implicit in assuming cities as inherently democratic spaces. While discussing a circuit-based analysis of the political communications within a democracy, Low notes that in a traditional understanding of democratic functioning, a continuous flow of feedback from citizens is a structural demand, where '*the longer the flows of communication between demos and political power the greater are the possibilities for democracy's corruption*…'. In this scenario, cities are assumed as 'privileged democratic spaces' that provide avenues for countering such challenges to effective citizen participation by 'shortening and purifying' the circuit due to increased proximity between different stakeholders. He, however, warns against the 'overvaluation' of emergent governance forms that tend to easily connect citizens with the policy-making and implementation apparatus. This is a remarkable observation that holds critical relevance for our efforts at contouring the concept of political commons and commoning in the next section.

Political Commons: Developing a Framework

The classical meaning of the term *political* is derived from the Greek word *polis*, meaning of or relating to the city-state. In generalist terms, a city-state is seen as a political unit with the infrastructure for institutional governance in place (tentatively) within a geographical boundary. The related verb *politheuesthai* deals with being a citizen and 'to be active in managing the affairs of the city' (Mulgan 1990). In the Habermasian knowledge of politics in human society, two points are established (Habermas 1974): firstly, its relation to the sphere of public activity, and secondly, the range of activities possible (accessing/assembling in public or expressing the personal). While exploring the issue of politics and its empirics in conjunction with science and technology studies, Gomart and Hajer (2003) pose a critical question—'*Is that Politics*?' (as a challenge to the central enquiry in political science—'*what is politics*?'). In their reading of John Dewey's work *The Public and Its Problems*, they discuss 'public' as having an emergent character (rather than as a fixed category) and 'politics' (in contrast to its 'institutional fix(ation)') as constructing and evoking collective actors in the form of state, society, and people. There is an essential verbification involved in the efforts at 'doing politics' (Wodak 2009). Politics in this reading is induced with a performative character with a set agenda.

In this context, if we try to define the commons as organically 'political', it may seem an easy act of umbrellifying a concept because all its related functions and entities are dynamically public in their origin and orientation. And anything public has the potential of being accorded a political tag as well. We shall try to avoid this and maintain the semi-exclusivity in the politicality of specific commons. Political commons can, therefore, be comprehensively understood in the following terms:

- Availability is significant for a ***meaningful social and public life***.
- Accessibility apparatus is ***ensured and governed by a recognised authority***, social or governmental.
- Rootedness of the common in a ***legal constitutional rights paradigm.***
- It provides transformative avenues for ***constructive engagement and social development***.
- A ***locale for conflict*** visibility, assessment, and management.
- Fosters ***innovation in institutions, processes, and ideas***.
- ***Source of resilience*** in exigencies (like pandemics, violent conflicts, natural disasters, etc).

In doing so, we further identify the '***SOFT***' characteristics (Fig. 3.1) of the political commons. These are elaborated below:

- **Subject**—people, the central character of all socio-political developments;
- **Object**—the democratic political function of meeting, engaging, deliberating;
- **Forces**—navigating the interoperable routes between market, state, and society/community;
- **Tools**—looking at technology and social processes as mutual-feeder channels for political communications.

The concept of political commons/commoning, thus derived, has the potential for wider purposive application on the following fronts:

- first, as an *identity category* (identification) of the commodity/entity/process;
- second, as an *idea category* (theorisation) for developing a conceptual clarity of those commodities/entities/processes;
- third, as an *instrument category* (application) for mobilising those commodities/entities/processes for tangible changes.

Identifying certain sectors/entities as 'political commons' (within/adjunctly to urban commons) may serve four major goals. Firstly, accord the status of imminent political relevance to the entity despite its 'common' character. Secondly, instil awareness about its power-embeddedness, ideological fertility, and communicative potential for citizens and state alike. Thirdly, impart authoritative and comparative legitimacy to the entity when juxtaposed against the similar mediums/entities readily available in the 'common' space of the city. Lastly, it will help leverage the entity as a crisis response channel for urban emergencies. These themes require further exploration beyond the confines of this chapter.

The political commons, however, should not be seen as incubated from the power politicking. Structurally, these may seem neutral, 'politicised' only by association, affiliation, and funding from the government/state. Instrumentally, it may engage in ideological propagation/erasure with scope for socio-political bandwagoning by stakeholders. The political commons in this sense largely include educational institutions, public-community healthcare systems, publicly owned/operated communication systems, etc., that are critical for the wellbeing of the resident population and impart infrastructural essentialism to the urbanism of the space and its future development. The (neo)liberality of these state-supported political commons, therefore, stipulates substantial socio-academic auditing beyond the minimal breadth of this chapter.

Community Media: An Example

> *Citizens can be the shock troops of democracy. Properly deployed, their local knowledge, wisdom, commitment, authority, even rectitude can address wicked failures of legitimacy, justice, and effectiveness in representative and bureaucratic institutions. The contemporary ways in which citizens make these contributions, however, assume neither the forms, purposes, nor rationales of classical participatory democracy.*
>
> Fung (2006)

Media, despite its technologically distinct and communicatively diverse forms in contemporary times, has historically had a typical *public/political function.* It pertains to information gathering, processing, and communication/dissemination. This made it a co-witness to any kind of governance or institutional developments in the polity, along with the citizens and the state. If this is to be considered a triad, then community media holds a crucial link between the way states and citizens interact and interpret the messages emanating from respective quarters. The explorations of *alternative media,* as opposed to mainstream media, highlight certain general traits in terms of its relatively smaller scale, orientation towards marginalised groups, independence vis-à-vis state and market, horizontal dispersion, facilitator of representational politics, and possessing non-dominant or counter-hegemonic discourses (Carpentier et al. 2003). The linkages between community communication and human development have also been researched, and concluded the important role these mediums play in democratisation, citizenship building, social struggles, and awareness raising (Milan 2009). Saeed (2009) also highlights the coterminous development of media and mass democracy.

In a way, community media is a choice response to the mainstream media, which inevitably gets entangled in 'fictionalisation of everyday politics' and in turn, results in disillusionment with politics itself (Wodak 2009). The journalism of the mainstream and alternative media also differs—while the former focuses on the legal dimensions of the news, the latter shows socio-economic issues of immediate relevance to the people, hence, promoting the christening of community media efforts as a 'radical tradition' (Harcup 2003).

Further, the dynamics of 'platforms' through which community media operates and the commoning is done also needs investigation. The essentially participatory online media is 'rediscover(ing) the social foundations' such that normative social structures and collaborations are becoming the basis for technological designs and interventions (Bollier 2007). The online platforms and content providers are laying 'strategic claims' in becoming 'curators of public discourse' with very little liability for what users of these platforms opinionate and a disproportionate influence on the information policy of the respective states (Gillespie 2010). These media platforms have also become the source of information procurement pertaining to citizens' political needs, policy feedback, and grievances, thereby generating greater participation from the public (Kumar et al. 2016).

The operations of community media as an alternate discursive space available to the masses are not devoid of its challenges. There are issues linked with the sustainability of community media platforms—like short-life, under-capitalised, and relatively smaller audience base (Harcup 2003). In their cultural analysis of community media, Howley (2015) also urges us to explore the performance continuum of the medium whereby it 'demonstrate(s) not only signs of resistance and subversion but evidence of complicity and submission as well'. Dreher (2010), while empirically detailing the 'politics of listening' in concomitance with the 'dynamics of speaking up' points to the fact that 'speaking up does not guarantee being heard, but rather depends on being "granted an audience"' and that research must take cognizance of 'silences and refusals of dialogues'.

Based on a literature survey and field-based observations of the community radios in India, the authors propose community media as not only an example of a political common but also as an effective political commoning tool. Community media, with its focus on *community* and *info-mediation,* possess the following characteristics (tabulated in Table 3.2). In this pursuit, the role of community media is explored as a principal political common with the potential of turning the available state-citizen communication infrastructure into an action-oriented, participative, inclusive, and transformative governance tool.

It has the capacity to not only harness the traditional mould of grassroot political governance aimed at imparting socio-economic agency to the citizens (social auditing of projects and processes, fiscal accountability of local governments, participatory developmental planning, etc.), but also incorporate the dynamic engagement realities of the socially volatile mediascape, and bouts of technological innovation fuelling a smart city. Political commoning is then acknowledged as a mutual discoursing process within the community, facilitated by the state from a 'principled distance' through an infrastructural platform, and adaptive to the challenges and demands of sustainable civic engagement.

Community Radio: Political Commoning in India

Community radio (CR) is a type of communication technology that works on the principles of electromagnetic radiation. It consists of a transmitter and a receiver. The basic design and operational principle make it a convenient tool for information dissemination at the grassroots level. Furthermore, CRs have three characteristics that

Table 3.2 Features and functions of community media as a political common based on literature survey and field-based observations of community radios in India (Source: Authors)

Key features of community media as a political common	Corresponding functions of the community media
Spatial (Virtual + Real)	• Information exchange between state-citizens in a public domain through a communication infrastructure, both digital and physical
Agential	• Discursive, interpenetration of the ideas between the triad—market, state, society/community • People may be both, passive or active recipients of the information delivered
Political innovation	• Constructive, cocreation of the content by the triad • Technologically re-igniting the traditional modes of democratic engagement • Info-mediation, exclusionary/inclusionary by way of content circulated
Civic enterprising	• Political activity (engaging, deliberating) through diverse technological platforms • Comanagement of the infrastructure • Popular voluntarism • Non-rivalrous yet competitive growth
Multi-utilitarian	• Cultural communications • Policy influence • Resilience and responsiveness during emergencies like COVID-19 pandemic • Avenue for regularised public engagement • Policy literacy and awareness of the masses

make them a potent community medium, i.e. 'community participation, non-profit making, and community ownership and management' (Malik 2015). CR provides a democratically moderated channel of communication with a transparent list of programmes and content. Since no personal data is directly needed for its operation and access, it may dissuade fears and negate the element of potential threat while providing crucial services like education, skills, agriculture-related information, cultural and linguistic preservation function, and moments of sensory 'escape' and entertainment.

Government of India's Central Sector Scheme—'Supporting Community Radio Movement in India'—seeks to provide 'resources, capacity, and technology' for the promotion of CRs in 'remote and rural areas, and to promote the socio-economic and cultural development of communities'. These are considered third-tier broadcasting corresponding to public (AIR) and private radio (FM) broadcasting. In the Indian context, studies have explored CRs 'counter-hegemonic' role vis-à-vis dominant discourses and in the development of 'participatory communication ethos' (Patil 2014). In the larger South Asian context, these are believed to have a role in addressing the 'voice poverty' of the otherwise marginalised groups and the macro-level institutional environment is the need for ‘democratic and sustainable’ CRs (Pavarala 2015). It allows for people’s participation in content creation, station management, information production and, most importantly, in its ability to facilitate people to ‘choose their own stories, express their voice, and define their identity’ (Malik 2015). These also have a crucial role in building women’s lives in terms of—giving education, skilling, overall development, and empowerment (Nirmala 2015).

These can, therefore, be seen as ‘social objects’ with unique existence among the larger institutional paradigm of media and democratic governance (Riaz and Qureshi 2017). The CRs are also embroiled in the ‘development discourse(s)’ of the nation, which is often contradictory to the theoretical roots of the CR movement itself (Backchaus 2020). This makes it a dynamic space of exchanges and counter-exchanges. Furthermore, the idea of ‘community’ in community radio is also up for deliberation. Bailur (2012), while exploring the concept of community, theoretically argues that these are indiscrete, dynamic, cognitive, and performed deconstructs. This, when related to conflict environments provides a relevant insight, i.e. if the communities are dynamic and non-rigid in their virtual composition and function, then there does exist a possibility of creating temporary and transitory communities engaged in political commoning, whereby it undertakes politicisation of the grassroots demands and channelises the power of a collective medium for civic participation.

On synthesising our conceptualisation of political commons with the explorations into community media, we generate a two-layered wheel of political common(ing) (Fig. 3.2). The inner layer depicts the key features of community media (an empirical example of political common), and the outer layer contains key components of the concept of political common. This abstract wheel seeks to perform two functions:

- Posit community media within a conceptual frame of political commons, suggesting a similar treatment for other undefined and unidentified political commons.
- Provide a roadmap for utilising the said common for political commoning, and suggests actively engaging with commons for the larger purpose of bolstering the democratic governance processes.

The inner wheel can be retrofitted with other examples of political commons, for instance, a public healthcare or education system, and spoked with a different set of features specific to that common. The outer layer, however, imparts a robust sheath of elements required for understanding the existing and newer commons within a public/political domain of a smart city.

Assessment

Yet we are less sure about what the practices of a democratic politics in our age will and should look like.

(Gomart and Hajer 2003)

The democratic ideals of informed civic engagement and inclusive governance models have influenced the conceptualisation of political commons in this chapter. We do not assume that all smart cities would be within a democratic polity or that only democratic ones are housing smart cities. Any objective empirical enquiry would indeed point contrarily. What we propose, however, is that for smart cities to be sustainable (socio-ecologically, ethically, or politically) and for the commons within them to be just and equitable, democracy pre-positions itself as a credible context.

Not all urban commons can be convincingly portrayed as political commons; neither can the political commons only be confined to urban spaces. The concept also does not attempt to replace the existing commons but rather refine them. Affixing *political* to the commons is to impart operative urgency to the concerned entity/process with respect to their critical role in the governance of smart cities (administrative accountability, feedback mechanisms, procedural and institutional transparency, public participation, inclusive structures, etc.). The resulting 'politicisation' of commons can, therefore, be used as a measure to place the commons (urban or otherwise) within the governance apparatus and channelise it in a manner to positively connect citizens with the state.

Leveraging community media as an example of a political common involved its pitfalls. The community, taken independently, suggests a correspondingly smaller group within a larger society, making it look like an isolated category. However, it was precisely this idea that supported its usage as an example of a political common. The geographical and issue-based limitation of the community media makes it an exclusively community-centric tool. As discussed previously in the chapter, one of the major challenges tosmart city governance relates to the effective distance between citizens and states (or between people and power centres) instilled due to the technological orientation of smart cities, despite the virtual proximity. Community media presents itself not only as a political common (with its public orientation, facilitating democratic engagements, promoting multi-stakeholder interests, and flexible interactions between the social and technological processes), but also as a potent tool for political commoning.

Finally, after providing our justification for *why cities in democracies*, *how political* and *what media*, we come to the crux of it all—the *commons* and *commoning*. Instead of studying in detail the length and breadth of an existing urban common, we venture into articulating why specific entities can be framed as political commons within the perimeters of a smart urban space. With political commons, we do not just suggest a static descriptive concept but a potentially performing concept. Commoning is also seen as an inextricable part of governing. This postulation may be useful in providing an analytical frame for looking at urban commons in smart cities or in identifying newer commons within them for planning inclusive and sustainable urban futures.

To conclude, while the material facets of human lives will inevitably face 'forced obsolescence', the socio-political traditions holding the societies together shall continue with minimal adaptations. The urban political life has historically and artistically been depicted as people meeting, engaging, and deliberating. Despite the 'technological embeddedness' (Anthopoulos 2017) of contemporary smart cities, these functions persist, albeit in different forms and through different mediums. Political common(ing) is, therefore, an attempt to facilitate the designing and production of inclusive and efficient governance in smart cities.

References

Anthopoulos LG (2017) The rise of the smart city. Springer International Publishing, Heidelberg, pp 5–45. https://doi.org/10.1007/978-3-319-57015-0

Arroub A, Zahi B, Sabir E, Sadik M (2016) A literature review on Smart Cities: paradigms, opportunities and open problems. IEEE Xplore, 1 Oct 2016. https://doi.org/10.1109/WINCOM.2016.7777211

Backhaus B (2020) Keeping it clean: exploring discourses of development on Indian community radio. Third World Quarterly 1–18. https://doi.org/10.1080/01436597.2020.1809371

Bai X, McAllister RR, Beaty RM, Taylor B (2010) Urban policy and governance in a global environment: complex systems, scale mismatches and public participation. Curr Opinion Environ Sustain 2(3):129–135. https://doi.org/10.1016/j.cosust.2010.05.008

Bailur S (2012) Who is the community in community radio? Econ Polit Wkly 47(17):92–99. https://www.jstor.org/stable/23214847

Beagle D (1999) Conceptualizing an information commons. J Acad Librariansh 25(2):82–89. https://doi.org/10.1016/s0099-1333(99)80003-2

Benkler Y (2003a) Freedom in the commons: towards a political economy of information. Duke Law J 52(6):1245–1276. http://www.jstor.org/stable/1373170

Benkler Y (2003b) The political economy of commons. UPGRADE 4(3)

Berkes F (2008) Commons in a multi-level world. Int J Commons 2(1):1–6. https://doi.org/10.18352/ijc.80

Bianchi I (2018) The post-political meaning of the concept of commons: the regulation of the urban commons in Bologna. Space Polity 22(3):287–306. https://doi.org/10.1080/13562576.2018.1505492

Bollier D (2003) The rediscovery of the commons. UPGRADE 4(3)

Bollier D (2007) The growth of the commons paradigm. In: Hess C, Ostrom EO (eds) Understanding knowledge as a commons: from theory to practice. MIT Press, pp 27–40

Bresnihan P (2015) The more-than-human commons: from commons to commoning. In: Kirwan S, Dawney L, Brigstocke J (eds) Space, power and the commons: the struggle for alternative futures, 1st edn. Routledge, Taylor & Francis Group

Carpentier N, Lie R, Servaes J (2003) Community media: muting the democratic media discourse? Continuum 17(1):51–68. https://doi.org/10.1080/1030431022000049010

Castelnovo W, Misuraca G, Savoldelli A (2016) Smart Cities governance: the need for a holistic approach to assessing urban participatory policy making. Soc Sci Comput Rev 34(6):724–739. https://doi.org/10.1177/0894439315611103

Cox SJB (1985) No tragedy of the commons. Environ Ethics 7(1):49–61. https://doi.org/10.5840/enviroethics1985716

Delmastro F, Arnaboldi V, Conti M (2016) People-centric computing and communications in smart cities. IEEE Commun Mag 54(7):122–128. https://doi.org/10.1109/mcom.2016.7509389
Dietz T, Ostrom E, Stern PC (2003) The struggle to govern the commons. Science 302(5652):1907–1912. https://doi.org/10.1126/science.1091015
Dreher T (2010) Speaking up or being heard? Community media interventions and the politics of listening. Media Cult Soc 32(1):85–103. https://doi.org/10.1177/0163443709350099
Feeny D, Berkes F, McCay BJ, Acheson JM (1990) The tragedy of the commons: twenty-two years later. Hum Ecol 18(1):1–19. https://doi.org/10.1007/bf00889070
Fox DR (1985) Psychology, ideology, utopia, and the commons. Am Psychol 40(1):48–58. https://doi.org/10.1037/0003-066x.40.1.48
Fung A (2006) Varieties of participation in complex governance. Public Adm Rev 66(s1):66–75. https://doi.org/10.1111/j.1540-6210.2006.00667.x
Gibson-Graham JK, Cameron J, Healy S (2016) Commoning as a postcapitalist politics 1. In: Amin A, Howell P (eds) Releasing the Commons: rethinking the futures of the commons. Routledge. https://doi.org/10.4324/9781315673172
Gillespie T (2010) The politics of "platforms." New Media Soc 12(3):347–364. https://doi.org/10.1177/1461444809342738
Gomart E, Hajer M (2003) Is that politics? In: Joerges B, Nowotny H (eds) Social studies of science and technology: looking back, ahead. Springer, Netherlands, pp 33–61. https://doi.org/10.1007/978-94-010-0185-4
Habermas J, Lennox S, Lennox F (1974) The public sphere: an encyclopedia Article (1964). New Ger Critique 3(3):49–55. https://doi.org/10.2307/487737
Harcup T (2003) 'The Unspoken - Said'. Journalism: Theor Pract Criticism 4(3):356–376. https://doi.org/10.1177/14648849030043006
Harvey D (2010) The future of the commons. Radic Hist Rev 2011(109):101–107. https://doi.org/10.1215/01636545-2010-017
Hess C (2008) Mapping the new commons. SSRN Electron J. https://doi.org/10.2139/ssrn.1356835
Hess C, Ostrom E (2007) Introduction: an overview of the knowledge commons, pp 3–26
Holder JB, Flessas T (2008) Emerging commons. Soc Leg Stud 17(3):299–310. https://doi.org/10.1177/0964663908093965
Howley K (2015) Communication, culture and community: towards a cultural analysis of community media. Qual Rep 7(3). https://doi.org/10.46743/2160-3715/2002.1975
Kumar H, Singh MK, Gupta MP (2016) Smart governance for smart cities: a conceptual framework from social media practices. Soc Media: Good Bad Ugly 9844:628–634. https://doi.org/10.1007/978-3-319-45234-0_56
Leitheiser S, Trell E-M, Horlings I, Franklin A (2021) Toward the commoning of governance. Environ Plann c: Politics Space 239965442110339. https://doi.org/10.1177/23996544211033992
Low M (2009) Cities as spaces of democracy: complexity, scale, and governance. In: Geenens R, Tinnevelt R (eds) Does truth matter? Democracy and public space. Springer, Netherlands, pp 115–132. https://doi.org/10.1007/978-1-4020-8849-0
Malik KK (2015) Our media, our principles. Journalism Stud 16(5):750–764. https://doi.org/10.1080/1461670x.2015.1054195
McCarthy J (2005) Commons as counter hegemonic projects. Capital Nat Social 16(1):9–24. https://doi.org/10.1080/1045575052000335348
Messick DM, McClelland CL (1983) Social traps and temporal traps. Pers Soc Psychol Bull 9(1):105–110. https://doi.org/10.1177/0146167283091015
Milan S (2009) Four steps to community media as a development tool. Dev Pract 19(4–5):598–609. https://doi.org/10.1080/09614520902866421
Moran EF (2019) Urban ecology and urban sustainability. In: Human adaptability an introduction to ecological anthropology. Routledge, UK
Mulgan R (1990) Aristotle and the value of political participation. Polit Theor 18(2):195–215. https://doi.org/10.1177/0090591790018002001

Nam T, Pardo TA (2011) Smart city as urban innovation. In: Proceedings of the 5th international conference on theory and practice of electronic governance—ICEGOV '11, pp 185–194. https://doi.org/10.1145/2072069.2072100

Nirmala Y (2015) The role of community radio in empowering women in India. Media Asia 42(1–2):41–46. https://doi.org/10.1080/01296612.2015.1072335

Nightingale AJ (2019) Commoning for inclusion? Commons, exclusion, property and socio-natural becomings. Int J Commons 13(1):16. https://doi.org/10.18352/ijc.927

Ostrom E (1990) Governing the commons: the evolutions of institutions for collective action. Cambridge University Press, Cambridge

Ostrom E (2000) Reformulating the commons. Swiss Polit Sci Rev 6(1):29–52. https://doi.org/10.1002/j.1662-6370.2000.tb00285.x

Patil D (2014) Exploring the subaltern voices: a study of Community Radio Reporters (CRR's) in Rural India. In: The qualitative report. https://doi.org/10.46743/2160-3715/2014.1024

Pavarala V (2015) Community radio "Under Progress": resuming a paused revolution. Econ Polit Weekly 50(51):14–17. https://www.jstor.org/stable/44002982

Pereira GV, Parycek P, Falco E, Kleinhans R (2018) Smart governance in the context of smart cities: a literature review. Inf Polity 23:143–162. https://doi.org/10.3233/IP170067

Razaghi M, Finger M (2018) Smart governance for smart cities. Proc IEEE 106(4):680–689. https://doi.org/10.1109/jproc.2018.2807784

Redfield R, Singer MB (1954) The cultural role of cities. Econ Dev Cult Change 3(1):53–73. https://doi.org/10.1086/449678

Riaz S, Qureshi I (2017) Emergence of a new institutional logic: shaping the institutionally complex field of community radio in India. Emergence 383–418. https://doi.org/10.1108/s0733-558x20170000050012

Rodríguez-Bolívar MP (2015) Smart cities: big cities, complex governance? In: Rodríguez-Bolívar MP (ed) Transforming city governments for successful smart cities. Springer International Publishing, Heidelberg, pp 1–7. https://doi.org/10.1007/978-3-319-03167-5

Rodríguez-Bolívar MP (2016) Characterizing the role of governments in smart cities: a literature review. In: Ramon G-GJ, Pardo TA, Nam T (eds) Smarter as the new urban agenda: a comprehensive view of the 21st century city. Springer International Publishing, Heidelberg, pp 49–71. https://doi.org/10.1007/978-3-319-17620-8

Rodríguez-Bolívar MP (2018) Creative citizenship: the new wave for collaborative environments in smart cities. Academia Revista Latinoamericana De Administración 31(1):277–302. https://doi.org/10.1108/arla-04-2017-0133

Saeed S (2009) Negotiating power: community media, democracy, and the public sphere. Dev Pract 19(4–5):466–478. https://doi.org/10.1080/09614520902866314

Shayan S, Kim KP, Ma T, Nguyen THD (2020) The first two decades of smart city research from a risk perspective. Sustainability 12(21):9280. https://doi.org/10.3390/su12219280

Soja EW (2011) Cities and states in geohistory. In: Hanagan M, Tilly C (eds) Contention and trust in cities and states. Springer, Netherlands, pp 211–226. https://doi.org/10.1007/978-94-007-0756-6

Stavrides S (2015) Common space as threshold space: urban commoning in struggles to re-appropriate public space. FOOTPRINT 16:9–19. https://doi.org/10.7480/footprint.9.1.896

Susser I (2017) Introduction. For or against commoning? Focaal 2017(79):1–5. https://doi.org/10.3167/fcl.2017.790101

Teli M, Foth M, Sciannamblo M, Anastasiu I, Lyle P (2020) Tales of institutioning and commoning. In: Proceedings of the 16th participatory design conference 2020—participation(s) otherwise, vol 1, 1. https://doi.org/10.1145/3385010.3385020

Thompson BH (2000) Tragically difficult: the obstacles to governing the commons. Environ Law 30:241–278. http://www.jstor.org/stable/43266763

Tomor Z, Meijer A, Michels A, Geertman S (2019) Smart governance for sustainable cities: findings from a systematic literature review. J Urban Technol 26(4):3–27. https://doi.org/10.1080/10630732.2019.1651178

Varvarousis A, Asara V, Akbulut B (2020) Commons: a social outcome of the movement of the squares. Soc Mov Stud 20(3):1–20. https://doi.org/10.1080/14742837.2020.1793753

Wodak R (2009) Doing politics. In: The discourse of politics in action: politics as usual. Palgrave Macmillan, UK, pp 1–27. https://doi.org/10.1057/9780230316539

Part II
Urban Growth, Agglomeration and Urban Infrastructure

Chapter 4
Learning from Contextual Diversity: Urban Sprawls of Greater Melbourne (West) and Chandigarh (Periphery) and Approaches to Their Sustainable Growth

Anil S. Thakur

Abstract The relationships of the expression and phenomenon of 'urban sprawl' with suburban and regional urban growths in spatio-temporal, socio-cultural, socio-economic and global contexts are rejigged here. Different contexts under which varied urban sprawls originate and perform interest this chapter. Pursuing traditional 'Emic' (insiders centred) and 'Etic' (cross-cultural, detached) approaches, we read the changing trends in cross-cultural suburbanisation(s). Further, the two independent constructs are corelated through an 'emic-etic' synthesis when the author engages in auto-ethnography (use of prior personal observations and experiences) and reinforces statistical and literature studies. With the background of living in the western part of Greater Melbourne (Australia) and Chandigarh (India) for 19 and 30 years, respectively, the author pairs the two locations and studies the former's suburban growth (urban sprawls) and the latter's periphery, notwithstanding their developmental and urbanisation levels, historical, cultural and political differences. Both inform the phenomena underlying their growth in different lights. We learn from their illuminating comparisons. Melbourne relates to the farsighted policies of visionaries like administrator Captain Arthur Phillip, the founder of the Australian urban and suburbanscape. Chandigarh, India's modern and Nehru's idealistic capital city, boosted the country's post-independence urbanism—a layered amalgamation of indigenous, Mughal and colonial settlements that manifest in transforming midsized Indian cities, towns and villages. In the following observations, we realise how shortcomings, even maladies of both the 'ideas-inspired' (Melbourne) and 'circumstantially hybrid' (Chandigarh) growths are being rectified via urban consolidation, conservation (sustainably justified densities), and promotion of smart-sustainable infrastructure including transportation.

Keywords Urban sprawl · Suburbanscape · Melbourne · Chandigarh · Urban growth

A. S. Thakur (✉)
Independent Researcher, Urban Planner, Designer and Architect, Melbourne, Australia
e-mail: asinghau@yahoo.com.au

U. Chatterjee et al. (eds.), *Urban Commons, Future Smart Cities and Sustainability*, Springer Geography, https://doi.org/10.1007/978-3-031-24767-5_4

Introduction

With the objective of understanding mechanisms behind the planned and unplanned physical growths and expansions of several large cities, we examine ‘urban sprawl’ both as a term and a significant global phenomenon operating within the realm of ‘urban growth, physical development and management’. It connotes interplays between cities’ planned contents characterised by their densities (e.g. Master Planned Communities (MPCs)), immeasurable intensities and low-spread spontaneous, unsustainable outward peripheral growths of the cities. In some situations, urban sprawls evoke a picture of ideal (well-organised; well-lived) sunny and green developments, and in others of disorderly informal settlements (slums).

Emical and Etical Approaches

Urban sprawls’ engagements in diverse geographic and socio-cultural contexts and societies are examined both ‘emically’ (singularly focused, insiders’ universal perspectives) and ‘etically’ (outsiders’ cross-cultural constructs).[1] To reconcile the perspectives of urban change developed in different locations from Emic and Etic positions, we follow the recommendation that “Emic and Etic standpoints should be regarded as two elements of a stereoscopic image—one that combines two points of view on the same data to represent its object” (Mostowlansky and Andrea 2020). Thus, the two self-sufficient (independent) constructs are corelated through the ‘emic-etic’ synthesis approach. In this process, the author uses auto-ethnography (prior personal observations and experiences) to reinforce the related statistical and literature studies.

Counting on decades of his experiences of living in the western suburbia of Melbourne (Australia); different locales of Chandigarh (India); and completing a Ph.D. on the city (Thakur 2012), the author studies the phenomena of urban sprawl advantageously[2] in contrasting if not opposing historical, socio-economic, socio-political positions and cross-cultural, peculiarities of the two places. The objectives underlying this work are also to:

– expand knowledge on ‘urban growth’ occurring via expansions and extensions of cities, especially when urban sprawls perform as its intermediary agents in varied contexts;
– know how the phenomenon of urban sprawl expresses in different situations.

Illuminating comparisons of the selected cities that follow bring to the fore the knowledge gaps that point to certain unsustainable and deficient urban growths

---

[1] For detailed description, see Pike (1954, 1988).

[2] Longitudinal (with the possibility of reading change over long stretches of time) rather than a cross-sectional study.

affected by different genres of urban sprawls mired deeply in contextual variegations. However, the ultimate concern is improving the sustainability and liveability of the core and outer growth (peripheral) areas through added knowledge.

Supportive Approaches and Representations: Spectacles and Landscapes

The author adopts inter-alia, multi-disciplinary and multi-planer approaches and employs academic disciplines potentially useful in the chapter's construction. The mentioned multi-disciplinary approach does not work alone on a singular plane but often simultaneously and instantly transacts many levels to resolve knotty issues in hand multilaterally. Also, these approaches are not limited to any discipline for too long. Being interceptive and interactive, they provide multi-dimensional views of realities at work, behind the too obvious and the hidden realities.

The author resorts to Debord's (1988, 1992) treatises of '*Spectacle'*, '*Comments'* and the expression 'landscape' (Newton 2013) to comprehend the socio-spatial changes holistically and the socio-politico characteristics of the present times, for example, beyond the limiting statistical projections. The resurgence of Capitalism in this world, in new avatars and new forms of capitalist governments running the society (e.g. left-wing libertarian, Tony Blair's 'Third Way'- the sugar-coated Capitalism with egalitarian inklings—a socially less contentious but a short-lived idea) are observed in ever-transforming and omnipresent spectacles of our societies closely related to the production and consumption cycles of our urban and suburban developments.

Conceptual Framework: Planning Tools (Controls), Urban Sprawls and Suburbs

Humans (including designers and planners) perceive and conceive physical environments and alterations they may require to make in their physical environments in geometric and 3-D forms ('Morphologies'). Next come the tools to realise the imagined and delineated environments. Planning tools range from legislative fiats to controls such as densities, land use, zoning, including Special Economic Zones (SEZs), Urban Growth Boundaries (UGBs), building bulk and form controls, etc., and strategies like investing in regional and local infrastructure, ring roads, highways, freeways, light rails, metro train projects, Bus Rapid Transit (BRT), Transit Adjacent Developments (TADs), Transit Oriented Developments (TODs) and employing value-capture approach for funding latest public transport serving suburban needs. The prime aims are one, to make residents' living sustainable, affordable and easy, and two, to introduce smart technologies and techniques for the management of urban sprawls, their expansion and extension projects.

Transforming landscapes, societies, their spectacles and morphologies of places isolated from one another (here Melbourne and Chandigarh) are the bases of our forthcoming contextually variant analyses. The imagery evoked by urban sprawl is pejorative and attractive, and so are the varying responses of planners and the public. From the author's angle, the above-listed controls are critical for any urban development at any scale. Further, we have definitional problems with 'density' that is multi-faceted and measurable. Intensity is an evocative expression that helps us read and decipher places' environments and the tempo (hyperness). One can feel but not quantify it realistically. Nevertheless, it is an important index of social space and, therefore, of the 'Spectacle'—a socio-politico creation and phenomenon that we rely on in this chapter.

Australian suburbs were born out of aversion to the slums of London and bad memories of the cramped living environments (Sjoberg 1960) that most Australian immigrants had inhered. Therefore, avoiding clutter and spending their future in a salubrious environment in Australian settings came as a natural choice (Davison 1993: 3–6, 1997). In retrospect, initial conditions did not improve environmentally or socially. The notion of 'Smellbourne', the notorious Rocks district of the 1820s in Sydney, worried Arthur Phillip and other colonists because of growing crime and poverty. Still, suburbs' living conditions and environments improved drastically in the long run. Noteworthily, Melbourne has held the rank of the most liveable city in Australia for the past several years (intermittently) and has been a ranker of the world's most liveable city (Blomkamp and Lewis 2019). What lies behind these coveted rankings? Perhaps the historic and farsighted measures taken by the city's inceptors of the nineteenth century and later sustained efforts of local premiers, strategists and planners of the modern era to make the city liveable have paid off in the long run.

Literature is replete with opposing and supporting views on urban sprawl. Irrespective of the two groups' for and against arguments, the author determines from the whelming literature that land use planning, zoning, density controls at variable scales (street, neighbourhood, release and metropolitan areas) and contexts are crucial for any urban development. Moreover, density has definitional problems as it operates through various scales and contexts. For example, the four authorities: McLoughlin (1991); Loder et al. (1993); Cardew (1996); WAPC (2000), propose their independent theoretical models for suburban developments based on varying nomenclatures, interpretations and values of densities at different scales (Buxton and Scheurer 2007).

Home aspirers' economic interests also cause the proliferation of urban sprawls. In Australia, when city living and housing (rental and ownership) becomes competitive and unaffordable, and the living areas shrink, several individuals resolve their housing problems by moving to peripheries where land is comparatively cheaper. The net advantage of moving to peripheral areas is that households get larger spaces for the same prices (Dielman and Wegner 2004). However, travelling time and transportation costs (trade-offs) may offset the savings. The trend, in short, gives impetus to the growth of suburbia that serves well the interests of new settlers. Indeed, individualistic priorities matter in making choices for the housing types and their locations. Accordingly, diversity in affordable housing for all segments of society becomes desirable if not necessary.[3] The top-down decision-making, formulation and exercising of policies often affect decentralised (contextually desirable) diffused urban growth. For instance, in MPCs where density controls as persons/acre/hectare or/km, building bulk, Floor Area Ratio (FAR), Floor Space Index (FSI), zoning, etc. are exercised to achieve officially appropriate and techno-politically approved development plans.

Greater Melbourne sprawls nearly 80–90 km (average) on all sides; some consider it excessive and extensive (e.g. Terrill 2018) and call for an increase in density in the middle ring to gain compactness. But then, density as a standard variable measure is illusionary and constructs different visions of multi-scalar developments. McLoughlin (1991), a proponent of the idea that an increase in density in the suburbs is not an effective strategy, argues that "increasing the gross residential density from 30 to 40 people per hectare would only reduce the radius of the city by one km and 35 people per hectare by only 500 m. Doubling gross residential density from 25 to 50 people per hectare (100%) would only increase the metropolitan density from 13.6 to 18.8 people per hectare (38%)".

We now turn to qualitative readings/observations particularly directed towards deciphering experiences of suburban living and its worthiness.

The concepts mentioned above relate independently to different urban growths and sprawls and generally to several other contexts that we address soon after.

Histories

As mentioned in the Introduction, we would be dealing with Melbourne as an outcome of British expansionism and colonisation promoted under the British flag and policies and Chandigarh as a consequence of India's efforts in search for post-independence India's identity and its future urbanism. While Melbourne is the most liveable city in Australia and has been named the 'world's most liveable city' for almost a decade on several global rankings (Blomkamp and Lewis 2019), Chandigarh has emerged over time as a world-renowned city. It represents the post-colonial Indian urbanism inspired by Le Corbusier's late-modernism and symbolises humanity's faith in its future. As we see later, both the cities shared the aspirations of providing salubrious living environments to their residents in different ways, times and contexts, and promoting healthy urban planning albeit with inconsistent results. At the urban growth and urbanisation levels, the colonial policy of developing and inhabiting

[3] Housing diversity exists in the mixed forms of Townhouses, Terrace houses, Apartments, detached housing, units, caravans, to suit budgets, lifestyles. According to Australian Bureau of Statistics (ABS) Melbourne inheres nearly 70% housing conventional detached housing, 16.8% Town Houses and 14.7% Apartments.

sister colonies of Australia and India varied. The former case involved founding humble settlements *de nouveau* that later grew into towns and subcolonies (nostalgically driven communities). In India, the policy of restricted meddling/involvement in old native settlements and promoting new developments in the vicinities of strategically important cities in the form of Cantonments, civil lines and bungalow areas was pursued in almost a set pattern. Traditional English architecture and climate-responsive frugal construction hall marked the development of the British Colonies of India (Thakur 2022). We take up Melbourne first and then Chandigarh.

Reading Melbourne as a British Colony, Land Possession and the Beginning of the Settlement Process

Here, we discuss the formative history of Melbourne, its gradual growth, interface with local urbanisation processes and a conceptual framework that helps us understand the development controls that structured the city and lent it the appealing character that it is known for.

The foundations of the urban settlement pattern in colonial Australia were historically laid by soldiers, sailors, in-land explorers, surveyors and administrators. In general, the trend of affecting healthy physical environments through controls was also perpetuated by European and Scandinavian doctors to relieve their W.W. ravaged industrial societies living in dark, dingy and unhealthy living conditions of slums.[4]

Melbourne Colony was established at the beginning of the Industrial era when steam engines, telegraphy (1840s Australia; 1851 India) and telephony (1879 Australia; 1886 India); railways, shipping and steel bridges, steel industries, roads-building works, surveying, mining, civil engineering, architecture (disciplines) etc., were burgeoning.[5] Melbourne's rather speedy growth (for the times it was set in) can be related to the pace at which the landmark historical events occurred, creating conditions for favourable growth of Australian colonies. Additionally, the upcoming technologies mentioned above and their applications quickened the rural and urban developments both in Australia with its untouched landscape and independent constitution and India (fairly developed rurally) with its historically layered landscape—an outcome of several invasions (primarily external) and takeovers; processes of socio-cultural assimilation and recasting of the inherited structures into the colonial systems of governance, trading, revenue collection, taxes, modes of production transportation, etc.

---

[4] Medical professionals had even prescribed some byelaws that lent light, ventilation, and openness in European and Scandinavian housing estates. However, such interventions resulted in the development of rows of sterile and stereotypical mid-rise blocks that endorsed the merits of the underlying scientific thought process but lacked architectural and environmental playfulness, and concerns for organised community participation in urban living.

[5] For infrastructure building by the UK in India see Lalwani (2016). Years for India are given to compare (sample) the diffusion levels of technology in the two colonies.

Exploring Teams under John Pascoe Fawkner deserve the honour of being called the rightful founder of Victoria colony's capital, Melbourne. John Batman initiated the first private purchase of the indigenous land of 600,000 acres to accommodate Melbourne and Geelong.

The purchase valued at over 60 million sterling in the 1880s was interestingly bought in exchange for goods (barter) such as blankets, shirts, flour, knives, etc., valued at around 200 pounds—an unbelievable low price.[6] Next comes the official onslaught on the *laissez-faire* arrangement between the natives and Batman. Soon after, the Home Government dismissed the settlement deal. The first public house was built in 1835 and was kept by Fawkner. Batman opened the first general store here. Melbourne was established in 1835. As per the first census in May 1836, 177 persons populated the area. The government was founded here on 29 September 1836. Capt. William Lonsdale, transferred from Sydney, was the first resident magistrate of the place Batmania/Glenelg, which was later named Melbourne by Sir Richard Burke (from Sydney) in March 1837.

On 1 June 1837, the first sale of Crown land was announced of half-acre town-lots. An amount of 35 pounds was collected from the sales. Exports started in 1837 with wool, tallow and hides amounting to nearly 10,200 pounds. Port Phillip announced the independent colony as Victoria in 1841. The first mayor of Melbourne was elected in 1842. A new constitution was proclaimed in Victoria in November 1855 (Ballantyne 1880). The government then pursued its twin interests of establishing towns and settlements (as part of its colonising efforts) and allured settlers from the UK and Europe to decongest cities, especially London (Sjoberg 1960).

Whereas the 1850s gold rush enabled inland centres like Bendigo and Ballarat to flourish, Melbourne derived economic benefit by becoming a centre of banking, commerce and trade, the status it continues to retain as a global city.

As gold mining declined, internal migration to Melbourne from the goldfields gave impetus to Melbourne's growth.

Melbourne: A City in Making

Australia is one of the most urbanised countries. By 1901, its state capital cities accommodated nearly one-third of the population the remainder lived in small urban centres outside cities.

Australia's metropolitan state capitals grew at different rates. In 2012, Sydney had a population of 4.61 million; Melbourne 4.17; Brisbane 2.15; Perth 1.83; Adelaide 1.26; Canberra 0.37; Hobart 0.22; and Darwin 0.13 million (ABS 2012; Hiller et al. 2013).

The seeds of Melbourne suburbia were sowed in the utopian visions of individuals like: Colonist Governor of New South Wales (NSW) and founder of Sydney Arthur

[6] This marks the beginning of trade of indigenous land. The possibility of dispossessing the aboriginal peoples of their lands by exercising allurement and or force cannot be overruled.

Phillip, who had pioneered interventions to induce contagion-free living environments in 1789; General William Light (1786–1839) for founding Adelaide, South Australia; Surveyor Robert Hoddle who marked the grid of CBD Melbourne (1.61 km × 0.80 km) in 1837 guided by the grid of NSW by Governor Ralph Darling. A sort of personality cult was developing in the late eighteenth century onwards urbanism. Davison's (1993:63) observation in hindsight that "Australia was born urban and quickly grew suburban" is tenable. Phillip had outlined and founded an idyllic pattern for urban development of Sydney's first settlement, promulgating thus:

"The streets be laid out in such a manner as to afford free circulation of air, and when the houses were built … the land will be granted with a clause that will prevent more than one house being built in the allotment, which will be sixty feet in front and one hundred and fifty feet in depth" (ibid).

Davison (1993) rightly credits Phillip for inventing famous three-quarter acre building blocks in suburban Australia. Interestingly, Phillip's executed vision for uniform and low-density developments for Sydney's first settlements set a precedent for Melbourne's outskirts. Today, the traditional, culturally preferred and circumstantially evolved 'sparse growth strategy' underlies Greater Melbourne's new suburbanism exuding Yimby[7] spirit in several councils' precinct plans. Overtime, Metropolitan Melbourne's Masterplan acquires a shape of three concentric rings. To encourage private ownership(s), mortgages are facilitated and managed through banking institutions/industries. Reserve Bank of Australia (RBA), States and Federal Government modulate interest rates, concessions for the first home buyers, waivers of stamp duty for the pensioners, etc. Conveyancing has been simplified through Property Exchange Australia (PEXA) portal, which streamlines purchasing and property exchange settlements.

Liveability directly rests with: a high Quality of Life (QoL) coefficient, easy accessibility to transport, amenities, social facilities, green spaces and entertainment areas, density, surface, etc. (Milder 2012). Interestingly, landmark descriptive one-liners for Melbourne have been 'Marvellous Melbourne' (Graeme Davison); 'Felix Melbourne, Australia' (Sir Thomas Mitchell) and in its present state, 'Fluid City' (Dovey 2005).

Urban Sprawls, Suburbs of Melbourne

In Sect. "Histories", we traced the inception of Melbourne and the emergence of suburban growth following the visions of Colonial administrators who preferred sparse growth and salubrious surroundings for the settlers of Melbourne. The Masterplan of Melbourne follows a concentric ring form comprising a series of 'edge cities'

[7] YIMBY (Csorba 2017) 'Yes In My Back-Yard' comes as an antonym of 'Not In My Back-Yard' NIMBY.

(suburbs), leap-frog developments interspersed with green wedges and suburbs[8] serving peoples' demand for subdivided and serviced land through mechanisms of MPCs (Costley 2006) and precinct plans sanctioned by Councils or Municipalities or L.G.s.[9] Further, as per Plan Melbourne 2017–2050, 65% of all new dwellings will be added in established areas, implying the middle ring suburbs will largely accommodate this housing growth. Per se, this points to the government's inclination "to appropriate infill development in established residential areas to ensure the middle ring is contributing to fulfilling the 65% forecasted in Plan Melbourne 2017–2050" (Winograd, n.d).

Western Suburbs of Greater Melbourne Following Sustainable Paths?

Five councils covering western suburbs of Greater Melbourne are Brimbank, Hobsons Bay, Maribyrnong, Melton and Wyndham. We focus on suburbs lying on the Brimbank–Melton district axis.

Today, Greater Melbourne comprises 1025 suburbs. As Melbourne's population grows, more suburbs are outpouring in the rings, including 6 km wide growth corridors, UGBs and green wedges (Buxton and Scheuer 2007:3). Refer Fig. 4.1a. The author holds that Melbourne's upcoming western suburbs are full, self-contained, liveable and engaging. Most new suburbs in the west are adopting more sustainable paths (e.g. class-A recycled water supply for some Melton growth areas; retaining biological diversity and controlling weeds and pests; 'greening the west project'; transitioning towards a circular economy). Moreover, from Victoria councils fund grants, Melton council got funds for the reduction of waste in landfill.

As long as suburban residents' presence is not required regularly in CBD, their everyday living is hardly affected. Adequate local amenities, entertainment facilities and social infrastructure care for their physical and psychological needs. The low-density suburban living, a mainstay of Melbourne urbanism, is both traditional (Romantic and Evangelic) and futuristic (continuity and break; harmony and contradiction). It is popular with most Australians and ethnic groups for its idyllic urban form and relatively affordable housing compared to CBD and inner suburbs. Moreover, suburban residents' immediate contact with nature is an additional boon/advantage. Melbourne's suburban culture embraces a mix of antique and contemporary values. Noticeably, it differs from the American scene, where fusing cultures and economy produced different sets of capitalist landscapes, identities and political beliefs.

---

[8] The term suburb in eighteenth century meant wasteland beyond the boundary of a town grazing grounds, market gardens (Davison 1993).

[9] Moreover, such urban sprawl growths may become subjects of redensification and diversification in the long run as with the case of first ring development(s) where concessions for additional areas and living units (Granny Flat Scheme) were permitted recently.

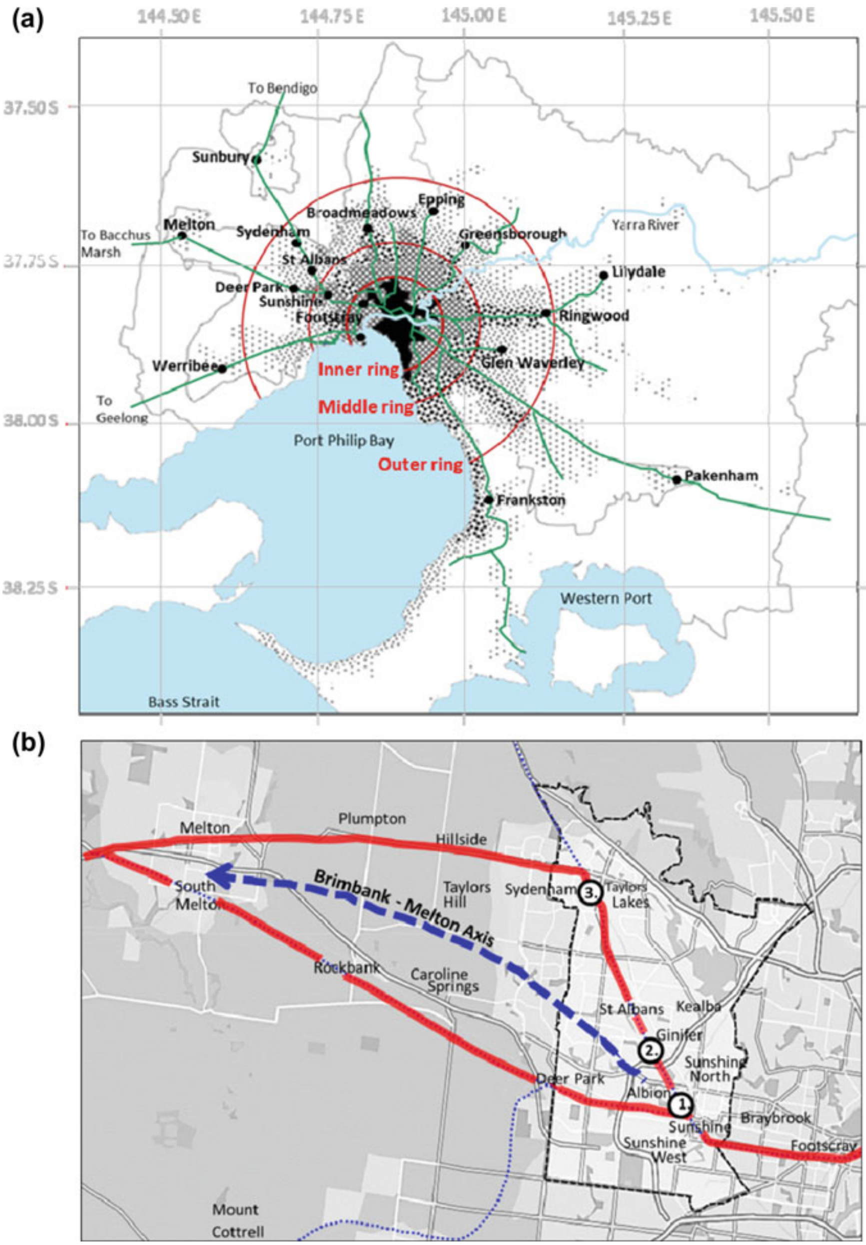


Fig. 4.1 **a** Inner, middle and outer rings of Greater Melbourne, and **b** positioning of western suburbs along the Brimbank–Melton axis

The already high and rising prices of suburban family dwellings are indicative of popularity of the greater Melbourne's western suburbs with public notwithstanding some shortcomings in the public transport network/facilities that are compensated by adequate unpaid public parking available in the suburbs.

Disapproval for low-density suburbs comes from rationalist planners and theorists who favour curtailing urban sprawl through higher densities. They also disapprove of the much-maligned urban sprawls that suffer from the unregulated supply of lands, deficient infrastructure (due to unclear roles and responsibilities of the private developers vis-a-vis government agencies), cuts on social amenities and needs, and other facilities for resident's everyday living and care. The live cases include Thornhill, Rockbank (lacking infrastructure, reneged promises of developers) and west Melton.

A noteworthy observation is that Greater Melbournes's outer-west from Rockbank—Mount Cottrell recorded the highest growth rate (34%), and outer-north Mickleham—Yuroke emerged with the second highest growth rate (28%). Interestingly, the largest and fastest decline of minus 11% is observed in Melbourne city (ABS release 29 March 2022).

Ongoing Work on Sustainability, Amidst Party Politics

Policies formulated and pursued, housing, infrastructure and urban development, education, estate revenue generation and management, and budgetary allocations are critical to the popularity and success of political parties in power at federal and state levels, here in Victoria and Metropolitan Melbourne. This is evident from several overlapping vision reports/plans, Masterplans produced so far, and others in the offing (e.g. Melbourne 2030 prepared under the stewardship of ex-Premier Steve Bracks; Plan Melbourne 2017–2050; Future Victoria 2021, PwC Australia City Pulse; Melton Vision—2021; Melbourne @ 5 million; Managing growth—infrastructure for Melbourne's outer suburbs; Plan Melbourne refresh 2015 etc. Political parties and affiliated governments tend to be identified with new and original proposals for developing and managing urban growth and fast-paced ongoing regional urbanisation. The latter two initiatives are exemplars of incumbent Daniel Andrews's Labour government.

Different/Competing visions carry some commonalities across sustainability (environmental) fronts like induction of pollution-free digital technologies; reduction of carbon footprint; increasing connectivity of suburbs to the CBD and their interconnectivity (e.g. reduction of travel times by introducing effective means of public transport) and how to make it economically feasible and viable. Public safety remains an overall concern for all. Greening cities and suburbs also seems to be a common aim/passion for all. Comparatively speaking, the new western suburbs are the least green, and the inner Yarra area is the greenest. Political parties in power and opposition adumbrate the concepts and ideas of enhancing QoL and happiness indices in the cities and suburbs on a general and bespoke basis. Some articulate their stands for future growth and management of Melbourne suburbia on a holistic basis with wider application befitting regional scale and providing strategies to meet diverse local challenges. Winogard (n.d:1) aptly put it as, "…revolving door of playing 'controls' makes development in the middle ring a game of roulette." The issues of Urban sprawl, as mentioned earlier in the Australian context, are pursued vigorously by both for and against lobbyists. As a fallout of this polemic situation, the 18 km tollway East–West Link project (connecting the eastern freeway with Melbourne's western suburbs using West Gate Bridge involving tunnel works) may be highlighted here as one of the most contentious and hotly debated projects both at the state (Labour party) and federal (currently Labour and earlier Liberal party) levels. The 17 billion project kick-started in 2014, discontinued and stalled over the allocation of funds vis-a-vis its usefulness—in reality, a politically inclined tussle. Also, it is impossible to separate development and its management from politics of economics (finances and funds).

Affordable housing and infrastructure build-up are keys to new developments. Related issues for the further expanding Victorian suburbanisation are the search for sustainable urban forms, urban design and public architecture. Plan Melbourne[10] efforts to promote strong population growth in regional Victoria. In tune with that, 'Regional Growth Plans' have been developed to set a land use framework for development in various regions. Then, there are important relationships between interface and peri-urban councils and the regional towns and cities that lie further away (Plan Melbourne Refresh).[11]

We are reminded of Newton's (2013) green, brown and grey field representations that are useful in envisioning healthy developments in Metropolitan Melbourne and driving future strategies and policies for Melbourne's sustainable regional development. Greenfield sites that inhere predominant agriculture use and little contamination are popular with the site selection consultants. These *tabula rasa*[12] sites are conducive to urban sprawl.

Brownfield sites represent the landscape replete with abandoned sites, e.g. sick industries, fallouts of changing modes of production and upheavals in the economy. Grey landscapes caused by closures of malls, supermarkets, bowling alleys with empty tarmac parking, etc., can be repurposed with little alterations and investments.

Contextuality and Differences

The chapter endeavours to read various human relations with living environments. These inform the choices people make for their built forms and settlement structures that, in turn, are influenced if not governed by local economies, leaderships, cultures and traditions. Whereas we take up Greater Melbourne's western urban sprawls and suburbs for our readings and analysis first, we need to be aware of variations in

[10] Plan Melbourne—Home https://www.planmelbourne.vic.gov.au.

[11] Plan Melbourne https://www.planmelbourne.vic.gov.au.

[12] Clean slate.

meanings attached to urban sprawls, suburbs and suburban living in the Eastern settings before we address Chandigarh.

In the Asian context, urban sprawls often comprise illegal settlements and encroachments contradictory to official plans drawn for the areas. Urban informality plays a vital role in Asian urbanity and politics. It impacts the landscape of places and renders them disorderly looks. The rift between commoners' plightful living and 'planners' dreams becomes pronounced and complicated with the dirty politics of vote-banks deep-rooted in Asian democracies. Leaders in India invariably perform the difficult balancing act of making the cities attractive for investments and keeping them slums-free. Slum voters that impart chaotic looks to cities are, on one hand, king-makers and on the other, the indispensable workforce that helps sustain cities. Beyond this, Asian societies under global pressure struggle to meet the SDGs and bear socio-cultural and financial costs. In line with this, in the ending part of the chapter, we will examine Chandigarh.

Contextualising Urban Societies

Debord's (1988) spectacles of three forms, 'concentrated' (personality cult or dictatorial), 'diffuse' (modern Capitalism of wealthy democracies) and 'integrated' (mixture of the above two), and other ideas have immense potential in describing the state of the world societies spread across different continents. We apply the 'Spectacle' theory in our readings of Melbourne and Chandigarh.

The interplay between 'universality' and 'place-specificity and boundedness', both intrinsic to the nature of 'urban sprawl', generate spectrums of differences in diverse societies such as wealthy democracies and developing economies.

Spectacles help us understand how and how far our societies are driven by contemporary Capitalism. They allow us to understand the climate in which the properties as commodities are produced and consumed (lived) by societies and the expanding role of mass-media projections and larger-than-life imagery that abound our social and private spaces in everyday living. Massive hoardings and digital billboard displays (already a highly competitive and specialised industry beyond advertising) sustain consumerism and ignite desires in prospective consumers. Debord considered spectacle a capitalist strategy to distract and pacify the masses. Of the omnipresence of the spectacle, he observed that "It can be found on every screen that you look at. It is the advertisements plastered on the subway and the pop-up ads that appear in your browser. It is the listicle telling you "10 things you need to know about 'x'". Further, "The spectacle reduces the reality to an endless supply of commodifiable fragments while encouraging us to focus on appearances. For Debord, this constituted an unacceptable "degradation" of our lives" (Morgan and Purje 2016).

Although the observations mentioned above hold good in the Asian context, they are complicated by the underlying economic considerations, development issues and politicking manifested in the parallel informal growths with varying shades of legitimacies and acceptances in the readings of Asian urban sprawls. To some, Asian informality is dehumanising and a source of discomfiture; informal sprawls are surprising and inspiring to others. Yet, to some others, such areas are highly productive and creative sites that host cohesive living despite all the odds dumped against them by the organised, better-placed segments of middle-classes and the super-rich societies.

'Desakota' Form of Suburban Development in South-Eastern Asia

McGee (1991) was the first to map the distinctions of the emerging Asian urbanism, especially in the S-E region. His treatise helps to understand the spectrum of spatial peculiarities of Asian urban. He panned specificities of the mechanisms and economic processes responsible for the distinct characteristics of S-E Asian urban developments in Asian mixed landscapes. Desakota, a combo of expressions 'Desa' (village) and 'Kota' (city), and its three forms of 'classical urban', 'sector' and 'multiple-nuclei' models explain the differences between the universal and the typical Asian urban structures and the ongoing Asian urban spatial transformations. Further, the S-E Asian landscape is largely characterised by many simultaneities like the coexisting disparate features as paddy fields, intensely farmed agricultural lands, wetlands, forests industries and then multi-storey developments—the regional contradictions, the transient expressions of peri-urban, urban, rurban growths on a rural–urban continuum.[13]

Hybridisation and Urban Sprawls

To tease out the in-work mechanisms underlying the hybridisation of urban sprawls of the Global South, we need to fore-mention the upcoming/in-waiting section on Chandigarh (the city raised from scratch—an outcome of MPC planning). Here we realise that urban sprawls of the Global South countries in general, hybridise their officially intended 'pure' Masterplan spaces. In this act, they betray the multiple causal forces like those inspired by the affluents' vested interests e.g. their second home choices; 'middle-classes' and low-income households' buying small lots in illegal fringe developments. Affordances of government and private peripheral lands in the squatting activity also exacerbate urban sprawling (Maier et al. 2009). The upcoming authorised and unauthorized informal colonies in Chandigarh (the unplanned contents) also point to the political affordances of the city's unplanned and unconstructed territory—the coarse side of urban sprawl. Comparatively, Australian urban sprawls are benevolent and uncontaminated.

[13] In contrast, some continuity exists in Victorian rather pure landscape.

The author dwells on the Melbourne region and the urban policies/strategies that direct and control its urban growth. Western suburban development at the intersection with the middle ring and the Melton–Ballarat axis interest this chapter. See Fig. 4.1b.

However, we do not hesitate to relate the development and management of other suburbs, councils and municipalities to their western counterparts whenever necessary in developing our arguments.[14]

Property, Values and Suburban Growth

Now, for a while, we defer the academic and theoretical subjects of managing urban and suburban growth, regenerating/transforming cities into happy cities (Montgomery 2013) and liveable urban spaces, and planning ideas that promise their deliveries. Instead, we consider the aspect of 'commercial success of new private developments affecting Melbourne's UGBs and development corridors. A development's success or popularity is practically measured in terms of appreciation in property prices (a function of demand) and the time it takes to complete its settlements in the real-estate markets.

As a part of the methodology adopted for this chapter, the writer includes the observations and readings of non-academics, professionals drawn from the real and 'live' world of realtors, including professionals and executives of leading Property institutions that keep track of ground realities of the property markets and their underlying currents. With this, we enter into the world of coalescing property related professions that work together to deliver liveable, affordable housing and appropriate urban forms and environments.

In this regards, some illuminating quotes are:

'Areas surrounding Port Phillip Bay featured most prominently in the analysis of annual median sale price growth in Melbourne's ever-sprouting western suburbs. Live in a ten-kilometre ring of the CBD, and you've done well. If you chose to build a new house in an estate of Melton or Hillside, you can pat yourself on the back too.' Pallisco (2007).

Further, Enzo Raimondo, CEO of Real Estate Institute of Victoria, describes the characteristics of the market thus:

'The west of Melbourne has a good combination of affordable properties, diversity of stock available, all of which has shown steady capital growth.' Further, western suburbs initiated in the past decade have been hit by investors and families seeking independent houses. Cases in point and under reference located in Figs. 4.1 and 4.2 are Deer Park, Sydenham, Caroline Springs, Taylors Lake, Taylor's Hill, Truganina, Tarneit, Rockbank, Plumpton, Point Cook and lastly, Wyndham vale, along Sydenham – Melton - Bacchus-Marsh - Ballarat axis. Seemingly, western

---

[14] The Australian Statistical Geography Standard (ASGS) 2020 edition of the Local Government Areas (LGAs) updates the definitions of local government boundaries that have occurred prior to June 2020. ABS—Australian Bureau of Statistics.

development authorities have acquired expertise in delivering successfully built urban environments (with a few exceptions) recognised academically as western urban sprawl or suburbs.

Importantly, recent closures (insolvency cases) of big builder companies (e.g. Langford Jones Homes, Wulfrun Construction, Metricon Homes, Westernpoint Building Pty Ltd and Snowdon Developments, to name a few) in the western suburbs relate to the financial crisis, material and labour shortages in the active COVID period, post-COVID recession, compounding monetary losses and rising interest rates. These are in no way suggestive of any failing demand or popularity of suburban living—a part of Melbourne culture.

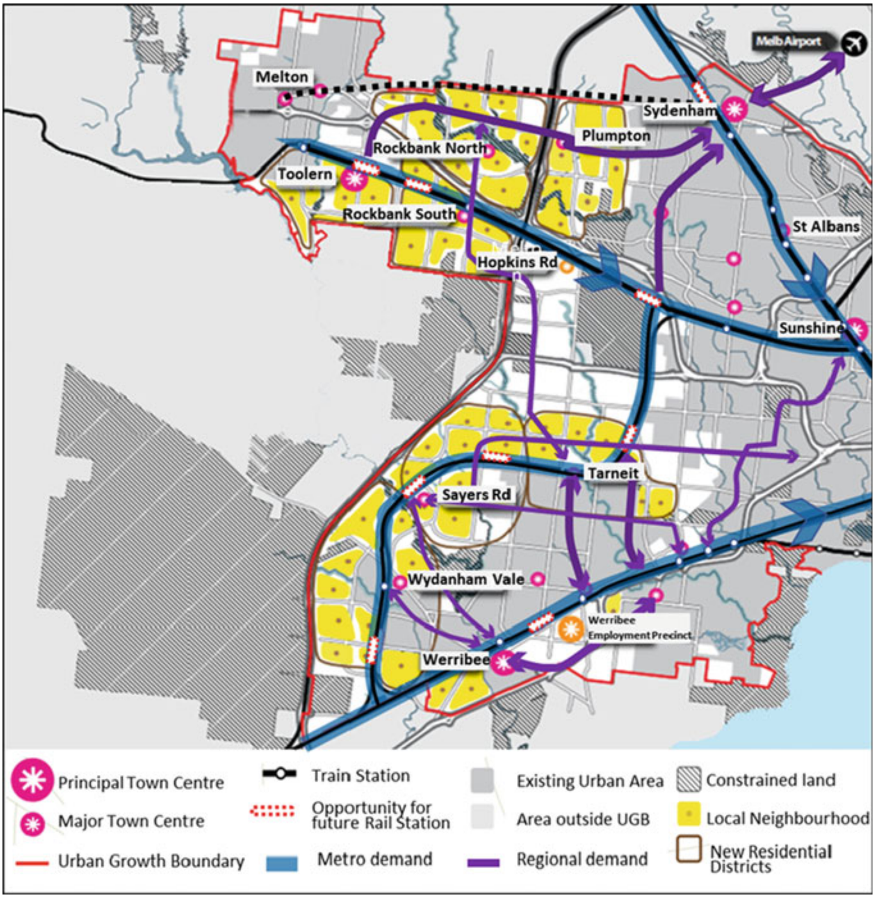


Fig. 4.2 Demand-oriented proposal to interconnect Greater Melbourne western suburbs via railways and BRTS (Developed from GAA (2011:52)

Experiences of Walking, Living in Melbourne's Western Suburbs

As mentioned in the introduction, the author has lived on the Westside of Melbourne middle ring suburbs, beginning with Sunshine, Albion, St. Albans, Sydenham and Melton South. The author's first-hand observations on suburban living of over nineteen years guide this subsection's writing. Many new suburbs mentioned earlier and above developed *de nouveau* or by infilling activities during this period. Moreover, the author's almost every day extensive inter-suburbs aimless (flaneur) walks help him reinforce the theoretical aspects of the literature on suburban living with the following practical observations:

Suburbs separated territorially on plans, at the walkers' perceptive plane, are contiguous and porous simultaneously. One could easily slip in and out of the territories of close-by suburbs. The author frequented walks to and fro from Albion, Ginifer and Sydenham. Sometimes author had 'pick-up' arrangements for return on the following routes in the western suburbs of middle ring, all located along the CBD—Watergardens or Sunbury Line.

The pedestrian routes followed by the author are listed below and for readers convenience are depicted in Fig. 4.3.

When in Albion (an old small suburb)

Frequented Routes:

Albion to Sunshine (a principal Town Centre and a major Train Station);

Albion–Sunshine–Sunshine North-Braybrook;

Albion–Sunshine West;

Albion–Sunshine–Central West Shopping–West Footscray (Barkly Street);

Albion–St. Albans;

Albion–Sunshine North; Albion–Sunshine West via Glengala (built upon an old village's lands).

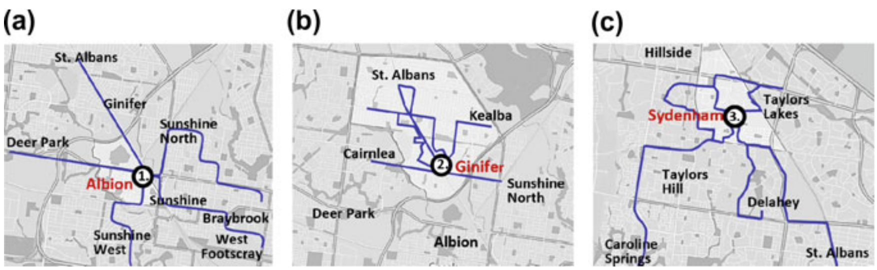


Fig. 4.3 Pathways followed by the author while living in Melbourne's western suburbs, originating from his ex-residences at **a** Albion; **b** Ginifer; **c** Sydenham

Later, when in Ginifer,

Routes:

Ginifer–St. Albans;

Ginifer–St. Albans–Kealba.

Ginifer–Cairnlea.

When in Sydenham (developed around an original village settlement edging Melton Highway).

Routes:

Sydenham–Footscray;

Sydenham–Taylors Hill;

Sydenham–Taylors Lake–Caroline Springs.

Notes:

The memory etched in the author's mind is of ongoing wood framed/timber construction in the new outer ring suburbs and infilling and reconstruction activities in the middle ring suburbs. (a) From the landscaping of the houses and their upkeep, one can easily know whether the house is rented (generally neglected) or owner-self-occupied. (b) Most independent one-family houses had one toilet separated from the seat. (c) Recurring green spaces on inter-suburb routes often appeared in the form of reserves, bountiful rail and roadside strips. (d) The developments characterised by low-density sprawl and low-lying private constructions in different styles of architecture in various suburbs betray their distinct construction periods. (e) In present times, a double garage and a small-pillared portico entry invariably mark the fronts of houses. (Do the garages get preferential treatment in house plans because they are the prized (versatile) spaces of western suburban homes?).

Houses close to bus stops and train stations are generally preferred for renting. However, proximity to transportation nodes sometimes becomes a negative factor because of the possibility of their turning into crime/feral sites. Walkability in low-density green maintained surroundings is an added advantage of suburban living.

The idea of the suburban as a place of peace and refuge, the mirror image of a slum, drew inspiration from romanticism as convincingly portrayed by Governor Arthur Phillip in his first settlements in Sydney in 1789. Arguably, it still works. Davison (1993). To a visitor of Melbourne, its plans seem logical and conducive to sustainable living and life enriched with balanced outdoor and indoor living. One enjoys public rejoicing, functions and engagements year-round in CBD (economical) and retreats to relaxed suburban life—a form of ideal living (Fig. 4.4).

Fig. 4.4 Views of Greater Melbourne's western suburban growth

Chandigarh

Chandigarh has metamorphosed from a sleepy administrative capital-cum-educational and medical centre to a 'techno-global-polis' (Chandigarh Administration's (C.A.'s) term used to 'project' the city for securing foreign investments). Private investments and middle-class consumers have played a vital role in this metamorphosis. In hindsight, Le Corbusier, the planner-architect of Chandigarh, was brilliant. Yet, seemingly, concerns of 'Sustainable Forms' and 'sustainable living' did not absorb him fully, at least not in the sense these terms are used today. He did not foresee how the market economy would intersect his plans for a stable order. Apparently, he concentrated on geometrical forms oriented spatial creativity and aesthetics—his forte and passion. As we explore the Chandigarh region and its periphery, we realise how a global economy and new forms of Capitalism impact its future growth in unexpected and unprecedented ways. The erstwhile rather pure city's sprawls and suburbs are shadowing it from all sides, and new tense socio-spatial relationships emerge in the region. The stakeholder governments of Punjab and Haryana exacerbate the tensions as we observe later.

The impact of the surging market economy becomes palpable in the above-said metamorphosis through Guy de Board's 'Spectacle' of the city's contemporary spaces of consumption. Such-like spaces defy local rules, bye-laws and regulations and ultimately legitimise the very change avoided by the intents of Corbusier's plans for the city.

Peripheral Transformations: Mega-projects, SEZs

Originally, the Chandigarh periphery control area was spread over 1430 km^2. After the reorganisation of the state of Punjab in 1966, 71.4% of the said area went to Punjab and 20.6% to Haryana. Chandigarh, as a U.T, today occupies 8.0%, i.e., 114 km^2 (70 km^2 of the city and 44 km^2 of the surrounding villages (Department of Tourism CA 2007:31; Chandigarh Master Plan 2031:15). The Punjab New Capital (Periphery) Control Act, 1952[15] performs opposite functions of UGBs in Australia[16] and it proved least effective. Indian legislation is inherently weak in exercising planning controls in areas related to urban development. First, misuse of the element of permissiveness deep-seated in Indian democracy and voters' power often intersect with legislative mechanisms and prevent them from functioning in the intended ways. For instance, 'the Right to Fair Compensation and Transparency in Land Acquisition,

[15] The Capital of Punjab (Development and Regulation) Act, 1952 and The Punjab New Capital (Periphery) Control Act, 1952, (PCA), Punjab Land Preservation Act (PLPA) 1990 control the development and status of areas that fall within a 10-mile limits of the city, and this range covers 408 villages. Of these, 330 villages are in Punjab territory, 56 in Haryana, and the remaining 22 in UT.

[16] Introducing no-construction zone within10 miles limits of the city.

Rehabilitation and Resettlement Act, 2013' slows land supplies for urban development even in its amended form. Second, poverty and informality take their toll on urban living while entrenched in local politics. In these respects, Chandigarh is no exception.

Returning to the peculiar circumstantial division of Chandigarh's periphery into three parts, it was a direct outcome of the trifurcation of east Punjab into three states of Punjab, Haryana and Himachal, where Chandigarh attained a U.T status. This development, good or bad, in hindsight, was a game changer for the planned unilateral growth and management of the Chandigarh region. Good because, becoming regional stakeholders, the two governments invested in the Chandigarh periphery in their respective states and timely catered to the growing demand for housing and infrastructure development of the original capital region. The two townships of Mohali (Punjab), a sectoral development contiguous with Chandigarh Phase-III on the S-W side, and Panchkula (Haryana), an independent township on Chandigarh's N-E side, were considered bad developments for Le Corbusier's well-defined and planned city. Allegedly, those burdened its social, educational, healthcare facilities and city infrastructure. Furthermore, the sprawling townships disrupted the intended stable centre–periphery relationship between Chandigarh and its uninhabited hinterland of yore.

To fast forward the history of the place, the conditions were ripening for global Capitalism to assert and for FDI to flow in the region, as reflected in the spectacle of the places and society of the late 1990s when Indian and its regional/neighbouring S-E Asian economies started looking up. On the front of urban development of Chandigarh region, worst followed when efforts to formulate policies of mutual interests of neighbouring states of Chandigarh, Punjab and Haryana failed and pushed their independent vested interests in the region. This is evident from Chandigarh Master Plan 2031,[17] where we observe that the Chandigarh–Punjab boundary intersects with the last row of Chandigarh Phase-III sectors; consequently, irregular residual areas emerge along it. See Fig. 4.5a.

Both stakeholders could benefit from sensible rationalising of the irregular profile of their shared boundary on the principle of give and take. Apparently, no exercise has followed on the ground to advance the idea of give-take rationalisation that is otherwise principally agreed by both parties. The situation warrants a strong mediating force to resolve this and other interstate issues hanging fire. Further, suchlike interstate gridlocks need to be examined along with prospects of strengthening professionalism, even if it means organisational restructuring, integrating quality and relevant academic and institutional research into the C.A.'s Urban planning agenda(s). Importantly, developing alternative and competitive 'vision reports' as seen in the Australian context is important but should not be too binding. Rigidity at all levels needs avoidance. Fluidity in thought processes needs encouragement. Later, we take note of the remarkable performance of the Greater Mohali Development Authority (GMADA) in asserting itself in the area and directing the lion's

[17] Visibly lone post-Le Corbusier Masterplan Report prepared primarily by local architects. It struggles to lead for managing future growth of the city.

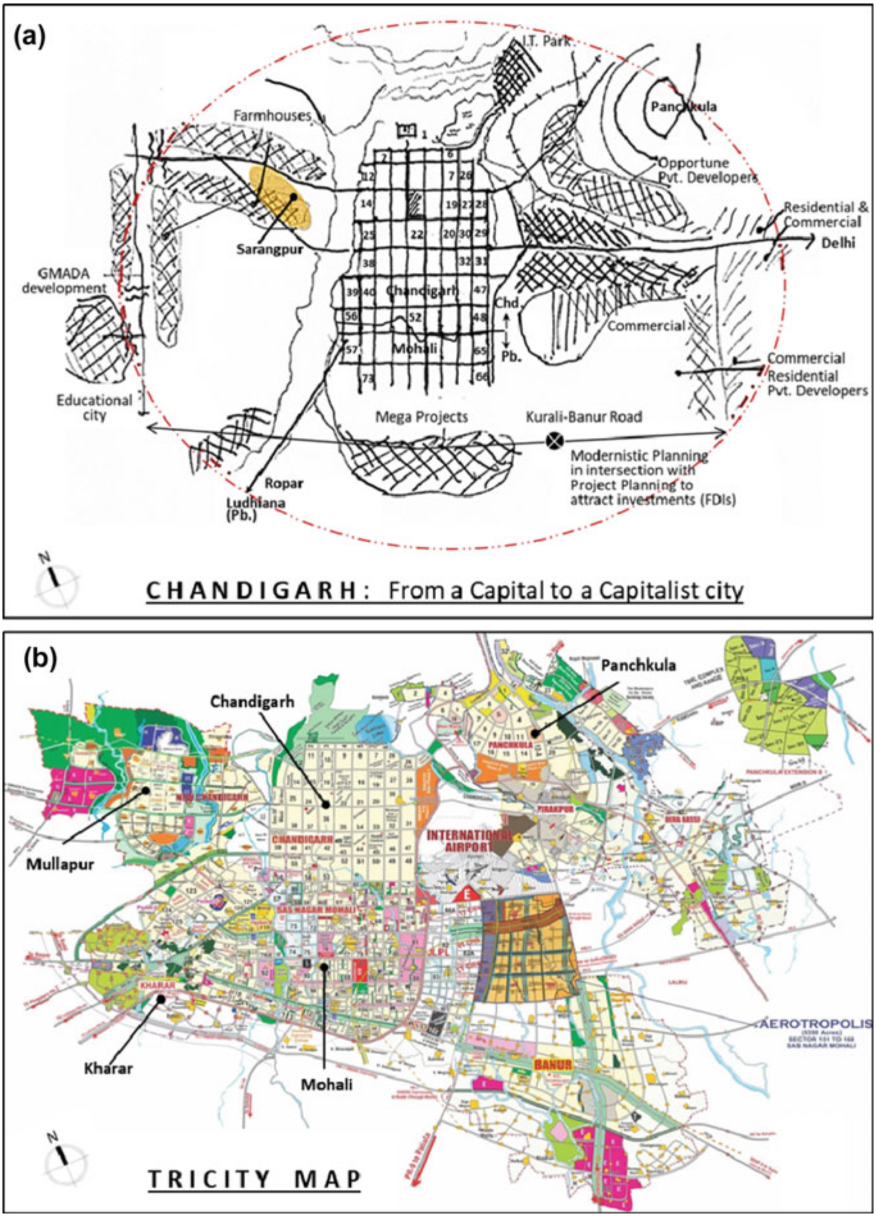


Fig. 4.5 **a** Author's sketch of 2009 depicting anticipated sprawls and growth of Chandigarh region including cues-based expected developments in its periphery; **b** The Tricity plan illustrating mixed/hybrid regional growth of Chandigarh region including the Aero-city replicating the spirit of Chandigarh (Realtor's map)

share of its urban sprawl growth in the region with a tie-up with the multinational JURONG Consultants Pte Ltd.

Periphery

Now we observe how Chandigarh's periphery is transforming in India's market-oriented economy and prevalent project planning trends and how these intersect with the pristine modernist urban planning of the city and its region.

In parallel to C.A.'s plans of locating various mega-projects such as I.T. and business parks, educational, health and film cities, etc. (not conforming to the original Masterplan), the neighbouring states in the city's peripheral lands are also promoting similar (parallel) ambitious projects. Agricultural land surrounding the city is changing hands and attaining urban features in contravention of the Chandigarh Periphery Control Act -1952 (CPCA-1952) (Saini 2005). The rift between project planning (via the private sector) and the original modernist plan is justified by the C.A. because such momentous growth supports U.T's economic interests and follows ambitious development agendas set out by the central government. Further, the infusion of politico-bureaucratic and corporate interests informs the SEZ projects. The politics of undermining the city Masterplan via the production of peripheral spaces through SEZs is discussed after this subsection. We must remember urban growth of a region is closely associated with its urban sprawls and suburbanism. See Fig. 4.5a.

Big Indian developers like DLF, Ansals, Unitech-Builders, Parsavnath, Omaxe, Uppals and other multinationals are lured by good real-estate prospects in Chandigarh. Real-estate companies are investing heavily in commercial and residential projects in Chandigarh's periphery. Such groups promote different marketing strategies, including some observed by King (2004, pp 132–7; 77; 151; 156–9).

In the wake of the ongoing project-based planning, Chandigarh will acquire specialised nodes in its periphery. See Fig. 4.5b. Since significant relationships exist between cities, their urban sprawls and peripheries, it is important to take a broad look of the Chandigarh region, including Mohali and Mullanpur that once suburbs of the Chandigarh region, over time, acquired distinct entities as parts of a conurbation in the making of which Chandigarh forms a part.

We will now examine the development trends in N-E; N-W; S-W; S-E peripheries. Refer Fig. 4.5.

Chandigarh developed from the original pristine part plan prepared by Corbusier. The plan is an emblem of a modernistic city pre-cast conceptually in Paris and placed on the Shivalik foothills almost as an object, quite oblivious of its regional settings, surroundings and local histories. Further, typically, CA avoids recognising its contiguity and proximity to the adjoining states' developments in the region, perhaps due to political reasons. Nevertheless, the author accounts for Chandigarh's regional periphery, including six areas of GMADA, especially Mohali and Mullanpur. As an example, the S-W periphery here refers to the regional limits set by Banur–Kharar road. See Fig. 4.5a.

North-East

The first phase of 'Rajiv Gandhi Chandigarh Technology Park' (RGCTP), one of India's largest, is nearly complete. About 25,000 IT migrant families will live in the new I.T. enclaves to the East of Chandigarh. Almost double this population of I.T. migrants are estimated to inhabit adjoining urban estates of Punjab, mainly Mohali. A medicity is also in the pipeline on 45 acres of land in the RGCTP.

The architecture being produced here for the national and multinational corporate houses like Infosys, DLF, IBM-Daksh, Bharti Airtel, Tech Mahindra, Essaar, Satyams, Net Solutions, Insigma, Infotech, eSys, KMG Infotech and Bharti Airtel (Gera 2007:1), a clear break from the Corbusian architecture is manifested. The tertiary modes of production (services and IT-based industries) express themselves in spaces that are vast, impersonal and non-referential.

Haryana government plans to: build an I.T. park on 200 acres of land; to merge Panchkula with a second township comprising 20 sectors with a 250,000 population in the S-E direction (Ray 2006; Saini 2003:1, 2006:3). U.T's warehousing project begins on 45 acres of prime commercial land close to the railway station in the East.

North-West

On this side of Chandigarh, an independent institutional area is planned on the land of Sarangpur village, where amusement-cum-theme park, education city, film city and equestrian academy are being developed. A botanical garden and an education (knowledge) city are under development. The area also has farms and farmhouses of influential city residents. GMADA is proactively developing New Chandigarh or Mullanpur (the first Eco-friendly Township of the region) on 6123.7 ha overlying 33 Punjab villages around Chandigarh,[18,19] See Fig. 4.5b.

DLF, Omaxe, Altus Space Builders and Innovative Housing Infrastructure Private Limited are the important stakeholders in this development, including an expressway to Anandpur Sahib.[20] Further, Chandigarh is getting connected to Himachal Pradesh (the third neighbouring state) through Siswan (a village on Chandigarh's N-E periphery Fig.) to Baddi (a new industrial town in Himachal) link road (25 km) and a

---

[18] On the 22nd June 2007, GMADA appointed multinational JURONG Consultants Pte Ltd. to complete a comprehensive Integrated Masterplan for its six Local Planning Areas (LPAs): Banur, Dera-Bassi, Kharar, Mullanpur, S.A.S Nagar and Zirakpur. Mullanpur is planned for gross residential density of 100 persons/acre. (JURONG Consultants Pte Ltd).; *Mullanpur Local Planning Area Greater Mohali Region Punjab (India) Master Plan Report 2008–2031*. https://www.gmada.gov.in/sites/default/files/documents/mullanpur-rpt-2011.pdf).

[19] Interestingly, phase-I of Chandigarh was laid over 43 km^2 and phase-II on 27 km^2 with planned densities of 17 and 60 persons/acre respectively. Present average density of the city is 9258 persons/km^2. https://chandigarh.gov.in/know-chandigarh/general-information.

[20] Sikh pilgrimage site where Guru Gobind Singh laid the foundation of the Sikh Panth.

direct railway link. Private developers are already augmenting the Baddi settlement into a residential-cum-commercial town.

South-West (Mohali-End on Kharar–Banur Highway)

The city periphery accommodating phase-III of Chandigarh has dense growth in sectors mainly comprising co-operative group housing.

The Punjab government has approved an IT Park on 500 acres on this periphery.

The Punjab government acquired agricultural land from farmers and made allotments to private developers at a reserved price. They, in turn, are developing independent communities and exhibit banners and hoardings to attract the attention of the commuters. A ditto trend is traced in Melbourne's underdevelopment sprawls. Imposing gateways to the mini-townships have become a standard feature for the emerging Indian urbanism.

Independent private developments have been constructed along the referred periphery along Kharar–Mohali–Banur Road. The MPC gateway communities exhibit thematic architecture (e.g. mixes of tropical villas and condominiums, red-tiled sloping roofs and implanted palm trees).

The developers' sales strategies centre on the concepts of 'good and elevated living, healthy and global lifestyles'. The strategy works understandably well, as nothing moves buyers more than the idea of owning a property in a setting like northern Chandigarh. Good living' is understandable because living and owning a property in central Chandigarh is held in great esteem among Punjabis. Also, to attract customers for their properties, the private developers vie each other by assuring buyers of a 'lifestyle more elevated than in the middle of Chandigarh'.

South-East: (Zirakpur) Along Chandigarh-Patiala; Chandigarh-Ambala-Delhi Highway

Parcels of agricultural lands towards the South-Eastern territory are also being utilised for private residential and commercial real-estate projects.

Here, the developers and the landowners deal directly, while the Punjab government plays the role of a mere 'sanctioning authority'. In this area, the promotional slogans are themed on 'flawless utilities' and 'abundant green spaces'. A combination of Western and Indian nomenclature and imageries come handy for marketing the projects. The city on this axis expands along the newly constructed, four-lane, 50-km-long highway between Chandigarh and Ambala.

Figure 4.6 depicts loose peripheral spaces of green fields being converted to independent housing and residential complexes. Commercial hubs and independent houses replace the old factories and kilns to make way for idiosyncratic and free styles of architecture. Here, we are reminded of the Desakota developments. Also visible in the figure is the plush glazed 'Paras Down Town Square' beside a large parcel of strategic land temporarily appropriated by migrants. (All the pictures are taken from the newly constructed bridge at Zirakpur on Chandigarh–Ambala highway).

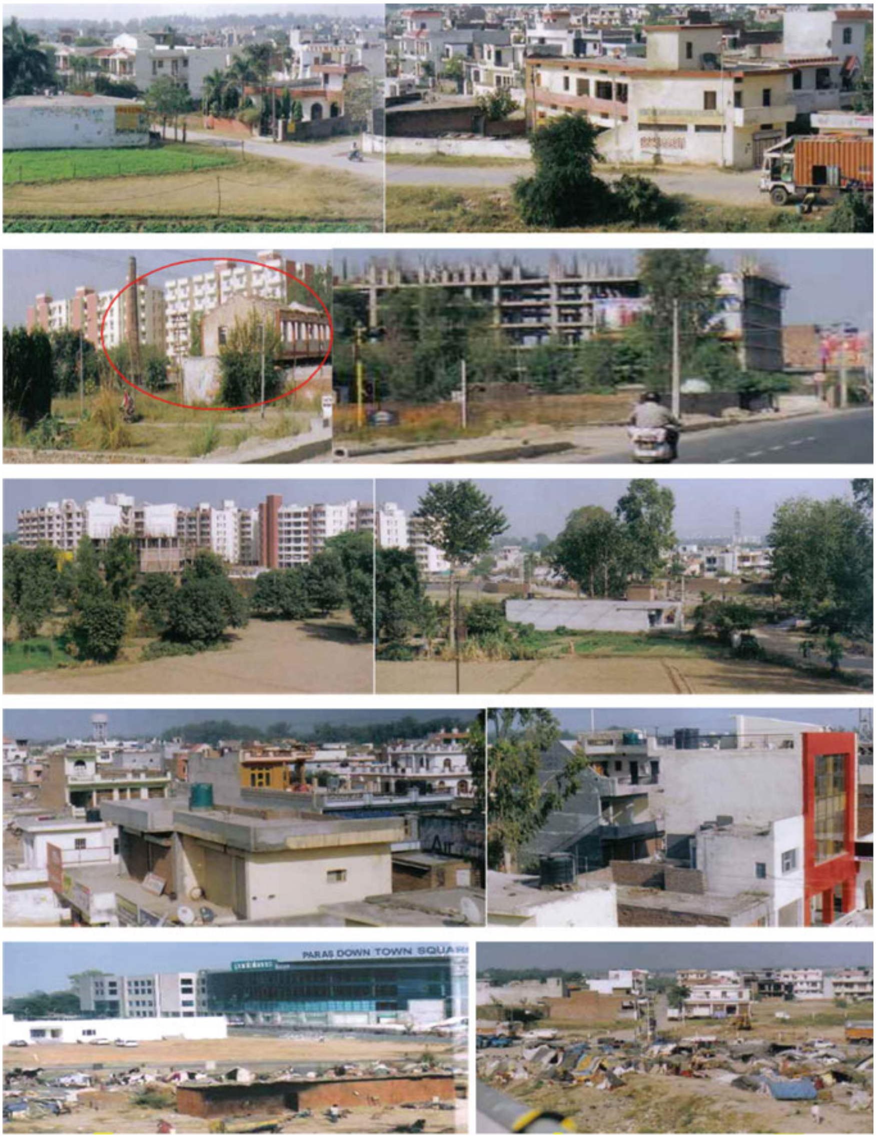


Fig. 4.6 Views of ongoing developments in the south-east periphery of the Chandigarh region

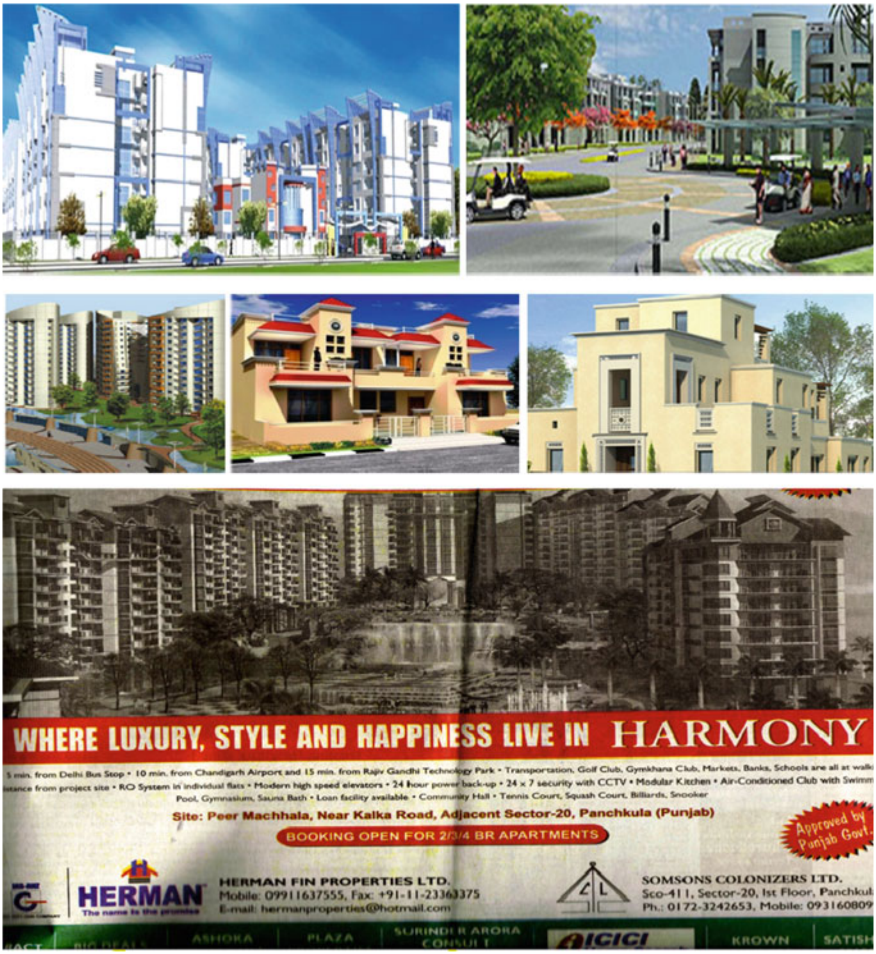


Fig. 4.7 Spectacles of urban development in the south-east, Chandigarh region

Figure 4.7 informs on a spectacle of the realtors' world that exhibits hoardings as 'crowded with dreams and ideas' to stir the imagination of the home buyers. Where there is an acute scarcity of water and electricity, the developers entice people with the imagery of waterfalls, pools and greenery.

SEZs

To relate the spatial change to global processes in an Asian context, we need to consider the growth of SEZs. Driven by the pressure to attain high economic growth rates, India resorts to developing SEZs to encourage and absorb FDI on the one hand and raise employment opportunities on the other. The Indian government has sanctioned more than 181 SEZs, and hundreds more are awaiting approval. They will materialise in various gated cities in different states and U.Ts of India. Under the scheme, lands are being handed over to the big national and international real-estate companies at throw-away prices with privileges like permission to develop independent townships within the SEZs, including commercial, residential areas, hotels, hospitals, markets, clubs, golf courses, casinos and recreation centres. Developers are also given rights to provide services to the inhabitants and to allot developed plots directly to the SEZ-approved units (Devasahayam 2006:11). Chandigarh has its share of approved SEZs, and so has Punjab around the vicinity of Chandigarh. One of these is being developed by the multinational 'Quark' ('Quark City' in sector-74 is a 25-story development). SEZs are the crucibles for innovative spatial change fostered by FDI. Chandigarh's surroundings transform with the shifting of its centrality and identity from a capital city to a capitalist city.

Emerging Scenario

The forerunning citywide observations of the Chandigarh section highlight two processes that determine the city's present growth. Under the first, the city grows following the logical, pre-planned path, notwithstanding differences that emerge in the built environment due to: additions and alterations to the existing fabric, time gaps in construction, the infilling activities of the new sectors and changing policies. Under the second process, growth is guided by the dynamics of local Capitalism and globalising economy. This growth can be divided into two subclasses. The first although falls within the project planning domain, it does not necessarily conform to the original Chandigarh Masterplan (mega-projects and SEZs being taken up under project planning) promoted by C.A. and adjoining state administrations within their respective boundaries. The second counts for 'opportunistic and speculative' growth initiated by private developers and speculators in the peripheries. The latter accrue profits from the 'novelty value' of the developments and their 'beckoning capacity'. The trend introduces kitsch and flashy architecture.

Differences and Distinctions

The ground realities of Greater Melbourne and Greater Chandigarh differ vastly. Melbourne Metro's 5,151,000 people spread over 9993 km^2 (2022) result in an average density of 515 persons/km^2; inner city population density reads as 19,900 persons/km^2 (ABS release 29 March 2022). In the latter case, 1,054,686 persons spread over 114 km^2 denote a density of 9252 persons/km^2 (2011 latest census of

India). Taking the forecited population as 1,191,000 (2022), the density of Chandigarh accrues to 10,447 persons/km^2. (United Nations Population Projections). In any case, Chandigarh (97.25% urbanised)[21] is far more densely populated than greater Melbourne.

The decadal growth rate of 17.10% during 2001 and 2011 is the slowest since Chandigarh's inception.[22] Does the trend indicate that neighbouring towns of Mohali, Panchkula, Zirakpur, Kalka, Kharar, etc. (within the 10-mile or 16 km periphery range), etc. provided the necessary alternative (affordable) rental and self-owned housing in the region? In a sense, these are the performing urban sprawls of greater Chandigarh, having much higher densities compared to the suburbs of the Melbourne region. As already discussed, densities are highly contextual (geographically and demographically). The contextual variations in controls and standards also destabilise the universal homogeneity of landscapes and regulate their diversity and hybridity, as demonstrated through Chandigarh's empirical study. Characteristics of urban sprawl and the character of suburbs vary trans-continentally.

Conclusions

The lineage of growths of Melbourne and Chandigarh vary substantially. The former is the outcome of historical and colonial excursions and the product of circumstantially evolving ideas and strategies for establishing colonies on natives' lands to expand the British empire's, trade and economy. Visionary administrators of various eras set the foundations of settlement structures and forms on the discovered lands. The latter case is the outcome of symbolism and modernism; a symbol of freedom, democracy, self-reliance and an ancient civilisation's faith in its future—a history-denying city constructed on a *tabula rasa* with the planning ideas and treatises that staunch modernist planner-architect-artist Le Corbusier had developed over his lifetime. Such contextual differences underlie developments of the two cities separated geographically by 7809 km.

Methodology-wise, Emic and Etic; Emic-Etic and Auto-Ethnography have paired well to develop and expand our knowledge and thoughts on the delineated subjects of suburbanisation and suburban living. We now have a better inkling of how urban sprawls play out in abounding diversity of political economies and varying socio-economic conditions that continuously shape our lives, lifestyles in short, our existence.

Legislative frameworks designed to streamline uncontrolled growth in India often give way and bend to external political and bureaucratic pressures and machinations of powerful groups or lots. The conflicts between deep socio-cultural structures and superficial modernity underwrite India's urban chaos to varying degrees. On the other hand, urban control legislation in Australia worked rather smoothly and effectively.

[21] Union Ministry of Housing and Urban Affairs. (18-May-2020).

[22] Highest being 394.13% in the formative decade of Chandigarh 1951–1961.

Melbourne accommodated its urban growth in concentric rings (comprising urban sprawls and suburbs) interspersed with growth corridors and green wedges, all contained within planned UGBs. Chandigarh region followed a multi-staged process of generating urban sprawls and suburban areas. First, come Panchkula and Mohali as suburbs (satellites) of Chandigarh. Then they grow into cities competing with Chandigarh. Finally, as they diffuse, they form a part of a regional conurbation that, visibly with its mega-periphery and bulk, overtakes and engulfs Chandigarh territory. Figure 4.5a, b demonstrates how the coalescing surroundings of Punjab and Haryana are overpowering Chandigarh from all sides except North-East (primarily a forest reserve).

The chapter informs on:

– changing human needs and values over time and their reflections in transforming environments observed via green, brown and grey field developments. The erstwhile urbanising Chandigarh shared characteristics of Australian low-density urban sprawl until due to the circumstantial bifurcation, it could not perform for long as a core in the core–periphery relationship that nourished the region. The development had two sides to it, one: introduction of dispersal and fractal growth in the region, two: loss of stability, certainty and clarity in managing its regional growth.
– effectiveness of universal 'planning controls (tools)' in diverse settings with varying results due to cultural pressures;
– accruing otherness and diversity in the cities and the roles of their histories in shaping their present and future QoL.
– The trends of exhibiting banners, hoardings with pictures of global lifestyles and displays of sample luxury houses and apartments along the highways on various community housing sites are common in Melbourne and Chandigarh (Figs. 4.4, 4.6, 4.7 and 4.8). They contribute to the capitalist spectacle of the places that thrive on firing the desires and imagination of the people at large. Spectacles generated by the real-estate developers enhance the attractiveness of the developments and give a human face to them. In all, the region undergoes a metamorphosis of multi-centric growths.

Simply put, the challenges of fast galloping urban population and escalating housing demand can be met only through 'expansions' (new areas) and 'extensions' (pre-existing) of habitable environments in vertical, horizontal and mixed-use forms of developments. Conceptually, by adopting the first possibility, we approximate the treatise of 'The culture of congestion' (Koolhaas 1994:134; Chapman 2007) that, in the context of present writing, relates to 'techno-rich vertical high density-sprawls'. With the second, we return to the well-developed, extensively used Australian suburban model of urban sprawls whose weakness on the public-transportation front is compensated by BRTS, TODs and linking them to strategic

Fig. 4.8 Selling houses as commodities in **a** Greater Melbourne; **b** Chandigarh region—similar spectacles

freeways, tramways and cycle tracks. The third, preferred by the mid-density advocates, brings us close to Jacobian pragmatics and walkable environments[23] enriched with social interactions. Much depends on individuals' preferences, so we must aim for diversified solutions for new suburban developments like compact and green layouts, diversity in housing and sustainable, liveable and safe environments. The last winding words are 'Affordability' and 'Contextuality'!

References

Ballantyne J (1880) Our colony in 1880: pictorial & descriptive, with new map of Victoria and plan of the city of Melbourne. M. L. Hutchinson, Melbourne. http://nla.gov.au/nla.obj-385743987

Blomkamp E, Lewis JM (2019) Marvellous Melbourne: making the world's most liveable city. In: Compton M, 't Hart P (eds) Great policy successes, pp 180–200, Oxford Scholarship Online: October 2019. https://doi.org/10.1093/oso/9780198843719.003.0010

Buxton M, Scheurer J (2007) Density and outer urban development in Melbourne city. Structures 07:1–18

Cardew R (1996) Residential densities in Sydney: defining and measuring residential densities. Austr Planner 33:105–113

Chapman M, Lehmann S (2007) Congestion and movement: cities crowds and Chandigarh. Des Philos Pap 5:129–147. https://doi.org/10.2752/144871307X13966292017595

Costley D (2006) Master planned communities: do they offer a solution to urban sprawl or a vehicle for seclusion of the more affluent consumers in Australia? Hous Theor Soc 23:157–175. https://doi.org/10.1080/14036090600862346

Csorba C (2017) Sprawl or suburbanisation? What's the difference? Blog: YIMBY. https://www.gapssualberta.com › blog › spraw-or-subur'. Accessed 3 July 2022

Davison (1993) The past & future of the Australian suburb. Urban Research Program, Working Paper No. 33, January. Research School of Social Sciences, Australian National University

Davison G (1997) The great Australian sprawl. Hist Environ 13:10–17. https://search.informit.org/doi/10.3316/informit.769402465333798

Debord G (1988) Comments on the society of the spectacle, Imrie M (Trans). Verso, London, New York

Debord G (1992) Society of the spectacle, New. Rebel Press, London

Dieleman F, Wegener M (2004) Compact city and urban sprawl. Built Environ (1978-) 30:308–323. http://www.jstor.org/stable/24026084

Department of Tourism Chandigarh Administration (C.A.) (2007) The modern historic core of Chandigarh, Nomination Dossier, Trans-border Serial Nomination "Urban & Architectural Work of Le Corbusier". UNESCO, Paris

Devasahayam MG (2006) SEZs as gated cities, The Tribune, Chandigarh, 30 October

Dovey K (2005) Fluid city: transforming Melbourne's urban waterfront. University of New South Wales Press, Sydney

Gera KA (2007) A new-look Chandigarh? Business Standard, 28 April. www.business-standard.com/India/news/new-look-Chandigarh/282691/. Accessed 26 May 2008

Growth Areas Authority (GAA) (2011) Growth corridor plans: managing Melbourne's growth. https://vpa-web.s3.amazonaws.com/wp-content/uploads/2016/10/Growth_Corridor_Plan_Managing_Melbournes_Growth.pdf. Accessed 26 June 2022

[23] Hiller et al. (2013) rightly notes that the 'high-density walking city' (walled) of the 1900s has been replaced by the 'medium-density city' of the 2000s.

Hiller BT, Melotte BJ, Hiller SM (2013) Uncontrolled sprawl or managed growth? An Australian case study. Leadersh Manag Eng 13:144–170

King AD (2004) Spaces of global cultures: architecture, urbanism, identity. Routledge, London, New York

Koolhaas R (1994) Delirious New York: a retroactive manifesto for Manhattan. The Monacelli Press, New York

Lalwani K (2016) The making of India, The untold story of British Enterprise. Bloomsbury Continuum, London. ISBN HB 9781472924827

Loder, Bayly, Nairn RJ (1993) Sustainable solutions, and PPK consultants. Greenhouse Neighbourhood Project, The low energy suburb. Summary and technical reports, Government of Victoria, Melbourne

McGee T (1991) The emergence of desakota regions in Asia: expanding a hypothesis. In: Ginsburg N, Koppel B, McGee TG (eds) The extended metropolis: settlement transition in Asia. University of Hawaii Press, Honolulu, pp 3–25

Maier J, Fadel G, Battisto D (2009) An affordance-based approach to architectural theory, design, and practice. Des Stud 30:393–414

McLoughlin JB (1991) Urban consolidation and urban sprawl: a question of density? Urban Policy Res 9:48–146

Milder J (2012) Sustainable urban form. In: van Bueren E, van Bohemen H, Itard L, Visscher H (eds) Sustainable urban environments. Springer, Dordrecht. https://doi.org/10.1007/978-94-007-1294-2_10

Montgomery C (2013) Happy city: transforming our lives through urban design. Farrar, Straus and Giroux, New York

Morgan T, Purje L (2016) An illustrated guide to Guy Debord's 'The Society of the Spectacle'. 10 August. https://hyperallergic.com/313435/an-illustrated-guide-to-guy-debords-the-society-of-the-spectacle/. Accessed 1 July 2022

Mostowlansky T, Andrea R (2020) Emic and etic. In: Stein F (ed) The Cambridge encyclopedia of anthropology. https://doi.org/10.29164/20emicetic. Accessed 4 Sept 2022

Newton PW (2013) Regenerating cities: technological and design innovation for Australian suburbs. Build Res Inf 41:575–588. https://doi.org/10.1080/09613218.2013.803921

Pallisco M (2007) Performance of Melbourne's Western suburbs this spring, Realestate Source.com.au, 28 October. https://www.realestatesource.com.au/performance-of-melbournes-western-suburbs-this-spring/

Pike KL (1954) Language in relation to a unified theory of the structure of human behavior. Summer Institute of Linguistics

Pike KL (1988) Cultural relativism in relation to constraints on world view—an emic perspective. Bull Inst Hist Philology 59:385–399

Ray RU (2006) Aiming to touch the sky, Hindustan Times Chandigarh (date unknown). p 1

Saini M (2003) HUDA to make owning house in foothills reality, The Times of India, Chandigarh, 21 August. http://timesofindia.indiatimes.com/articleshow/141610cr. Accessed19 Jan 2009

Saini M (2005) Money makes periphery go round, The Times of India, Chandigarh, 19 November

Sjoberg G (1960) The preindustrial city, past and present. The Free Press, New York

Terrill D (2018) Pursuing a growth path no one wants. Blog: Smart Cities. https://www2.deloitte.com/au/en/blog/shaping-future-cities/2019/pursuing-growth-path-no-one-wants.html. Accessed 29 June 2022

Thakur AS (2012) Chandigarh: processes and mechanism behind the ongoing transformations in the modern city. PhD thesis. The Faculty of Architecture, Building and Planning, The University of Melbourne

Thakur AS (2022) Contextualising urban sustainability: limitations, tensions in indian sustainable-smart urbanism perceived through intranational, international, comparisons and district city, Ambala City. In: Chatterjee U, Biswas A, Mukherjee J, Mahata D (eds) Sustainable urbanism in developing countries. CRC Press, Boca Raton, pp 18–39

Western Australian Planning Commission (WAPC) (2000) Liveable neighbourhoods: a Western Australian Government sustainable cities initiative, 2nd edn. WAPC, Perth

Winograd R (n.d.) Melbourne's middle ring. https://mecone.com.au/articlesandnews/melbournes-middle-ring/. Accessed 1 July 2022

Chapter 5
Urbanisation and Urban Villages: An Overview of Slum Communities in India

Mark Ethan Harrison and Madhuri Sharma

Abstract In 2011, over 65 million people lived in slums in urban India. A slum is an informal settlement that largely consists of dilapidated housing, small living area, without adequate access to clean and potable drinking water, sanitation and unstable renting agreement. Within these slum settlements exist real people and communities whose lives revolve around the nexus of urban (in)formal economy, with hopes and dreams for a better future for themselves and their next generation, as they take decisions to out-migrate from underdeveloped rural areas. These informal and yet vibrant communities often become the backbone of urban economies. Despite a lack of basic amenities, these settlements provide affordable housing to a significantly large share of slum dwellers in India's cities. This chapter reviews academic literature along six major themes to summarise the accomplishments so far, and existing gaps that need further attention. These include the following: (1) Effects of Globalisation and the Neoliberal Economy in Housing Crises and Growth of Slums in India, (2) Neoliberal Economy and Wage Inequality, (3) Changing Patterns of Economy—From Formal to Informal, (4) Rural–Urban Migration and the Role of Urban-centric Economic Bias, (5) Livability in Urban India and Declining Quality of Life and (6) Methodological Focus in Urban Slum Scholarship in India. This chapter concludes with suggestions for under-researched lines of work with the hope of a spatially informed policy intervention.

Keywords Urban India · Informal settlement · Dilapidated housing · Informal economy · Out-migration

M. E. Harrison
University of Tennessee, Knoxville, TN, USA
e-mail: mharr129@vols.utk.edu

M. Sharma (✉)
Department of Geography and Sustainability, University of Tennessee, Knoxville, TN 37996, USA
e-mail: msharma3@utk.edu

U. Chatterjee et al. (eds.), *Urban Commons, Future Smart Cities and Sustainability*, Springer Geography, https://doi.org/10.1007/978-3-031-24767-5_5

Introduction

According to the UN-Habitat, over 1 billion people lived in slums worldwide in 2016 (HTTP1). This number is huge, but not surprising given the fast rate of urbanisation globally. India's rate of urbanisation has also increased consistently since 1947 (Sharma and Abhay 2022). The Census of India (2011) suggests there are 377 million urban dwellers, with this share increasing by 2.76% between 2001 and 2011. With fast urbanisation also comes in the growth and expansion of urban slums, given the limited availability of resources to provide quality housing to all. India is unique since a large part of its population still participates in agricultural work. At the same time, it is relatively difficult to pinpoint the number of people who have left their agricultural work and migrated to cities in search of better opportunities, often settling in slums; and given the lack of record keeping on migration in much of the global south, an accurate assessment of these numbers is difficult (Nandy et al. 2021). What is true, however, is that a large share of these migrants ends up settling in the urban slums, creating spaces of clustered poverty while experiencing lower quality of life (Abhay and Sharma 2022; Sharma 2017; Sharma and Abhay 2022).

In this chapter, while we summarise various aspects of fast urbanisation and growth of slums in urban India, it is critical to understand the reasons for its growth and expansion in today's developing world. According to Bandyopadhyay and Agrawal (1981), there are two reasons contributing to the development of slums: the partition of India in 1947 that led to large numbers of refugees and the Industrial Revolution. Slums play important roles in the lives of urban migrants because most often these are the most affordable housing in urban areas. The conditions of slums may be worse than their homes in the countryside from where they originated, but these are typically the only options these migrants have. If we are to look back into history, slums are not new. Slums were usually put in areas near centres of dynamic economic growth as they served as residential centres of the service labour. Since the economic liberalisation of India starting 1990s and onward, the prevalence of slums has been on a rise in the cities of Mumbai, Delhi, Kolkata, Chennai, Bangalore and other second-tier metropolises. India's census categorises urban areas into four types: statutory towns, census towns, urban agglomerations and urban growth centres. Statutory towns are towns that are allowed to have municipality (Jain and Korzhenevych 2020). Census towns are villages with at least 5000 people in the last census recorded, and at least 75% of its male working population not engaged in non-agricultural activities (Mukhopadhyay et al. 2016). To be described as a census town, population density must be at least 400 people per km^2. An urban agglomeration is a continuous spread of urban areas that cover one or more towns, and the population stays above 20,000 people (HTTP2). Finally, urban growth centres are areas around a major city outside of its city limits, with its own distinct features, such as railways, universities, or ports. India's urban structure holds importance as this becomes a major pull factor for those migrating from rural to urban.

This chapter summarises scholarly work focused on some of these issues and the effects of slums in India along six major dimensions as discussed below in the methodology section. In doing so, we identify major lines of research that need further attention such that suitable policies can be implemented at national, regional and local scales to help improve the lives of slum dwellers. As such, the remainder of this chapter discusses the research approach taken in completing this chapter, followed by an overview of existing literature in five thematic subsections, with the sixth and last subsection providing an overview of research methodologies, data sources and scale of analysis as applied in select literature reviewed here. Finally, we discuss major conclusions drawn from the wide gamut of literature reviewed, and the policy implications of suggested new lines of research. Because of the rising effect of globalisation in India since 1991, in this chapter we focus specifically on literature published in the 1990s and onward. It is our belief that access to proper housing is a human right and our research aims to provide new pathways towards examining these inequalities.

Methodological Approaches

In this chapter, we provide an overview of published scholarly work along six major dimensions: (1) Effect of Globalisation and the Neoliberal Economy in Housing Crises and Growth of Slums in India, (2) Neoliberal Economy and Wage Inequality, (3) Changing Patterns of Economy—From Formal to Informal, (4) Rural–Urban Migration and the Role of Urban-centric Economic Bias, (5) Livability in Urban India and Declining Quality of Life and (6) Methodological Focus in Urban Slum Scholarship in India. It is important to point out that even though the term ‘slum’ has a negative connotation, these are real people and communities who have built a vibrant economic ecosystem while residing in these slums. As such, this chapter points out issues that exist within slums, but we neither advocate nor oppose the eradication of slums due to multi-faceted social and economic consequences of slum removals in developing economics.

The discussed articles have summarised their study areas, scale of analysis, major findings and the shortcomings. The literature reviewed in this chapter was gathered from online databases, such as Google Scholar and JSTOR. We performed content analysis to discuss India’s slums while grouping these into five broad themes. The aim of our research is to identify the areas that have still not been addressed in slum scholarship, and how might a geographic approach help policymakers, geographers and social scientists to help build an economically and spatially just society.

Thematic Lines of Research

Effect of Globalisation and the Neoliberal Economy in Housing Crises and Growth of Slums in India

To understand the challenges that exist and have existed in India, one must know the history of India, particularly India's relationship with The Great Britain. Colonialism (Islamic and European) had existed for a long time, but modern colonialism started around the fourteenth century. Europe wanted to explore the world in desire for raw material and was particularly keen on starting trade routes with South Asia. As such, India was repeatedly battered by annexation and forced treaties because the Great Britain and other European powers wanted control over India (HTTP3). While there is little published research on this topic, it would be beneficial for academicians to establish the connection between the British colonisation of India and present-day economic policies that caused the persistence of slums. A recent work (Chakraborty et al. 2022) has indeed looked at the growth of urban slums and quality of life from the framework of colonialism and its segregationist policies, which still mimic today's urban landscapes in Kolkata. While colonialism of India is general knowledge today, it is important to remember the impacts it has had on its people, culture and economy even decades later. Thus, colonisation and globalisation are connected because the economic benefits of globalisation in contemporary times are similar, albeit to a new order well captured in the term *neoliberal economy*.

Globalisation has had an impact on growth and expansion of slums because of its role in the urban economies of developing countries, which has further exacerbated the urbanisation processes, thereby inducing growth of slums in the urban areas of India. Today, not only do more slums exist in the world than at the beginning of the first globalisation era, but they are denser than they ever have been. Globalisation today, as captured in the term *neoliberalisation,* has negative consequences for developing countries (Davis 2006) as it also widens the income gaps between formal and informal sectors, even though it has helped advance the economies of the developing world to some extent (Woo and Jun 2020). Neoliberalism has made multi-faceted imprints on urban areas, especially in the global south. Since the initiation of more conservative fiscal policies, such as the privatisation and liberalisation of trade policies since 1991, it has forced more than 20% of the population of India to live in slums, creating more urban poor. Woo and Jun (2020) propose the Economic Globalisation Hypothesis to explain this process—that the more economically globalised a country is, the more likely it is to have higher share of its people living in slums, given that much of the peripheral and semi-peripheral world lacks in resources and sound policies to provide decent urban housing for the fast-expanding urban migrants.

Some scholars (Weinstein 2014) assert that because places like Mumbai have become more globalised and there is a push for globalisation, it leaves slums like Dharavi in the periphery. Weinstein points out that the government of Mumbai had created a redevelopment project in 2004 to transform Mumbai into a 'world-class city' by getting rid of slums. However, getting rid of slums is not an easy solution because not only do slums, like Dharavi, have a significant contribution to Mumbai's and overall India's economy, but there are real people and real communities who live there and have long since built a synergistic ecosystem. Cultures and people thrive in these slums. Weinstein (2014) contends that a public–private partnership would be ideal for the 'Dharavi problem'. Mumbai can be considered a dual city, where the formal and informal are interdependent on globalisation (Bardhan et al. 2015). Since slums are places of labour and capitalism in their own right, globalisation influences the types of work that thrives in slums. For example, within Dharavi, there is a leather industry that exports products to foreign brands, an apparel industry and pottery makers that are typically created by the Kumhar (pottery) community. Dharavi makes over $1 billion every year and has many economic opportunities created by globalisation (Hasan et al. 2017; Kaur and Kaur 2014). The formal urban area of Mumbai is a financial and commercial hub. Within Mumbai, there are also many chemical, pharmaceutical and petrochemical industries. Among all the cities in India, Mumbai receives the most foreign direct investment, with The Bank of America, Volkswagen and Disney as examples of multi-national companies with corporate offices in Mumbai. Given the skyrocketed real-estate prices, many of the low-to-mid-waged workers live in Dharavi and commute to these work opportunities. Thus, based on the relevance of slum economy and slum dwellers' contribution to overall economy in contemporary globalised Mumbai, we believe that improving the infrastructure within slums rather than eradicating them entirely might be a workable solution, although its feasibility needs to be researched further.

Neoliberal Economy and Wage Inequality

In the new global order, India is not alone in its participation in the International Monetary Fund (IMF). The IMF gives access to a variety of loans to numerous countries across the world, and these loans come with a set of terms and conditions. These policies must be considered 'good' by the IMF, with the ultimate goal being able to stabilise the country receiving the loans while promoting poverty (*sort-of*) reduction and growth (Vreeland 2019). However, these policies have severe consequences on numerous segments of the vulnerable population as the drastic reductions in welfarist programs put these groups at the greatest risk. With subsequent cuts in various government-assisted programs, the most vulnerable in rural and urban areas fell victims to the direct and indirect impacts of IMF's policies (Vreeland 2019). The predatory loans from the IMF tend to hinder the growth of developing nations because of how high interest rates are and how ineffective the IMF is in balancing inflation for developing nations (Vreeland 2019). Cumulatively, these policies produced a large share of poor across rural and urban spaces alike.

Alongside, wage inequality was another outcome of India's neoliberalisation starting in the 1990s. While poverty declined in the 1990s, economic growth largely benefited those relatively wealthy, and income was not and is not distributed equally. Between 1983 and 1999, the most important finding of wage inequality was reflected in the wage increases of wealthy groups—as noted from their individual tax returns. The 1991 liberalisation of trade in India had significantly increased wage inequality within its labour force (Kumar and Mishra 2008). The trade reforms were exogenous, surprising many lawmakers, and soon India was on a pathway to dramatically liberalise the external sectors which led to significant decline in tariffs from 117 to 39% within a span of 10 years (Kumar and Mishra 2008). Until the 1980s, India's trade with the rest of the world involved high tariffs and non-tariff barriers with an import licencing system, which had protected India's economy. This, however, took a deep dive with the involvement of the IMF as the social safety net enjoyed by Indians were lost against IMF's stringent policies in exchange for IMF's loans.

In 1991, when the new government took over, the Indian economy was experiencing issues. There was an external payment crisis coming, and India's foreign currency holdings were less than $1 billion (Kumar and Mishra 2008). Because of the export–import policy (EXIM), all import licencing was eliminated. This meant that all capital and intermediate goods could be imported freely, apart from consumer goods. Some scholars (Kumar and Mishra 2008) assert that trade liberalisation could affect industry wages in competitive markets if there is immobility of labour. Further, trade liberalisation could also impact wages in perfectly competitive models if the workforce was heterogeneous. Kumar and Mishra (2008) explain that the existence of wage premiums in India could be because of lack of perfect mobility of labour across different sectors in India, and hence, the decrease of tariffs correlated with the decrease of wages among the Indian workforce. Surprisingly, the decrease of wage equality impacted the skilled workforce, whereas the unskilled workforce experienced increase in wages. This meant that the sectors that had the largest change in tariffs largely hired those considered as 'unskilled workers'—thus creating a new type of socio-economic polarisation across space. Kumar and Mishra found that the relationship between industry wage premiums and tariff rates was inherently negative.

According to Mehta and Hasan (2012), however, reallocation of labour and wage shifts occurred because of economic liberalisation. They asserted that the liberalisation in service sectors also had an impact on wage inequality and these impacts were much larger than the overall impacts of the trade liberalisation. Almost 30–66% of the increase in wage inequality was because of skill premiums and change in wages that cannot be linked to just trade liberalisation (Hasan et al. 2017; Mehta and Hasan 2012). However, Mehta and Hasan acknowledged that Kumar and Mishra's work on trade liberalisation changed the industry wage premiums. The IMF would again loan money to India in 1997. The crisis in 1991 was not devastating because of lack of private sector debt and India's banks not holding foreign assets. By 1997, also they did not hold bank holdings either. Compared to other countries, however, India was not as vulnerable, which helped India's economy stay stable in the 1990s (Woods 2006).

In short, the neoliberal economy and the concomitant increase in wage inequalities within the urban spaces have successfully created clusters of urban poverty in ever-expanding and densely growing cities of India. And while the wage inequalities within these urban spaces have contributed to declining qualities of housing and lives for the slum dwellers, the regional disparities in economic opportunities in the formal and informal sectors alike have also widened due to the urban-centric policies in India (Patnaik 2007). The wage differentials between the rural and urban counterparts were still quite high to propel fast urbanisation and uncontrollable rural–urban migration. The neoliberal policies, as such, have succeeded in creating various types of socio-economic inequalities at various scales—regional and local—within the intra-urban contexts of major metropolises of India, and this has created a new global order of socio-economically polarised new world cities.

Changing Patterns of Economy—From Formal to Informal

Uneven Development, Outmigration and the Role of Remittances

Due to uneven development, India's rural regions are in dire poverty. Part of this is also because of India's bias towards urban development, essentially overlooking the rural regions (Sharma 2017). The world systems theory formulated by Immanuel Wallerstein asserts that there are 'core' countries which are more industrialised and advanced, whereas the peripheral and semi-peripheral countries remain less developed (Wallerstein 1987). When applying this theory to India's rural versus urban dilemma, where the urban centres in India are the 'core' and the rural areas are the 'periphery', there is no doubt that much of the rural and semi-urban areas remain largely neglected. Following this framework, even in contemporary India, agriculture still comprises a large share of its workforce, with gradual waning out over recent years (Choithani et al. 2021). India has experienced three major changes in the past few decades: shifting away from agricultural employment by large numbers, rapid urban growth and villages becoming more urbanised with improved quality-of-life amenities (Choithani et al. 2021). West Bengal is one such example that has experienced significant out-migration, with Uttar Dinajpur (UD) being a major exporter of workers (Mishra and Sarkar 2021). UD being one of the poorer districts in West Bengal, with low literacy rate and bad infrastructure, has forced people to migrate, seasonally or permanently, towards urban areas seeking for better opportunities.

According to Mishra and Sarkar (2021), there are studies that have reported both positive and negative effects of out-migration of workers to urban areas. The negative is long working hours, low wages, unstable employment, employer exploitation and poor working and living conditions. However, they also report that out-migration provides them with better employment and wages compared to locations where they resided originally, and other benefits of these urban areas include better household welfare, access to information and better life outlook. It is important to note, however, that the autonomy and participation in the domestic setting as well as outside of it also occur for out-migrants in urban areas. According to Mishra and Sankar (2021), most of the urban migrant population are single (60%) as often only the males out-migrate in search of work, while leaving behind their female partners and other family members in rural locations, gradually creating social and family disharmony. The authors also suggest that at least 50% of these out-migrants are literate.

It is also important to acknowledge the role of remittances of migrants' income back to their families at home—a critical reason for rural–urban migration. When migrants move to urban areas, they often settle in slums to not only being able to live and work without spending their entire money on rent, but also to be able to save and send money back home. 85% of migrants send money back home, with almost 67% of migrants sending money back home every two months, and 24% of migrants sending it monthly (Mishra and Sankar 2021). The impact of remittances on families in rural areas is huge because remittances, sometimes, count for the household's entire income, if not most of it. While these remittances are usually not a lot, they significantly help reduce rural poverty in India (Castaldo et al. 2012). This makes the whole situation more complex as the urban migrants who are struggling to keep a roof over their heads are forcing themselves into urban working poor. But by doing so, they are somehow alleviating rural poverty back in their places of origin. This situation can be addressed by creating pro-rural economic opportunities that can somehow reduce urban migrants.

Rural–Urban Poverty and Employment Policy

Nandy et al. (2021) asserted that programs that are public-works based have been critical towards policies addressing unemployment, poverty and inequality in rural India. In 2005, India launched the Mahatma Gandhi National Rural Employment Guarantee Scheme (MGNREGS). This policy intended to reduce rural out-migration by ensuring employment and income security in rural areas. The key policy goals of the program included: social protection for the most vulnerable living in rural India, security of livelihoods, including water security, soil conservation and improved land productivity, empowerment of the socially disadvantaged, mitigating push factors for rural out-migration, deepening democracy and creating more transparency in the government. However, this policy fell flat because according to the World Bank, while there were many people who tried to find work, most were unsuccessful in finding meaningful employment. Another problem with the program was lack of awareness about this program. As such, this program had mixed results and did not prove to be very effective.

Political Discrimination and the Dynamism of Slum Votebanks

There is also evidence of political discrimination against rural out-migrants. According to India's Constitution, 'all citizens shall have the right to move freely throughout the territory of India, to reside and settle in any part of India'. However, Gaikwad and Nellis (2020) claim that politicians are discriminatory towards rural migrants, especially those originating from specific regions/states of India as they are viewed as outsiders, uneducated and uncivilised, and they feel that their constituents may be hostile towards migrants and electoral issues.

In contrast, other scholars assert that slum residents' votes—their votebanks—are extremely important to the outcomes of elections (Zhang 2018). A votebank has remained a contentious political discourse in India, which is a bloc of voters from a specific community who consistently support candidates in elections that will vote according to the politically divisive policies of specific governments. In the case of slums, votebanks usually target issues that slum dwellers care about. However, to sway away voters towards personal agenda, many politicians allow illegal settlements to be constructed and give away poverty relief funds around election seasons. This has remained a major issue in the illegal settlements in numerous urban slums of contemporary India (Sharma 2017). The term 'political society' was created to describe the relationship between slum inhabitants and governmental agencies making welfare policies (Zhang 2018). Divisive policies help retain these votebanks, and most of the time only a small slice of the promised policies will be implemented. In this entire process, though, several new illegal encroachments and illegal slums get created, exponentially expanding the clusters of urban poor (Sharma 2017).

Rural–Urban Migration and the Role of Urban-Centric Economic Bias

People relocate to urban areas for better jobs or education that they cannot find in their hometowns. When migrants arrive at urban centres, they are faced with high rent prices. A historical overview of rental policies in Mumbai provides some insights into the struggles that the slum residents face. Mumbai implemented rent control policies to help fight inflation and protect renters from evictions after World War I. The Bombay Rent Act of 1947 stated that tenant payment to landlords had to remain at or below standard rent prices, which are determined by the courts (Zhang 2018). It was extended in 1999 and since 2010, 19% of properties in Mumbai were protected under this act. Unfortunately, many property owners let their properties stay empty rather than rent for a cheaper price to low-income citizens. According to Zhang (2018), this act had negative effects on affordable housing in Mumbai. It ignored inflation rates and gave no incentives to landlords for upkeep of their properties. Rents were not allowed to rise even if landlords were to improve the quality of rental housing, creating an unprofitable situation for landlords. As such, many landlords were unwilling to rent their properties. These policies also made landlords want to build more expensive housing where they could charge higher rents, which did not appeal to the rural migrants, making slums look more appealing to them (Zhang 2018).

Yet another issue that came out of the rent control act was the deterioration of rental units that had already existed. In response to that, the state government created the Mumbai Building Repairs and Reconstruction Board to help fix this issue. The reasoning behind the act was to collect more taxes to renovate rental units, but progress has been slow since its passing in 1971. According to Zhang (2018), rent-controlled housing continues to deteriorate. In addition to rent control policy, Mumbai slums are also impacted by land use policies. Zhang (2018) asserts that the combination of both land use policies and rent control policies has disincentivised the private sectors for good quality housing construction.

Zhang also uses the credibility thesis and applies it to the study of urban informality to understand the persistence of slums and the function of slums. The credibility thesis suggests that property and land are determined by their functions (Ho 2014). The problem with rent control laws in India is that none of the two parties involved in these rental agreements benefit from the laws. Some scholars have argued that because of lack of benefits for both landlords and tenants, the policies have basically failed, and it is time they learned more from other countries who have rent control laws in place so that some reforms to the current laws could hopefully help (Dev 2006). Zhang (2018) also points out that there is low-income housing outside of Mumbai, but due to lack of transportation and commute times, people opt to live in the slums instead. A revamp of public transportation and more low-income housing in large cities like Mumbai would be beneficial to slum population.

Livability in Urban India and Declining Quality of Life

Urban Livability and Legacy of British Imperialism

The 'livable' city was not a concept until the industrial revolution, which refers to the notions of survival of citizens regarding access to electricity and water, quality housing, rate of crime and sanitation (Chakraborty et al. 2022). The American idea of a livable city is very different from the reality that city dwellers face in developing nations like India. India's Census shows that only 31% of India's population was urban in 2011, and much of the urban space in India is limited in livability. Chakraborty et al. (2022)'s analysis found that the colonial policies of the British government not only restricted themselves to making Kolkata a military installation, but also intended to transform Kolkata into a trading port. Kolkata's racial segregation highlighted the divisions that the British colonisation had created in the city, with the better locations occupied by the Whites and the thin slice of elite Indians whereas other less desirable spaces/wards were inhabited by the average and below-average Indians, with low-quality amenities. Kolkata was just a rural district in India until 1690 when agents for the English East India Company arrived for trade opportunities. Sutanuti, Kalikata and Gobindpur were merged to create the city of Kolkata in the eighteenth century. According to Mukherjee (2012), a white town was created for the British near the Old Fort William. However, Kolkata was sacked and recaptured by the British in 1757. Construction of a new Fort William took place in Gobindpur. The native population was pushed north of the city, and it was not as well constructed as the white town. The white town was constructed with care and had beautiful architecture, earning the nickname ‘City of Palaces’ (Mukherjee 2012). The native city had a mix of both old and new, creating slums for the people who worked for the British and rich Indians.

According to Mukherjee (2012), the colonial legacy still impacts the growth or lack thereof in Kolkata. North Kolkata has a large amount of mixed land use that comes with the existence of slums, while the areas of the former white town have lower population growth and lower density. According to Chakraborty et al. (2022), the regions where indigenous people were moved were considered chaotic and anarchist to the colonial powers in Kolkata. The colonial forces in Kolkata brought their concept of urban planning and implemented it into the ‘White Town’, where ideals based on spaciousness, improved household amenities, sanitation and beautification were promoted (Chakraborty et al. 2022). They also found that the current rate of dilapidation is dominant in North and East Kolkata, where the ‘Black Town’ was placed. Chakraborty et al. (2022) also found that the level of ‘good’ conditioned houses was scattered in the North, East and Western parts of Kolkata. The Southern part of Kolkata, however, had 70% of their housing in ‘good’ condition. Spatially, these patterns proved that the segregation that the British government had put into policy still impacts the city and its livability. Thus, there are noticeable markers in India, as well as in other developing nations that remain tattered with the legacies of colonialism and imperialism even today.

There is no doubt that the occurrence of urban slums in India has a huge impact on the people who live in and around them. However, not everyone’s experience is the same and not everyone has the same outlook. People are pushed to migrate for different reasons and generally the quality of life is greatly impacted by their own view of life and their unique situation. According to Sharma (2017), the informal economy provides opportunities for those in slums, giving then a relatively better quality of life (economically, culturally and politically) compared to where they came from, even though this may not be *at-par* quality at a global scale.

Health of Slum Dwellers

In the last two years, COVID-19 has ravaged the entire world, and India is no exception. There is very little scholarly work on COVID-19 cases and the impact it had on India’s slums. According to Mukhopadhyay (2021), however, there were 32.7 million cases in India by the second wave of the infection. In a study conducted from March 21 to August 21 in 2021, the author found that the slum residents of Kolkata were at huge risk of COVID-19 transmission because of low education, poor civic facilities, limited family spaces and their physical environment, and the sharing of toilets and water points (Mukhopadhyay 2021).

According to Chimankar (2016), the most serious diseases in India are transmitted by air, water, soil, or food. Inadequate health care, sanitation, infrequent garbage collection and water provision create conditions where diseases spread easily. Individual health and hygiene are also impacted by the availability of drinking water and proper sanitation. All these reasons cumulatively add to very high child mortality in India (Chimankar 2016), making it one of the highest in the world. The level of infant and child mortality is an indicator of quality of life, but neonatal mortality is quite high in urban slums, particularly in Southern India (Vaid and Evans 2017; Vaid et al. 2007). In a study conducted in the slums of Agra, India, it was found that only 41% of the children were immunised (Ghei et al. 2010). The same study also found that only 44% of India's total children are fully immunised (i.e. full vaccinations for tuberculosis, DPT, polio and measles).

Adult health is also at risk in slums. According to a study conducted in Chennai, Viswanathan and Tharkar (2010) reported that 17.2% of the sampled population suffered from respiratory illnesses whereas 13.5% had other types of illnesses. Further, the mean haemoglobin levels in the population of 20 years and older were only 12.3 ± 2.4 gm/dl for males and 11.1 ± 1.4 gm/dl for females. These levels show anaemia, with females at far greater risk. Likewise, Viswanathan and Tharkar (2010) also found 21.4% of the adult population suffering from hypertension whereas glucose intolerance affected 8.6% of adults. It is important to note that a lot of these issues often go undiagnosed due to economic conditions of people and lack of generic health awareness, and even though hypertension and diabetes are lifestyle-related disorders, they are still prevalent widely among the poorer segments in India. The quality of home environment also plays a huge role in their overall wellbeing and health. Environmental pollution, polluted water sources, lack of nutritious food, dilapidated housing, spousal and child abuse, and lack of health care are all contributors to poor health of slum dwellers. Some scholars assert that a failure to recognise slums as separate spaces from the city has had adverse effects on the slum dwellers as they tend to be marginalised and denied basic services (Ezah et al. 2017). It is important to recognise that while most slum dwellers have barely enough money to get by, a serious illness could put them back into dire poverty, and potentially homeless.

Mumbai's cotton textile industry boom in the nineteenth century had created the need for more housing in Mumbai to accommodate the rural migrant labour needed to fill the labour needs of the textile industry. Thereafter, the petroleum industry also took off, creating more in-migrants into Mumbai. Since the migration pattern was largely for single males, housing was created to fit that need, which were one-room tenements called 'chawls' (Bardhan et al. 2015). While the migration patterns changed overtime, the housing opportunities showed no change in their supply and affordability. These housing eventually also often become residence for families with wives and kids. Originally, they were rented out to industrial workers, but the chawls were not upkept, creating worse living conditions with time for these dwellers, eventually denigrating the quality of housing in these slums. Overall, then, these habitations also became spaces of negative human behaviour, with varieties of physical and mental health issues and declining quality of life (Sharma and Abhay 2022; Thomson et al. 2013).

Methodological Focus on Urban Slum Scholarship in India

In this subsection, we highlight the methodological approaches in select scholarly work (Table 5.1) and identify major shortcomings in our reviewed work. Thus, the Table 5.1 is not a complete compilation of the wide literature reviewed in this chapter. Our review identified these listed dimensions that need further research. These include spatial analysis of slum poverty and slum population, particularly density of unemployment and/or under-employment and their proximity to employment clusters. Further research linking the British colonialism in India and its impacts on current socio-economic status of the slums would be beneficial as well. Female migration remains under-researched, especially in developing economies. Also, the use of qualitative interviews and case studies illustrating experiences of those who live and work in slums in India would add a human element to this body of research.

Spatial Analysis as a Tool—Economy, Health, Circular Migration and Female Migrants

Some scholars (Baud et al. 2008; Choithani et al. 2021) conduct spatial analysis of urban slums. Choithani et al. (2021) describe the social transformations (i.e. shifting occupations and livelihoods) that impact rural–urban migration. These cases could be enhanced through use of interviews and case studies to add a human angle to their findings. Baud et al. (2008) map urban poverty using the 'livelihoods assert framework' model to describe multiple dimensions of deprivation, and their implications on geographic areas and sectors targeted by Indian politicians. While they conduct spatial analysis, the comparison of smaller slums in India would be beneficial, as smaller urban areas and their slum clusters go un-researched whereas significance of money and resources are allocated towards slum dwellers in the mega-cities of India. Meanwhile, other scholars (Bardhan et al. 2015; Chimankar 2016; Echanove and Srivastava 2016; Ezah et al. 2017; Nandy et al. 2021; Sarkar and Mishra 2020; Zhang 2018) analyse other aspects of urban slums in India. Nandy et al. (2021) analyse the implications of slum-related employment and policies, while also discussing how to expand current employment policies. In doing so, they provide an interesting critical analysis of MGNREGS. We think that the use of remote sensing data would add a spatial dimension in explaining the ineffectiveness of MGNREGS. Zhang (2018) analyses the economic importance of slums and their prevalence. A spatial analysis of employment density and their proximity to population centres would add meaningful spatial insights in Zhang's research. These interventions could help policymakers to address employment policies for slum population by making spatially just policies.

Ezah et al. (2017) provide good analysis of health in slums. A GIS-based visualisation of the prevalence and density of unhealthy clusters could be insightful, even though we are aware of the confidentiality issues in acquiring health data. Spatial knowledge on the location of poor health clusters in slums could be critical to policymakers in improving health infrastructure and its accessibility for slum dwellers.

Table 5.1 Methodological approaches in select Urban scholarship

Article title and authors and journal	Research focus/questions	Area of study and scale of analysis	Methodology applied	Pros and cons of the analysis
Sharma and Abhay (2022). Urban growth and quality of life: inter-district and intra-district Analysis of housing in NCT-Delhi, 2001–2011–2020. *GeoJournal*	Urban growth sprawl and how it impacts quality of life of Delhi's residents	Districts and Subdistricts of NCT, Delhi, India	Remote sensing data to examine urban built-up space and census data linked to examine change in quality-of-life indicators	Pros: Provided good overview of how the urban sprawl in NCT Delhi has expanded over two decades and how has that changed quality of life of residents Cons: A few case studies through interviews or focus groups could add a human angle to the findings
Choithani et al. (2021). Changing Livelihoods at India's Rural–Urban transition World Development	Social transformation that impacts rural–urban migration like occupation shifts and livelihoods	India	GIS data and buildings and field visits to investigate the relation between urbanisation and development	Pros: good analysis of urban versus rural employment Cons: Interviews and case studies could add a human angle to findings
Nandy et al. (2021). India's Rural Employment Guarantee Scheme—How does it influence seasonal rural out-migration decisions? Journal of Policy Modeling	Analyses implications of employment policy and discusses how to expand the scale of MGNREGS	India	Uses the Indian Human Development Survey to secede the impact of MGNREGS	Pros: Gives good analysis and description of the MGNREGS Cons: GIS/remote sensing data could add a spatial aspect in explaining the effectiveness of MGNREGS
Zhang (2018). The credibility of slums: Informal housing and urban governance in India	Explains and analyses why slums are prevalent as well as describes why slums in India are major socio-economic and political hubs	India	Fieldwork and 40 interviews	Pros: Gives good analysis of political and economic importance of slums Cons: A clearer spatial analysis would help provide insight into populations and urban density of slums

(continued)

Table 5.1 (continued)

Article title and authors and journal	Research focus/questions	Area of study and scale of analysis	Methodology applied	Pros and cons of the analysis
Vaid et al. (2007). Infant Mortality in an Urban Slum Indian Journal of Pediatrics	Explains infant mortality in India's Urban slums from 1995 to 2003	Vellore, India	Used birth history, immunisation records and infant mortality datasets of infants to determine infant deaths in this area of India	Pros: good record of general infant mortality in Vellore Cons: Would be beneficial to add factors contributing to a higher mortality rate of boys in Vellore
Ezah et al. (2017). The history, geography and sociology of slums and the health problems of people who live in slums	Explains in 4 sections the issues and health problems concerning slum dwellers	India	Used past studies and DHS, UHS and NCSS data to describe the health problems within slums	Pros: Gives good overview and analysis of slum health Cons: The use of GIS could help visualise the health issues and what could potentially be causing clusters of health problems
Gaikwad and Nellis (2020) Do Politicians Discriminate Against Internal Migrants? Evidence from Nationwide Field Experiments in India	Identified political inequalities that slum dwellers face, particularly internal migrants, from politicians	India	Compiled lists of sitting municipal counsellors in 28 cities and produced letters to these counsellors claiming to be citizens of internal migrant status to get a response on the following issues: religion, migrant status, gender, problem type, political party and skill profiles	Pro: good research and analysis of the problems that internal migrants face Cons: no insight on internal migrants who are part of the LGBTQ community

(continued)

Table 5.1 (continued)

Article title and authors and journal	Research focus/questions	Area of study and scale of analysis	Methodology applied	Pros and cons of the analysis
Baud et al. (2008). Mapping Urban Poverty for Local Governance in an Indian Mega-City: The Case of Delhi Urban Studies	Maps urban poverty, using 'livelihoods assets framework' to describe multiple deprivations, examining the implications for area and sector targeting by policymakers	Delhi	GIS datasets and census datasets	Pro: the use of GIS gives a good spatial analysis of urban poverty in Delhi Con: Would be useful to include smaller slums to draw comparisons
Bardhan et al. (2015) Mumbai slums since independence: Evaluating policy outcomes Habitat International	Describes the informal economy and policies affecting slums following the independence of India	Mumbai	Census data	Pro: Gives good analysis on major policies impacting Mumbai Cons: Would be beneficial to have better spatial analysis of Mumbai past and present to show how policy has impacted populations; Would be beneficial to have background info on how colonisation of India impacts the informal economy today
Sarkar and Mishra (2020). Circular labour migration from rural India: A study of out-migration of male labour from West Bengal. Journal of Asian and African Studies	Describes how circular migration impacts India's economy as well as economic and social impacts on populations in the informal sector	Districts within West Bengal	Census data and interviews	Pros: Analyses migrations patterns in the informal economy well Cons: More emphasis on female migrants would add a better even gender perspective to migration. Spatial analysis would contribute as well

(continued)

Table 5.1 (continued)

Article title and authors and journal	Research focus/questions	Area of study and scale of analysis	Methodology applied	Pros and cons of the analysis
Bandyopadhyay and Agrawal (1981) Slums in India: From Past to Present International Refereed Journal of Engineering and Science	Describes how India's slums are impacted by their past and how that past is prevalent today	India	Census data	Pros: Gives good description of urbanisation of India Cons: Does not provide any contributing factors from India's past (pre-1947)
Echanove and Srivastava (2016) This is not a slum: What the world can learn from Dharavi World Policy Journal	Gives a description of slum life in Mumbai	Mumbai	Secondary sources	Pros: Gives great description of issues in Mumbai as well as positives Cons: adding spatial analysis by income level in Dharavi to point out where the poorest populations are
Chimankar (2016) Urbanization and Condition of Urban slums in India Indonesian Journal of Geography	Describes the conditions and why slums are prevalent	India	Census data	Pros: Gives great insight into slum conditions Cons: Spatial analysis of slum clusters for all of India would be beneficial for further study
Kumar and Mishra (2008). Trade Liberalization and Wage Inequality: Evidence from India. Review of Development Economics	Analyses the liberalisation of trade and its impact on wages	India	Micro-labour market data and data on tariff and non-tariff barriers from the National Sample Survey	Pros: Gives great insight to the liberalisation of trade and its impact on wages Cons: Could benefit from spatial analysis to show the distribution of wage and show what communities are being negatively impacted throughout India

Vaid and Evans (2017) and Vaid et al. (2007) analyse the level of infant mortality rates and health status of slum dwellers in Vellore, India. Here too, a spatial insight could be beneficial in illustrating the clusters of high infant mortality and their gender disparity. These could be useful for policymakers in improving their health conditions by targeting fuller vaccination coverage in the slum community.

Bardhan et al. (2015) discuss informal economy and policies affecting slums since the independence of India. This research could have benefited from a spatial approach by likening the impact of British colonialism in Mumbai's slums and how the slum-living and informal economy are tied to each other. Sarkar and Mishra (2020) describe how circular migration in India impacts the economy as well as the social and economic experiences of the labour engaged in the informal sector. In particular, this research could benefit by focused emphasis on female migrants whose contributions to a variety of informal labour often get masked due to lack of measurement tools. Spatial analysis could help assess volume of circular migrants, which would eventually help initiate and implement targeted policies in the rural and underdeveloped parts of the country.

India's Past–Present Linkage, Economic Wellbeing and Discrimination

Bandyopadhyay and Agrawal (1981)'s research on how India's contemporary slums are impacted by their past histories provides a good understanding of India's urbanisation processes. However, not much is known about their pre-1947 (before independence) histories, especially from a geographic lens—an area that needs academic intervention. In contrast, Echanove and Srivastava (2016)'s analysis of slum life and earnings in Mumbai and Chimankar (2016)'s analysis of conditions of slums and their prevalence in South India provide a decent understanding of their contemporary status. Both studies could benefit from a spatial approach as these steps help with targeted intervention.

Gaikwad and Nellis (2020) identify political discrimination faced by slum dwellers. However, there is no insight into the inequalities faced by other marginalised communities, such as the LGBTQ+ and other migrants and minorities. Given the new civil acceptance laws concerning the LGBTQ+ communities in India, we believe these must have started making changes to the economic and cultural landscapes in poorer urban settlements where they used to live. These could comprise innovative lines of academic spatial inquiry. Finally, Kumar and Mishra (2007)'s focus on trade liberalisation and its concomitant impacts on wage inequality in India provides a good understanding of the economic relationships. However, every space has distinct characteristics in terms of migrants and their human capital preparation. These could be addressed at much deeper levels through spatial and detailed econometric approaches.

Conclusions

An analysis of issues pertaining to contemporary urban India comprises an under-represented line of research, especially within American and western academia, and this chapter hopes to fill in this void to some extent. The most imperative pathway for future research includes empirical study of migrants and citizens of slums, particularly those focused on the human and spatial dimensions of migrants' lives and their livability. We also found that GIS/Spatial-based analysis of various issues such as female migrants, slum dwellers' health and the role of British colonialism in the prevalence of slums and contemporary informal economy is the apparent pathways for pursuing future geographic research. Studying slum population, health and migration through a geographic lens would be beneficial to the slum dwellers and slum economy. A study of female migration in India would shed light on gendered perspectives of migration. Much of the current research heavily leans toward analysing male migrants, which is largely true in the context of Indian migration system where women are left behind in their villages to care for the elderly. However, how does their life get impacted due to partial and seasonal abandonment from the out-migration of males is an area worth studying.

The numbers and size of slums have continued to grow in India, especially since the 1990s, as economic liberalisation has impacted its economic structure. People continue to migrate to India's urban centres because of underdeveloped rural India and the false economic premises and perceptions of globalisation-induced urban economy, which has dramatically reshaped the informal sector in urban India (Gupta and Mitra 2002). Most of the reviewed scholarly work here were largely housed in the programs of urban studies, sociology, economics and political science. We believe geographers can contribute towards the *spatiality* of slums while likening them with their impacts on people and communities. This is more important due to the enormous physical, human, cultural and economic diversity of India's 1.4 billion people. Out of a global count of 1 billion slum dwellers, India's slum population makes up for a significant share of the global total. Given the significant role of rising India in today's global political economic order, it is far more important now than ever that a timely and focused spatialised assessment be conducted on India's slums and their quality of life. This will help policymakers with spatialised interventions which will, hopefully, provide the slum dwellers with a ray of hope towards achieving their middle-class dream.

Significance and Policy Implications

We also believe past imperialism has facilitated the creation of urban-centric economic policies in India, and colonialism had a role in shaping its cities and villages in contemporary times. Thus, a historical geographic perspective on the role of Islamic imperialism and the British colonialism in creation of urban villages and slums and their current livability and socio-economic polarisation, especially given the significance of informal economy in urban economy in India, would add another dimension to academic research. Most of the published research so far has focused on post-1947 India, and not much is known about India's pre-independence urban villages. These topics are under-researched, especially from a geographic perspective, and some insights on those could be useful in rewriting pro-rural economic and socio-spatial just policies.

The economic conditions of Indian slum dwellers hold special significance, given the role of informal economy in India's total GDP. Slums are spaces of specialised and spatialised economic ecosystems, with real lives and real communities. These need appropriate economic interventions. Given the urban-centric economic biases that aggravate rural–urban migration, it is critically important to conduct a timely analysis of rural India's economy and how the under-development and wage inequalities among rural villages and small towns impact the current levels of uncontrolled out-migration. This must include special focus on female migrants, since the perspectives of female migrants and women's contributions to India's informal economy have remained largely ignored in academic work.

References

Bandyopadhyay A, Agrawal V (1981) Slums in India: from past to present. Population 23:46–14

Bardhan R, Sarkar S, Jana A, Velaga NR (2015) Mumbai slums since independence: evaluating the policy outcomes. Habitat Int 50:1–11. https://doi.org/10.1016/j.habitatint.2015.07.009

Baud I, Sridharan N, Pfeffer K (2008) Mapping urban poverty for local governance in an Indian mega-city: the case of Delhi. Urban Stud 45(7):1385–1412. https://doi.org/10.1177/0042098008090679

Castaldo A, Deshingkar P, McKay A (2012) Internal migration, remittances and poverty: evidence from Ghana and India

Chakraborty A, Sharma M, Abhay RK (2022) Colonial imprints in contemporary urban livability: an inter-ward analysis of Kolkata. GeoJournal. https://doi.org/10.1007/s10708-022-10606-7

Chimankar DA (2016) Urbanization and condition of urban slums in India. Indones J Geogr 48(1):28

Choithani C, van Duijne RJ, Nijman J (2021) Changing livelihoods at India's rural–urban transition. World Dev 146:105617. https://doi.org/10.1016/j.worlddev.2021.105617

Davis M (2006) Planet of slums. Verso, London

Dev S (2006) Rent control laws in India: a critical analysis. SSRN Electron J. https://doi.org/10.2139/ssrn.926512

Echanove M, Srivastava R (2016) This is not a slum. World Policy J 33(2):19–24

Ezeh A, Oyebode O, Satterthwaite D, Chen Y-F, Ndugwa R, Sartori J, Mberu B, Melendez-Torres GJ, Haregu T, Watson SI, Caiaffa W, Capon A, Lilford RJ (2017) The history, geography, and sociology of slums and the health problems of people who live in slums. The Lancet 389(10068):547–558. https://doi.org/10.1016/s0140-6736(16)31650-6

Gaikwad N, Nellis G (2020) Do politicians discriminate against internal migrants? Evidence from nationwide field experiments in India. Am J Polit Sci 65(4):790–806. https://doi.org/10.1111/ajps.12548

Ghei K, Agarwal S, Subramanyam MA, Subramanian SV (2010) Association between child immunization and availability of health infrastructure in slums in India. Arch Pediatr Adolesc Med 164(3):243–249. https://doi.org/10.1001/archpediatrics.2009.277

Gupta I, Mitra A (2002) Rural migrants and labour segmentation: micro-level evidence from Delhi slums. In: Economic and political weekly, pp 163–168
Hasan R, Kapoor N, Mehta A, Sundaram A (2017) Labor regulations, employment, and wages: evidence from India's apparel sector. Asian Econ Policy Rev 12(1):70–90. https://doi.org/10.1111/aepr.12160
Hensman R (2001) The impact of globalisation on employment in India and responses from the formal and informal sectors. International Institute for Asian Studies (IIAS)
Ho P (2014) The 'credibility thesis' and its application to property rights: (In)secure land tenure, conflict and social welfare in China. Land Use Policy 40:13–27
HTTP1: Slum Almanac 2015–2016: UN-Habitat. UN. (n.d.). Retrieved May 9, 2022, from https://unhabitat.org/slumalmanac-2015-2016-0
HTTP2: Census of India 2011 (2008) Circular No.3 Formation of Urban Agglomerations for the 2011 Census, Last accessed on 27 May 2022 at https://www.censusgujarat.gov.in/Downloads/Circulars/RGI-Circular-03.pdf
HTTP3: The National Archive (n.d.)
Jain M, Korzhenevych A (2020) Urbanisation as the rise of census towns in India: an outcome of traditional master planning? Cities 99:102627. https://doi.org/10.1016/j.cities.2020.102627
Kaur G, Kaur S (2014) A study of slums in Mumbai with special reference to Dharavi. Int Res J Manage Sociol Humanity 5(5)
Kumar U, Mishra P (2008) Trade liberalization and wage inequality: evidence from India. Rev Dev Econ 12(2):291–311. https://doi.org/10.1111/j.1467-9361.2007.00388.x
Learning curve british empire. The National Archives (n.d.) Retrieved 26 Mar 2022, from https://www.nationalarchives.gov.uk/education/empire/g2/cs4/background.htm
Mukherjee M (2012) Urban growth and spatial transformation of Kolkata metropolis: a continuation of colonial legacy. ARPN J Sci Technol 2:365–380
Mukhopadhyay P, Zerah MH, Samanta G, Maria A (2016) Understanding India's urban frontier: what is behind the emergence of Census Towns in India? 19 Dec 2016). World Bank Policy Research. Working Paper No. 7923, Available at SSRN: https://ssrn.com/abstract=2887778
Mukhopadhyay J (2021) Occurrence of COVID-19 in Kolkata slums during second surge. Asian J Med Sci 12(12):32–38
Nandy A, Tiwari C, Kundu S (2021) India's rural employment guarantee scheme—how does it influence seasonal rural out-migration decisions? J Policy Model 43(6):1181–1203. https://doi.org/10.1016/j.jpolmod.2021.09.001
Office of the Registrar General, India (2008) Census of India 2011—Circular No.3 Formation of Urban Agglomerations for the 2011 Census, New Delhi, 3 Nov 2008
Patnaik U (2007) Neoliberalism and rural poverty in India. Econ Polit Weekly 42(30):3132–3150. http://www.jstor.org/stable/4419844
Sarkar S, Mishra DK (2020) Circular labour migration from rural India: a study of out-migration of male labour from West Bengal. J Asian Afr Stud 56(6):1403–1418. https://doi.org/10.1177/0021909620967044
Sharma M (2017) Quality of life of labour engaged in the informal economy in the national capital territory of Delhi, India. Khoj: Int Peer Rev J Geogr 4(1):14–25
Thomson H, Thomas S, Sellstrom E, Petticrew M (2013) Housing improvements for health and associated socio-economic outcomes. Cochrane Database Syst Rev (2). Art. No.: CD008657. https://doi.org/10.1002/14651858.CD008657.pub2. Accessed 28 Feb 2022
Vaid A, Mammen A, Primrose B, Kang G (2007) Infant mortality in an urban slum. Indian J Pediatr 74(5):449–453
Vaid U, Evans GW (2017) Housing quality and health: an evaluation of slum rehabilitation in India. Environ Behav 49(7):771–790. https://doi.org/10.1177/0013916516667975
Vreeland J (2019) The international monetary fund. In: Lechner FJ, Boli J (eds) The globalization reader, 6th edn, Essay. Wiley, New York, pp 267–272

Viswanathan V, Tharkar S (2010) Can the divide be bridged: overview of life in urban slums in India. Indian J Community Med: Official Publ Indian Assoc Prev Soc Med 35(1):198–199. https://doi.org/10.4103/0970-0218.62562

Wallerstein I (1987) World-systems analysis. Social theory today, vol 3, Chicago

Weinstein L (2014) 'One-man handled': fragmented power and political entrepreneurship in globalizing Mumbai. Int J Urban Reg Res 38(1):14–35

Woo B, Jun H-J (2020) Globalization and slums: how do economic, political, and social globalization affect slum prevalence? Habitat Int 98:102152. https://doi.org/10.1016/j.habitatint.2020.102152

Woods N (2006) Understanding pathways through financial crises and the impact of the Imf Lynne Rienner

Zhang Y (2018) The credibility of slums: informal housing and urban governance in India. Land Use Policy 79:876–890. https://doi.org/10.1016/j.landusepol.2017.05.029

Chapter 6
Sustainable Urban Management of the Mainstream and the Margin: Reflecting on Delhi and Its Peri-Urban Transformation

Sanchari Mukhopadhyay and Sucharita Sen

Abstract The city of Delhi and its peripheries have undergone profound changes in the last two centuries owing to both a rise in the population and an increase in economic growth, causing tremendous changes in the overall land use pattern. The recent trends in the urban development post-economic liberalisation indicate a sharp turn in transforming Delhi into a global city that highly serves the purpose of the 'capital' and therefore the very goal of neoliberalisation. The opening up of the Indian economy to the international markets has essentially changed the politico-administrative arrangements which are strongly getting reflected in the overall context of the development of the large cities. Examples can be drawn from the ambitions expressed by the government to make Delhi a 'world-class city' and the hosting of landmark events as prominent steps towards such transformation. This framework of development often counters the concerns of building an inclusive city and intensifies the polarisation process. The chapter reflects upon the transformation of the peri-urban space of NCR Delhi and the redefinition of the urban landscape following the ideology of world-class development. First, it presents a broader picture of the overall development of the peri-urban Delhi by discussing the pattern of change reflected in its physicality as well as the sociality, and second, it initiates a discussion to examine the role of media advertising, especially of the real-estate housing market in reinvigorating the meaning of the urban.

Keywords Urban transformation · Peri-Urban · Growth · Development · Media representation

---

S. Mukhopadhyay (✉) · S. Sen
Center for the Study of Regional Development, School of Social Science, Jawaharlal Nehru University, New Delhi 110067, India
e-mail: sanchari.bdn@gmail.com

U. Chatterjee et al. (eds.), *Urban Commons, Future Smart Cities and Sustainability*, Springer Geography, https://doi.org/10.1007/978-3-031-24767-5_6

Introduction

In the process of locating Delhi in the discourse of urban development, it is imperative to understand both its past and present trends of growth and characterisation of the city space. The city of Delhi and its peripheries have undergone tremendous changes in the last two centuries owing to both a rise in the population and an increase in economic growth, causing enormous changes in the overall land use pattern. However, the recent trends in the urban development post-economic liberalisation of the early 1990s indicate a sharp turn in transforming the capital into a global city that highly serves the purpose of the 'capital' and therefore the very goal of neoliberalisation. The opening up of the Indian economy to the international markets essentially changed the politico-administrative arrangements, marked by the state's partial withdrawal from many age-old sectors as well as increasing private intervention[1] and refashioning the overall context of the development in the large cities. In this place, examples can be drawn from the ambitions expressed in the Master Plan for Delhi as 'vision 2021' as the government officially declared its objective to make Delhi a 'world-class city' and the 2010 Commonwealth Games preparation as one of the landmark events as a prominent step taken towards such transformation (DDA 2007). The intent is also pronounced in the recurring slogans of the chief ministers of Delhi to materialise the dream of making Delhi a 'world-class destination' and to make it the 'best city in the world'. All these intentions following the neoliberal framework of development also counter the concerns of building an equitable as well as inclusive city as per the stated agendas of the National Urban Renewal Mission and intensify the polarisation process—what can much rather be referred to as the 'politics of forgetting[2]' (Fernades 2004).

The chapter focuses on the transformation of the peri-urban space of the NCR[3] Delhi and the redefinition of the urban landscape following the ideology of world-class development. It is divided into two sections. The first offers a broader introduction to the tenets of development at the peri-urban Delhi by discussing two key elements, one the pattern of change reflected in the physicality and two the main actors or beneficiaries of such development as its central intellectual motifs. The second section then extends the discussion to examine the mediating role of media advertising, especially in the real-estate housing market in reinvigorating the meaning of the urban, more importantly of the development at the peripheries. This, thereby, is expected to provide an overview of the dichotomous spatial pattern in the peri-urban development of the capital city and complement the strand of existing literature on the growth of Delhi as a city of world-class importance as well as understanding the socio-cultural consequences of the process of urban restructuring.

[1] For example, in Delhi, electricity distribution was privatised as well as the solid-waste management (Vinayak and Ghosh 2006; cited in Dupont 2011).

[2] 'Politics of forgetting' marks the 'political-discursive process' through which the marginalised are rendered invisible within the dominant political culture where a particular section of the population has been given the upper hand on monopolising the space.

[3] National Capital Region—NCR.

Data and Methodology

The first part of the analysis is mostly based on the existing literature on the growth of Delhi and the physical as well as the social impact of its expansion to the peripheries. In correspondence to that, some quantitative techniques have been applied to construct maps that can substantiate the change with visual interpretations and calculations that can aid in understanding the changes over the period. To find out the degree or level of urbanisation, an urban-rural ratio has been calculated and to trace the pace of urbanisation annual exponential growth has been calculated using census data.

The methodology for constructing the maps is explained in different steps as follows.

Step.1: To analyse changes of urban expansion over time, a set of three Landsat images were acquired for the years 1990 (TM), 2000 (TM) and 2015 (OLI/TIRS). Geometrically and radiometrically corrected images were procured from the online source of the Earth Resources Observation and Science (EROS) Data Centre of the US Geological Survey (USGS) (http://earthexplorer.usgs.gov) in GeoTIFF format.
The source of data and their characteristics are given in Table 6.1.
Step.2: Data pre-processing.
Step.3: The satellite data was analysed using remote sensing tools.
Step.4: Digital classification techniques were used to group pixels to represent land cover features through supervised classification.
Step.5: Using the classification techniques created land use and land cover classification of Delhi NCR (1990, 2000, and 2015) divided into six following classes: (1) Water body, (2) Built-up area, (3) Vegetation, (4) Agricultural land, (5) River bed and (6) Arawali ridge.
Step.6: Accuracy assessment: The accuracy of LULC maps produced was evaluated using overall accuracy (OA), producer's accuracy (PA), user's accuracy (UA) and Kappa statistics.
Step.7: Grid analysis prepared through ArcGIS spatial analysis tool in ArcGIS software.
Step.8: With the help of ArcGIS software, all layouts (maps) have been made.

Table 6.1 Details of spatial data used for this study

Data	Data types	Source of data	Details about data	Period
Landsat TM	Spatial	USGS satellite images	(30 m resolution) Path 147, 146 and Raw 40, 41	August 1990, January 2000
Landsat 8 OLI	Spatial	USGS satellite images	(PAN 15 m, 30 m resolution) Path 147, 146 and Raw 40, 41	November 2015

The second part of the analysis is based mostly on the actual images from the field, and printed advertisements in the leading daily newspapers with some banners and hoarding found around the Delhi agglomeration over the period between 2017 and 2019. The newspapers have been selected owing to their highest circulation rate and therefore a better probability of receiving advertisements. In this place, it is also important to state that mostly the single page advertisements have been taken into account assuming they have a larger scope of influencing the masses. While most real-estate advertisements have been taken into account for the analysis, the review of the advertisement includes details such as the location of the property, the title and price range, the byline as well the accompanying text and a description of the images taken into consideration. In addition to the newspapers, the banners and hoardings also appeared to be an ideal lens which can provide a dimension of the changes that are prominently being desired as well as taking shape to serve the locals, aiming the global. The aim of such an analysis, following Fernandes (2000), is not to deconstruct individual images but to weave them together first to identify particular themes within the images and texts and second to gain a perspective on the current pattern of urban development in the neoliberal city, aspiring to fit onto an international imagination. For this purpose, more focus has been given to the thematic interpretation of the visual and the textual descriptions of the properties aiming towards understanding the promotional intent, rather than assessing the effectiveness.

Images portrayed in the print media through advertisements and big hoardings have prominent spatial connotations which have significant relevance for the present study. In this case, it is expected that image-making is a part of the marketing strategies of the real-estate developers and, therefore, is responsible, in a major way, for remaking the meaning of the 'urban' and the (re)construction of urban places both in physical terms and as imaginary spaces. The argument in this place centred around the fact that globalisation in India has created a certain kind of ambitious vision of the urban which led to the restructuring of the urban space keeping in mind a particular category of people and a particular mode of production. The specific questions that are being addressed are: How is the urban being placed in front of the masses through the representations? And what are the dominant modes of development in contemporary cities? This essentially prepares the base for building further arguments on the changing material condition as well as the sense of place of the people in the cities, falling into different socio-economic categories.

Results and Discussion

Understanding the City Spaces, Its Peripheries and Apprehending the Changes in the Process of Urban Growth

Where precolonial Delhi has 'no suburbs in the sense of people moving out of a crowded city', the idea of the city expanding to its peripheries has prominently been a nineteenth-century phenomenon as the high-end residential enclaves started appearing dominantly. Therefore, the changes in the metropolitan nature of the city have particularly come to notice since the neoliberal policies of the 1990s. However, the class remained a determining element in the manner in which the peri-urban expands as the spatial processes operate differently for the upper-class population and the working class while the role of private enterprises continues to be critical in restructuring the traditional borders of the capital city. The section, therefore, divides the discussion into two parts: first, identifying the city as purely a physical entity to understand the changes in its marginal territory and second, exploring the social dimension of the growth of the city by treating it as a social entity (Table 6.2).

Table 6.2 Year-Wise variation in the degree of urbanisation and pace of urbanisation in Delhi

Census year	Degree of urbanisation			Pace of urbanisation		
	Percentage of urban population	Percentage of rural population	Urban–rural ratio	Annual Expo. growth rate (in %) of total population	Annual Expo. growth rate (in %) of urban population	Annual Expo. growth rate (in %) of rural population
1901	52.7	47.2	111.7	–	–	–
1911	57.6	42.5	135.3	0.20	1.6	−0.86
1921	62.3	37.7	165.4	1.7	2.5	0.45
1931	70.3	29.7	237.0	2.6	3.9	0.27
1941	75.8	24.2	313.0	3.7	4.4	1.63
1951	82.4	17.6	468.2	6.4	7.5	3.22
1961	88.6	11.3	788.6	4.2	5.0	−0.26
1971	89.7	10.3	871.1	4.3	4.4	3.37
1981	92.7	7.3	1275.6	4.2	4.6	0.77
1991	89.9	10.1	892.7	4.2	3.8	7.41
2001	93.2	6.8	1366.1	3.8	4.2	−0.05
2011	97.5	2.5	3906.3	1.9	2.4	−8.13

Source Computed from Census of India, A-Series, Paper 2, Rural–Urban Distribution of Population

Table 6.3 District-wise growth rate of population in NCT Delhi

Districts	Annual exponential growth rate (in %)			Decadal growth rate (in %)		
	Total	Rural	Urban	Total	Rural	Urban
NCT of Delhi	1.92	−8.13	2.38	21.21	−55.65	26.83
North-West	2.45	−2.15	2.82	27.81	−19.37	32.64
North	1.28	−9.65	1.69	13.62	−61.91	18.41
North-East	2.37	−18.83	3.11	26.78	−84.79	36.49
East	1.55	−16.41	1.66	16.79	−80.63	18.02
New Delhi	−2.32	–	−2.32	−20.72	–	−20.72
Central	−1.04	–	−1.04	−9.91	–	−9.91
West	1.78	−26.04	2.17	19.46	−92.60	24.23
South-West	2.67	−4.51	3.40	30.65	−36.27	40.51
South	1.87	−25.79	2.56	20.51	−92.42	29.13

Source Computed from primary census abstract of Delhi, 2001, 2011

(a) **Delhi as a Physical entity: Tracing the Transformation of Spatial Morphology of the City in Expansion**

Delhi is a fast-growing metropolitan city where the population has grown at a remarkable rate of 21.21 between the year 2001 and 2011 and at a rate of 46.31 in the previous decade[4] (Tables 6.3 and 6.4). With migration contributing as a major factor in the growth of the urban agglomeration, Delhi has been listed as the most urbanised state in India with a 97.5% urban population[5] and is tend to reach nearly 40 million by 2030. This extortionate population growth is contributing largely to the spatial expansion of the city outward to the peripheries, which further creates a fuzzy socio-spatial relation at the margins. As shown in Fig. 6.1, the urban sprawl, however, follows a specific direction following the major roads and thereby establishing a connection between the peripheral towns of Gurgaon, Faridabad, Ghaziabad, NOIDA and Greater NOIDA, located in adjoining states of Haryana and Uttar Pradesh. This de facto urban relationship made Delhi India's largest metropolis at around 30 million (2020 projected population), also illustrating the complex management system of the expanding megacities beyond any practicable limits.

Nevertheless, with the saturation of the city centre in terms of growth along with its exorbitant real-estate prices, the present-day growth is taking place mostly at the peripheries, often following a certain corridor of development (Table 6.4). Such peri-urban pockets are, therefore, experiencing new forms of urban development aiming at particular cultural as well as social communities. It should be highlighted here that while the city centre is still a mix of both cheaper and high-end options, the newly urbanising suburbs are mostly maintaining a class factor in building their

[4] Census of India, 2001, 2011.

[5] Census of India, 2011.

Table 6.4 Directional rate of city expansion (in percentage)

Direction	Directional rate of expansion in percentage		
	15 km buffer	30 km buffer	45 km buffer
East	184	432	289
North	145	**892**	**712**
North-East	86	383	393
North-West	23	385	364
South	82	390	373
South-East	121	**876**	243
South-West	148	438	**890**
West	84	416	219

Source Calculated by the Researcher

infrastructure. Such restructuring of urban spaces further keeps the people belonging to lower economic strata out from such urban development even when they often are expelled from the core and forced to move to the periphery.

Therefore, with Delhi's sprawl following certain paths (Fig. 6.2, Table 6.2), the most phenomenal changes are visible along with the ring towns, projected as the hub of new economic opportunities and constructed and marketed largely by private entities. These specific pockets within the margin are characterised by mushrooming high-end elevated structures, mostly residential complexes with shopping malls[6] and commercial centres. Therefore, a two-sided pattern emerges at the peri-urban, where on the one hand, older imprints are continually dissolving, and on the other hand, the newer urban neighbourhood is emerging, bearing a specific class identity. Although historically Delhi has a long-standing practice of image-building as a capital city and a background of urban cleansing[7] in the name of development, the obsession with elitist urbanism gained acceleration following the neoliberal framework and strengthened with the international frame of reference. Such a model of urban development lead to a 'certain repetition and standardisation' of urban forms, manifested through the proliferation of similar-looking high-rises and gated communities, emergence of gigantic shopping complexes and business centres as well as multiplication of flyovers and infrastructural networks (Dupont 2011). As noted by Dupont (2011), the pervasiveness of the 'global city model' has also become a 'reference point' for various politicians as well as vision makers for 'climbing up a hierarchy' overlooking the issue of its problematic implementation and socio-political as well as economic contexts.

[6] With the first mall opened in 2001 in South Delhi and Gurgaon, there are nearly 100 shopping malls in Delhi metropolitan area today, making it the 'default mall capital of India' (The Economic Times, May 18, 2015).

[7] Examples can be taken from massive slum clearance operations during the period of emergency (1975–1977) and demolitions marked by the beautification drive during the Asian games, 1982 (Dupont 2011).

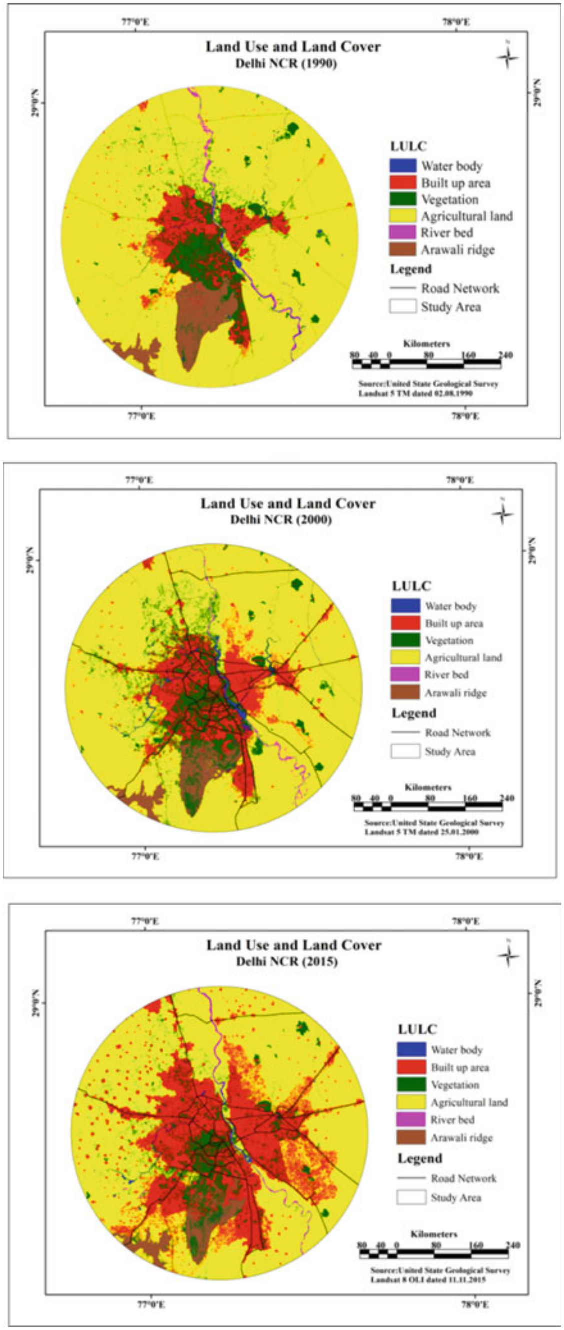


Fig. 6.1 Change in the land use land cover of Delhi NCR 1990–2015

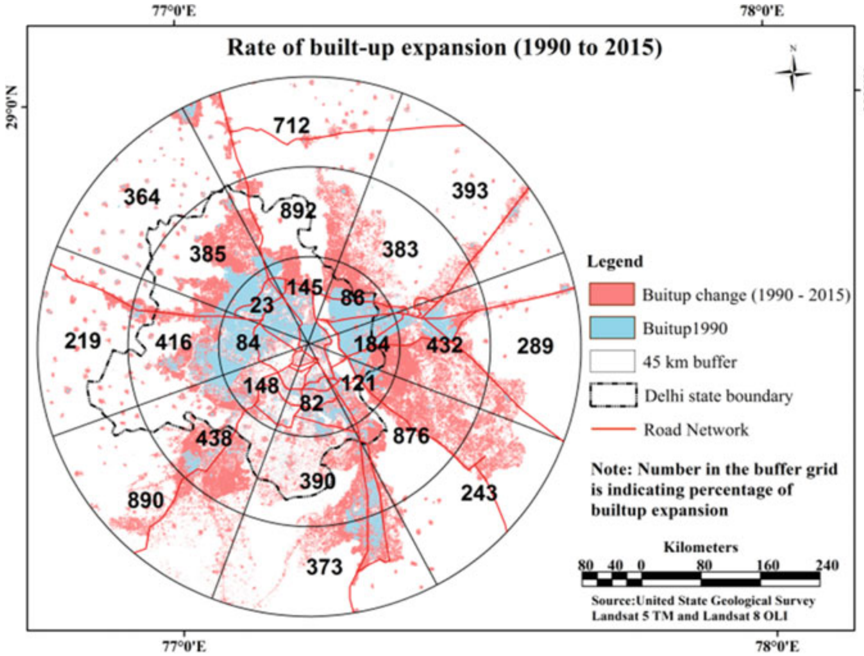


Fig. 6.2 Rate of change in the build-up expansion (1990–2015). *Source* Constructed by the researcher

On that account, one of the fundamental forces that are shaping the contemporary peri-urban is the rapid escalation of the land values which further leads the state actors tapping into the real-estate markets to ensure large-scale financial gains and greater control over the spatial change of the urban. This politics of land management focusing on the political economy of land monetisation has a substantial impact on the emerging spatial pattern of peri-urban development, where Goldman termed such phenomena as 'speculative urbanism' as the state continues to facilitate corporate land speculation towards building world-class infrastructure. This 'real-estate turn' is also in conformity with the seminal work of Harvey on the tendencies of over-accumulation of capital resulting in increased investment in the 'secondary circuit' that essentially encompasses investment in the built environment.

As constructions are taking place at a rapid rate to ensure profit maximisation from the land appropriation along with the promise of a world-class future, many of the residential units are said to be bought as investments rather than for living purposes. However, placing Delhi in such a framework of world-class city development also reveals the existence of a vast pool of unsold residential properties along with stalled real-estate projects owing to the financial crisis. Examples of over-accumulation can be taken from the ghost societies of Greater NOIDA, the Faridabad region as well as the areas along the Dwarka expressway, etc., where the construction of properties has not responded well to the market forces. This can be attributed to the fact that the private builders are mostly catering to the affluent population[8] where the property prices are largely beyond the reach of the majority marking a significant shortage of housing for the lower-income population.[9] As noted by Ghertner (2015a, b), the average prices of the newly constructed flats today is often a hundred times the mean annual income of the average Delhi population, making it impossible for a larger share of the citizen to purchase a piece of property in the city. A large amount of this unsold inventory also has been reported creating a vicious cycle discouraging customers from buying flats in those areas even after massive price corrections across the peri-urban Delhi to escalate the demand. The peri-urban in actual ground reality is characterised by the unstable land claims that are contradictory to the urban illusion created by the developers and as portrayed in the mainstream media; to quote Ghertner (2015a, b), the transformation at the margin is shaped by 'empty income projections' leading to the production of 'empty apartment buildings' while the 'invisibilised poverty trends' keep on replacing the low-income areas by high-end properties that a few can afford.

Contemporary Delhi, therefore, is redefining itself with multiple processes superimposing on the other which as explained by Roy (2003) is a 'deliberated' and 'informalised process' often in violation of the official Master Plans but informally endorsed by the state. With examples from India's largest shopping mall complex to be built on Delhi's southern ridge violating the land use provisions of the Delhi Master Plan and an adjacent slum settlement designated as illegal by the DDA for creating nuisance to the middle-class residences being demolished without compensation, the fallacy of the 'plan-ness' of the urban space in Delhi has often surfaced prominently. According to the aesthetic mode of governing, therefore, one should be careful between whatever 'looks planned' and is defined as legal and something that does not look 'world-class' and sanctioned as unplanned and not desirable as being part of the city. This also brings out the grey areas of development and contradicts the categorical characteristics of 'urban-ness' by producing 'layers of differences'.

(b) **Delhi as a Social entity: The Dominance of Elite and the Emergence of Middle Class in the Urban Space and the Consequences for the poor**

Following the 'globalisation' aspects and the influence of an international model of modernisation, as advocated by Sandhu and Sandhu (2007) there is significant social transformation owing to the reshaping of the societies with respect to the various micro- and macro-level social processes that are very specific to the concept of 'globalising cites'. This urban restructuring with a strong element of socio-spatial inequalities is described as the 'new spatial order' by Marcuse and Kampen (2000), while Banerjee-Guha (2002) preferably calls it a 'socio-spatial disorder' in explaining the situation in the Indian context. Therefore, on the one hand, the removal of the

---

[8] Dupont (2011), Ghertner (2015a, b).

[9] As pointed out by economic survey, a total 95.6% of housing shortage is within the economically weaker section. Source https://www.bbc.com/news/world-asia-india-32644293.

poor from the visible part of the city marks the emergence of 'bourgeois environmentalism',[10] on the other hand, the high consumption capability of the elites and the emergence of the new middle class[11] with class aspirations have played a critical role in modifying the urban landscape of the capital city and its peripheries, appeared as the 'hybridised form of globality' (Fernandes 2000).

In such a scenario, where the capital has been portrayed as the embodiment of 'India Shining', the poor are often considered as the 'disturbing elements' and to 'mar the image' of the nation (Fig. 6.3). From farming communities being evicted from their traditional dwelling places to the relocation of the families[12] to the city's far reaches and to the pitiful conditions of the workers at the construction sites, the poor suffered the most in materialising the dream of a clean-beautiful-modernised vision of the world-class Delhi. Building the global city, therefore, is contradicted by the act of marginalisation where the process of eradication, as well as consignment of the working class, are indicative of the state's attempt to enforce a new urban restructuring that can live up to the vision of the aspiring global city, supported by the consumer attitudes of the upper class. In this place, as highlighted by Broudehoux (2007), it can be said that the image building of a city is highly synonymous with its 'social beautification'.

In order to maintain the global vision of urban, the state has formulated policies to reclaim the public spaces and manage them that can satisfy the upper-class desires. The example of such a 'bourgeois dream of remaking the city' is also prominent in the change in the governance pattern and is visible in the formulation of urban programs. The Bhagidari scheme in Delhi launched in 2000 as a citizen-government partnership reflects one of such transformations as this is highly inspired by the theories of corporate governance (Srivastava 2009). With the introduction of the scheme, unlike the conventional participatory governance that usually targets the urban poor, the middle class, therefore, have given more authority to claim the city as the program provides an opportunity to control the urban spaces which otherwise can be seen as an excellent program to establish participatory democracy and inclusiveness. In this place, Srivastava (2009) questions the outcome of the scheme which strictly defines who 'belongs' to the urban spaces and put forth how it is limiting the rights of many 'unwanted' while expanding the claims of a few on the basis of class dynamism. Therefore, as underlined by Ramakrishnan (2013), the matter of class often becomes the sole factor in the process of urban restructuring while criminality and illegality are

---

[10] Baviskar (2003, 2010).

[11] The McKinsey report by the NCAER's data, titled 'Bird of Gold: The Rise of India's Consumer Class' predicted India's class distribution by 2015 and claimed that over the next two decades, the middle class will grow to more than 40% of the population from the current 5%. In the report, McKinsey also prepared a chart called 'escaping poverty' showing people moving up the 'imagine income ladder' where the poor has been portrayed as the future rich people. India has thus been showcased as the epitome of future investment opportunity and one of the world's largest consumer market (Information derived from Ghertner 2015a, b).

[12] From 1990, since Delhi government adopted a new slum policy, until 2007, around 65,000 families had been relocated to the resettlement colonies located at the distant urban peripheries (Dupont 2011).

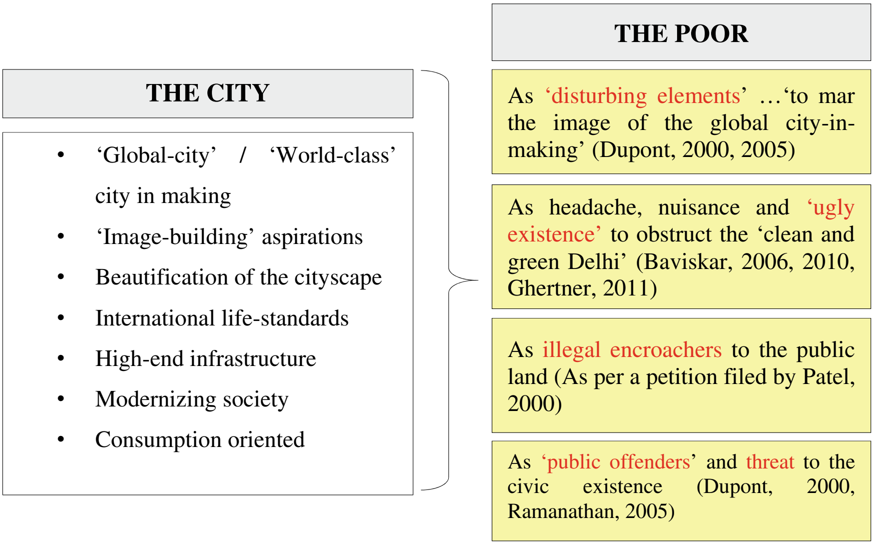


Fig. 6.3 Trend in urban development versus the representation of the poor in the capital city. *Source* Constructed by the author

increasingly being associated with the poor and their practices in the urban spaces. This particular context of the emergence of class identity as the neighbourhood associations called Resident Welfare Associations (RWA) and the changing political nature of the government of Delhi[13] sets the precondition for analysing the spatial practices at the peri-urban and reflects the current frame of urban development in major cities of India.

As Delhi's recent development confirms the trend envisioned by Harvey (1989), the shift to entrepreneurialism in urban governance involving speculative construction of the idea of a city and therefore 'creation of an attractive urban imagery', the next section tries to explore the reality through visual images from the field in the peri-urban as well as the real-estate advertisements portraying the vision of the aspiring global city.

[13] The formulation of the Bhagidari (meaning 'collaborative partnership') programme has been seen as an attempt to decentralise the system of urban governance in India. The aim of the scheme was to provide both the government and the citizen a common ground to solve problems and manage public assets; however, the changing role of the RWA drew criticism for not including a larger segment of population, i.e. the poor. Therefore, while the programme strengthened the role of the middle class in the city, their activities, having a strong class interest, in many ways have been directed against the urban poor. RWA's protests against affirmative actions and Master Plans guidelines to regularise illegal commercial establishments operated by the low-income residents are some of the examples (Chakrabarti 2008).

Examining the Trend of Urban Development Through Visual Images

A shift in the urban development, as well as governance away from social redistribution to becoming the sole engine of growth in alliance with the private capital, has largely been deployed by the strategies of city branding and the very construction of the image and narrative of 'world-class'. Such a discourse found its theoretical base in the literature of urban entrepreneurialism conceived by David Harvey in 1989 and practically draws its reference from the understanding of the politics of visibility in Mumbai city by Fernandes (2004) and the scrutiny of the urban images of the city of Ahmedabad,[14] by Renu Desai (2012).[15] Therefore, whereas Harvey (1989) highlights the aspect of reorienting priorities from urban managerialism to urban entrepreneurialism, Fernandes (2004) and Desai and Sanyal (2012) are found to work towards understanding the strategies of place marketing to shape the entrepreneurial city and the resultant implications of such practices on the people of the city.

With a similar objective, this section, therefore, briefly examines the dominant images and narratives of the capital city of Delhi based on the visual materials from the field and additionally from the newspapers and real-estate banners and expects to explore the dominant interpretations of the city and the differentiating meaning of spaces/places exercised by those interpretations.

(a) **Images from the Field that Explains the Nature of Urban Expansion**

As Partha Chatterjee writes, the construction of the new post-colonial global metropolis is heavily influenced by the 'intensified circulation of images of global cities through cinema, television and the Internet as well as through the Indian middle classes' far greater access to international travel.[16] Such mental images of the world-class city, therefore, are well-reflected in the images taken at the field around the peri-urban Delhi as they display a similar pattern of incessant development of those in the West, visioning a higher value future. This on the one hand with an extortionate emphasis on building high-quality facilities and creating a clean and glamourised model of the urban when creating a sense of placelessness owing to their similarity in the pattern of construction, also makes it difficult for the poor, accounting for nearly fifty percent of the population, to visualise a place for themselves. The peri-urban targeting the superrich; therefore, when bears the imprints of luxury and exclusivity, it also simultaneously carries the narratives of subjugation and marginalisation. Such a scenario complies with the observation made by Saskia Sassen (in Sampath 2017) when she was interviewed by The Hindu on her reflections on the nature of the current urban development, as she goes on saying '*One clear trend is a vast and very visible expansion of the luxury zone, for fancy offices and fancy residences, accompanied*

[14] Desai and Sanyal (2012) called this as a 'promotional coupling of the city and region' as Ahmedabad has been re-imagined towards the larger agenda of promoting Gujarat as a state.

[15] In Desai and Sanyal (2012).

[16] Chatterjee (2004), as cited in Ghertner (2015a, b), 23–24.

by an almost invisible expulsion of the working classes and modest middle-class families from locations where they may have lived for several generations'.

In the first place, the shift in the very structure of urban land usage is evident from the construction of luxury apartments en-mass which ensures stark differences in the visual as well as spatial forms of the city in expansion. This transition, however, can be hailed as a sign of Delhi becoming increasingly international where an emphasis on lifestyle enhancement (e.g. the concept of clubhouse) and providing state-of-the-art facilities to the residents has been considered the most significant marketing strategy. Projection of international orientation is prominent through naming the complexes where such politics of labelling also reveal the positioning of the urban in the context of the neo-Marxist commodification debates. In this place, the desire of the new middle class though exerts a considerable amount of influence, and the developmental shift towards market-oriented strategies is found to be most significant, especially in the context of liberalisation (Fernandes 2004).

The following photographs, therefore, reflect upon the kind of urban expansion that is taking place in peri-urban Delhi, which might also be a case for the other major urban centre across the nation. The descriptions of each of the photographs explain its significance and draw attention to the spatial as well as socio-psychological morphology of the urban evolution to the peripheries. These have profound implications in preparing a base for understanding the various stakeholders at the margin and the transformation of their living spaces as well as engagement with the urban (Photographs 6.1, 6.2, 6.3 and 6.4).

The photographs from the field, therefore, well-established the proliferation of the luxury zones facilitated by the private investment and the real-estate functioning as the most dominant factor towards urban development at the peri-urban. The following

Photograph 6.1 Image taken in the peri-urban areas of NOIDA demonstrates the enormity of the construction of high-rise residential buildings that are invariably engulfing the rural fringes. Most of these housing units are empty at the current time owing to the fact that it serves as a store of financial investment, rather than as a home for the people to live in (Fieldwork 2019)

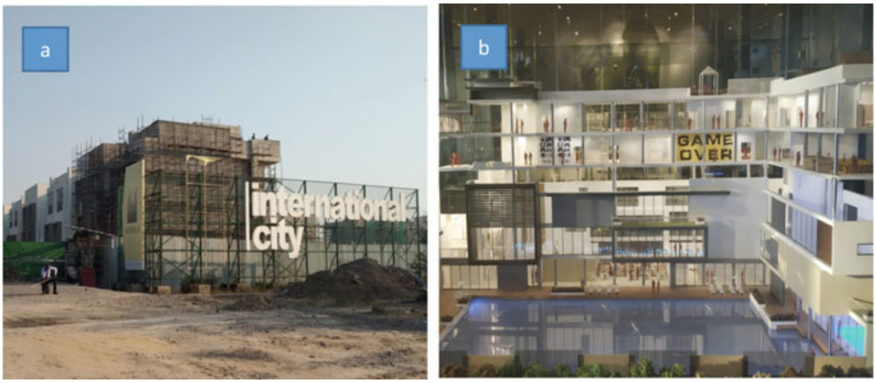
Photograph 6.2 The image was taken at the peri-urban NOIDA and Gurgaon, demonstrating the incessant construction activities at the margin, following a similar pattern of spatial arrangement. High-rise residential complexes often appear grid-like and are supplemented with commercial complexes and patches of green areas within (Fieldwork 2018)

Photograph 6.3 As one of the dominant sights of the peri-urban Delhi, gigantic hoardings along the roads exhibit ongoing residential projects and attractive deals to draw customers. Number **a** showcased the strategy to sell the property as a token of investment in the New Year while number **b** exhibits the exclusivity of the project and its VVIP attributes (Fieldwork 2018–2019)

subsection delves into the specificities of the sector largely to make sense of characteristics that are increasingly becoming the ethos of development. Broadly, they also provide evidence for understanding the global city paradigm currently in fashion.

(b) **Analysis of Advertisements to Understand the Current Dynamics of Urban Development**

The contribution of media as integral to the city's marketing strategy is prominently visible where example can be taken from the famous slogan '*From walled*



Photograph 6.4 Taken in the juncture of Delhi and Gurgaon, Number **a** portrays the tendency of projecting the 'international' orientation of the real-estate projects at the peri-urban through naming and number **b** displays the model of clubhouse facilities that claim to provide 'international level' facilities like spas, salon and yoga guided by international personalities (Fieldwork 2019)

city to world city' popularised by one of the leading newspapers of the country, the *Times of India*. Therefore, one of the ways, the changing nature of the space can be perceived is through the various projections of the media, through advertisements, and banners and contents of magazines and newspapers. As depicted by Fernandes (2000), the media images are, therefore, a portrayal of the idealised vision of the country (specifically urban in this context) on the dominant depiction of the higher-income population and their newfound pattern of commodity consumption. According to her, the representations demonstrate India's shifting relation with the global as they rest on the narratives of development. Moreover, the commercials are often designed to cast a persuasive impact and illustrate the political culture of the nation-state in the wake of neoliberalisation (Fernandes 2000; Pollay 1986; cited in Ganahl et al. 2003).

The study has taken up references from the leading newspaper advertisements, particularly those that reflect the kinds of urban development and dominant city infrastructures. In this place, what Lefebvre (1991) has stated as abstract space has found its importance, as this forms the locus of fashion, art as well as advertisements and subsequently shape the ideology. Spaces, therefore, contain representations derived from the established order and found their authority through the places that underpin them. What popularly has been called the 'world-class city' is, therefore, manifested through such spatial representations as a symbolic fabric which further essentialised the spatial specificities prominent around the peri-urban Delhi.

Most of the promotional slogans talk about a 'new experience' and a 'dream destination' while a set of advertisements also highlights the kind of luxury that awaits in the whole new world situated on the periphery of Delhi. Such slogans are created by the developers to reap the benefits of the elite and upper-middle classes of the city in search of a better quality of life that the notion of 'urban' envisioned to provide. The languages of promotion, therefore, highlight the factors that shape the idea of a 'global city' which to quote Dupont (2005) is a 'blend of ecological utopia and modernist projections' and reveals the fantasies and aspirations behind constructing a particular identity in the city. King (2004)[17] calls this the emergence of 'spaces of global cultures', Dupont (2011) outlines this as an attempt to create a 'distinct Indian Identity' while Broudehoux (2007) termed them as the 'new spaces of exclusion' marked by the dominant choices of the elite class and therefore reconfiguring the existing socio-spatial fragmentation. The section, therefore, sits on an argument by Perkins (1989) that the real-estate developers appropriate and commodify the established meaning of the places and the advertising continues to promote what is urban to satisfy their end. The meaning of a place is closely related to the class structure, where the preferences of the dominant classes represent greater interest and value. This strongly influences the way places are being imagined and further planned and managed.

Advertisements of real-estate consultants are, therefore, not only creating physical space by presenting buildings of a particular kind but also serve as phenomena that have consequences for the social restructuring of the urban experiences.[18] On the one hand, while they reflect the choice and interests of the elite and middle-class purchasers, on the other hand, are found to be neglecting the sense of place of the working class by its very design that is restrictive to their mobility. Interaction with the real-estate developers reveals the provision of a three-tier security system around the housing complexes while the value of such properties often seemed to be threatened by the presence of the settlement of the labouring class and their noisy presence along the road, making an economic means from the large-scale construction activities. Therefore, the promotion of the city having an international affiliation in a way has created a distinct neighbourhood largely segregated by the class of the population.

Most of the advertisements are often seen to highlight the sense of happiness and contentment of the potential homebuyers associated with goods and services, whereas very few have tried using factors such as proximity to nature and the significance of a greener landscape for better living to tap into the customers. Therefore, the idea of urban life is increasingly being portrayed as a place equipped with the provision of modern conveniences and making a status, rather than as an inclusive place for the children to grow with a collective identity. Out of the total 100 advertisements, every image portrayed a similar representation of the urban with the text conveying a similar message of exclusivity. Amidst showcasing the high-end structures, it is also significant to notice that the human imprint is invariably minimal in such photographs which can also be attributed to the greater sense of privacy and a nominal sense of community. The emphasis given to leisure and other high-end service-related facilities indicates a growing focus on the questions of lifestyle. Entertainment enterprises

---

[17] As cited in Dupont (2011). For detail, see King (2004) *Spaces of global cultures: architecture, urbanism, identity*. Routledge, London and New York.

[18] Parkins et al. have argued the housing advertisements to have both physical and ideological properties, communicated and sustained through visual imagery as well as written text. Where in local scale these assert the contemporary aspects of culture and environment, they can also be positioned in the context of global discourses of construction of urban space (See Parkins et al. 2008).

ranging from restaurants and malls to luxurious sports complexes and clubhouses with facilities like saunas and spas are largely being promoted as a necessary factor in choosing a place to live. While earlier clubs were exclusive and a few in number, the present-day expansion of such social spaces to the housing complexes marks an increasing demand for exclusiveness in society which also serve as a symbol of one's status. Therefore, real-estate advertisements increasingly are seen to be highlighting the materiality of urban life and encouraging the emergence of new social and cultural practices[19] towards a 'new urban aesthetics of class purity' (Fernandes 2004). The increasing significance of leisure and entertainment opportunities should, however, be understood in terms of a broader process of socio-cultural restructuring of 'urban' that prominently serves the interest of the growing middle-class as well as the elites. The new era of consumerism is also characterised by specific market strategies that prominently capitalise on security combining the gated nature of the housings with three- to four-tier boundaries. Often better urban living is conjectured to be attained through a strong sense of security.

Therefore, claims that are prioritised in the advertisement depict what exactly is being privatised and how the urban development/expansion is conceptually carried out. Terms like luxury and exclusive have been featured in more than 80 advertisements while the descriptions specifically highlight the dwellings being 'stylish, "architecturally designed", and providing a 'top of the world experience' (Fig. 6.4). In addition, references to idealised accounts of green spaces as well as locations closer to malls and restaurants have been used as an indicator of quality living. The emphasis thereby took two predominant forms: one referring to the sensory experiences owing to the luxurious nature of the property and the other to the high-end facilities (lifestyle enhancement opportunities) that the site is providing (Table 6.5).

The practices involved in such re-imaging of the urban by strategic manipulation have a significant influence on the residents of the city. Where the dominant discourse highlights the image of the city that is more 'sanitised, commodified and distorted in accordance with the perceived demands of the global marketplace' (Doel and Hubbard 2002, in Desai 2011); such practices also consciously and unconsciously suppress the everyday experiences as well as a sense of place of the marginalised.

Summing Up

The chapter seeks to examine the present trend of urban development in the capital city of Delhi by the pattern of its physical growth as well as through the strategies of representing the city echoing a particular narrative of being urban. Stemming from

[19] On a similar account, while narrating the rapid growth of leisure and other service-related industries in the metropolitan city of Mumbai, Fernandes (2004) has referred such trend as 'bar and restaurant culture'. The contemporary Mumbai therefore is said to be witnessing a proliferation of upmarket bars and restaurants instead of smaller restaurants and Irani shops, catering to the general masses. Fernandes attributed such shift with the rise of new middle class and their increasing concern related to status.

Fig. 6.4 Frequently used adjectives in the real-estate advertisements. *Source* Conceptualised by the researcher

Table 6.5 Textual themes as in the promotional advertisement

Textual themes	As major highlight	As ancillary highlights
Lifestyle	53	15
Features within the site	19	58
Features within the house	0	38
Proximity/accessibility value	3	37
Nature/green space	11	41
Rarity/exclusivity value	14	4
Safety value	0	53
Total	100	100

Source Newspaper Real-Estate Advertisements, 2017–2020

the uneven processes of globalisation, this, therefore, has attempted to develop a base with the popular arguments of urban 'entrepreneurialism', 'place marketing' and the 'politics of forgetting'. While the land use data displays how the peri-urban development takes shape along specific corridors, prominent literature in the domain indicates the class biases of the city expansion, in conformity with the vision of a world-class city, idealised by 'modern, privatised, slum-free city environment', and the advertisements indicate towards the attempt of projecting the urban as an ideal space for development owing to the world-class services and international facilities it possesses which in turn ensures the stronger insertion of the city region in the capitalist space economy. Such a comprehensive portrayal of the image also serves to define the power structure within the city with the prominent rise of Westernised consumer culture. Articulated through the 'politics of erasure and denial', the practice is further deepening the spatial divides and reproducing the class divisions, other than providing possibilities of eliminating them. As one of the prominent components of private sector components of the present-day growth machine, the real-estate expansion also creates segregated urban geography, without an exception.

The process of urban expansion, therefore, has gained momentum with the globalisation and neoliberalisation processes and further intensifies the conversion of rural to urban leading to rampant land acquisition, and regeneration of the city centre, causing relocation and rebuilding of the new giving a push to the process of migration. This might help to closely look into each of the processes and attempts that sketch out a comparative framework for understanding the trend of urban development and its consequences for those who hardly fit into the vision of the 'world-class'. The attempt to explore the exclusionary urban practices seeks to craft the consequent emergence of alternative forms of urban citizenship on an everyday basis with the overarching construct of urban at the background within which the working poor are based and continue to negotiate. This is in lieu of the conclusion drawn by Fernandes (2004) in her analysis of contemporary Mumbai where she asserts the importance of understanding the state practices as well as exclusionary definitions of citizenship to produce a version of the urban that ensures the emergence of an urban model of consumer-citizenship and 'seeks to displace the political claim of marginalised social groups to resources such as jobs and housing'.

References

Baviskar A (2003) Between violence and desire: space, power, and identity in the making of Metropolitan Delhi. Int Soc Sci J 55(175):89–98

Baviskar A (2010) Spectacular events, city spaces and citizenship: the Commonwealth Games in Delhi. In Anjaria JS, McFarlane C (eds) Urban navigations: politics, space and the city in South Asia. Routledge, New Delhi, pp 138–161

Banerjee-Guha S (2002) Critical geographical praxis: globalization and socio-spatial disorder. Econ Polit Weekly 37(44/45):4503–4509

Broudehoux AM (2007) Spectacular Beijing: the conspicuous construction of an Olympic metropolis. J Urban Aff 29(4):383–399

Chatterjee P (2004) The politics of the governed: reflections on popular politics in most of the world. Columbia University Press

Chakrabarti P (2008) Inclusion or exclusion? Emerging effects of middle? Class citizen participation on Delhi's urban poor. Institute of Development Studies (IDS) Bulletin, no 38

DDA (Delhi Development Authority) (2007) Master plan for Delhi 2021 [notified on 7 February 2007. Vide S.O. No 141, published in the Gazette of India Extraordinary, part II, section 3, sub-section (ii)], Delhi
Desai R (2011) Entrepreneurial urbanism in the time of Hindutva: city imagineering, place marketing and citizenship in Ahmedabad. Urbanizing Citizenship: Contested Spaces in Indian Cities. Sage, New Delhi, pp 31–57
Desai R (2012) Governing the urban poor: riverfront development, slum resettlement and the politics of inclusion in Ahmedabad. Econ Polit Weekly 47(2):49–56
Desai R, Sanyal R (2012) Urbanizing citizenship: contested spaces in Indian Cities. Sage Publication India Pvt Ltd
Doel M, Hubbard P (2002) Taking world cities literally: marketing the city in a global space of flows. City 6(3):351–68. In Desai R, Sanyal R (eds) Urbanizing Citizenship: Contested Spaces in Indian Cities. Sage Publication India Pvt Ltd
Dupont VD (2011) The dream of Delhi as a global city. Int J Urban Reg Res 35(3):533–554
Dupont V (2005) The idea of a new chic Delhi through publicity hype. In: Koshla R (eds) The idea of Delhi. Marg Publications, Mumbai
Fernandes L (2000) Nationalizing "the global": media images, cultural politics, and the middle class in India. Media Cult Soc 22(5):611–628
Fernandes L (2004) The politics of forgetting: class politics, state
Ganahl DJ, Prinsen TJ, Netzley SB (2003) A content analysis of prime time commercials: a contextual framework of gender representation. Sex Roles 49(9–10):545–551
Ghertner DA (2015a) Rule by aesthetics: world-class city making in Delhi. Oxford University Press, New York
Ghertner DA (2015b) Why gentrification theory fails in "much of the world." City 19(4):552–563
Harvey D (1989) From managerialism to entrepreneurialism: the transformation in urban governance in late capitalism. GeografiskaAnnaler: Ser B Human Geogr 71(1):3–17
King A (2004) Spaces of global cultures: architecture, urbanism, identity. Routledge, UK
Lefebvre H (1991) The production of space, vol 142. Blackwell, Oxford
Marcuse P, Kampen RV (2000) Globalizing cities: a new spatial order? Riley-Blackwell, Hoboken
Perkins HC (1989) The country in the town: the role of real estate developers in the construction of the meaning of place. J Rural Stud 5(1):61–74
Ramakrishnan K (2013) City futures: aspirations and urban imaginaries in Delhi. Kaleidoscope 5(1):100–108
Sampath G (2017) I think we need more cities: Saskia Sassen. The Hindu
Srivastava S (2009) Urban spaces, Disney-divinity and moral middle classes in Delhi. Econ Polit Weekly 338–345

Chapter 7
Are Informal Economic Spaces of Street-Vending Sights of 'Disorderly Urban Environments' and Sprawl? A Case Study on Hawkers of Kolkata

Madhubarna Dhar, Amrita Sen, and Archana Patnaik

Abstract While an ever-increasing and economically marginalised urban population is a principal constitutive element when thinking about urban sprawl, another significant element is the embodied aspiration of the growing Indian Middle Class to live in a 'world-class city'. In this chapter, we aim to explore the political economy framework on how class-animated city spaces lead to newer images of urban frontiers eluding the realities of sprawl and disorder that they constitute. Informal economic activity by the vendors is seen as a spilling 'hazard' by middle-class citizens, who believe that public spaces like streets, pavements and parks should be hygienic and spectacular, and enhance the quality of urban life. With its omnipresent role in redefining the legitimacy of 'worlding cities', the neoliberal state is usually at odds with the vendors' interests and makeshift vending spaces. Nevertheless, at the same time, it concurs with growing motorised vehicles, redundant infrastructures and 'spectacular' high-rises to accomplish its goal of 'accumulation by dispossession'. In this article, drawing on an intersectional conceptual framework and empirical observations from street vending in Kolkata, we trace a route to look into urban environments as subsumed within popular mass politics and not as a linearly ecological category. We establish that street-based livelihood activities, despite being popularly seen as sprawl and a 'city-hazard', formatively proliferate through powerfully shaped strategies of politics and governmentality.

Keywords Informality · Street vendors · Kolkata · Urban sprawl · Environments

M. Dhar (✉) · A. Sen · A. Patnaik
Department of Humanities and Social Sciences, Indian Institute of Technology Kharagpur, Kharagpur, India
e-mail: madhubarnadhar@kgpian.iitkgp.ac.in

A. Sen
e-mail: amrita.sen@hss.iitkgp.ac.in

A. Patnaik
e-mail: archana@hss.iitkgp.ac.in

U. Chatterjee et al. (eds.), *Urban Commons, Future Smart Cities and Sustainability*, Springer Geography, https://doi.org/10.1007/978-3-031-24767-5_7

Introduction

This work explores a discursive frame of urban environmental consciousness, influencing 'the public discourses on spaces, practices and population' (Bandyopadhyay 2011, p. 297). To this end, it positions street vendors as steady actors within the informal economic sector of a city. Street vendors, commonly known as hawkers in India, offer a range of goods and services primarily to the middle and marginal classes of the city, often at affordable and pocket-friendly prices. The National Policy on Urban Street Vendors (2009) states that hawkers or street vendors are 'self-employed workers in the urban informal sector, who offer their labour for selling goods and services without any permanent built-up structure'. City streets, sidewalks, overpasses, markets and pavements are ideal spaces where hawkers settle for sale, often in temporary, static, or makeshift structures. Hawkers constitute an essential and significant part of the urban landscape of India yet are often threatened, dispossessed, harassed and evicted. This treatment of the hawkers partly owes to a vision of city planning and beautification which considers urban informal economies as illegitimate and therefore problematic—broadly, a planning perspective that regards informal economies as 'distortion of public space' and a kind of urban sprawl and public nuisance (Onodugo et al. 2016, pp. 95–96; Bandyopadhyay 2015).

A significant section of government administrative techniques, coupled with class-animated elite visions of urban environmentalism, acts to engage proactively in the constitution of civic and orderly city spaces. Baviskar (2011) points out that the mission of 'cleaning up' city streets often targets the urban marginals, including street vendors, beggars and performers. Mainstream literature on urban studies focuses on a larger vision of 'worlding cities'; they examine models of Asian urbanism in determining prospective turns towards post-colonialism and aligned articulations of developmental pathways infused by power and authoritarian knowledge (Roy 2009, p. 308). Such powerfully shared visions of neoliberal globalisation in modern cities restrict informal economic activities to a large extent, leaving the urban poor with little leeway apart from contestations, resistance and political mobilisation—popular mass politics become the only emancipatory weapons. The process of staking claims to spaces in cities with predominant environmental agendas necessitates deeper engagements with the very nature of subaltern negotiations (Bandyopadhyay 2011, 2015).

The chapter aims to extend the analytical focus of the city worlding process by explaining how pre-eminent and politicised environmental agendas in cities animate spaces of informality. A systematic shaping of the urban environment by the middle class through widespread public debates on environmental issues and parallelly emerging strong representation in the media, politics, scientific establishment, NGOs, bureaucracy, environmental institutions and the legal system has led to the construction of an urban environmental activism, with significant civic disregard to issues of social justice, and inequalities (Mawdsley 2004, p. 81; Baviskar 2011). Gentrified and middle-class-animated city spaces and the larger vision of 'urban ecological planning' dislodges informal economic actors in the city, like street vendors (Basu and Nagendra 2020). Such a disregard is omnipresent when it comes to street vending spaces in a city, which are contested not only because they lack legal status but also because they depredate the health, hygiene and 'environment' of the city (Harvey 2009; Baviskar 2011; Pakalapati 2010). We also show that neoliberal models of urban development have agentialised a range of local, regional and transnational actors in creating new environmental politics and novel forms of communal organisation leveraging urban institutions (Kashwan et al. 2019).

We argue how an exclusive focus on ecological urbanism has led to a distinctive social production of the city's nature that disproportionately benefits many urban residents (Heynen et al. 2006). Street vending is often seen as a 'hazard' to middle-class citizens, who believe that public spaces like streets, pavements and parks should be cleared of sprawl and look hygienic and spectacular and enhance the quality of life (Baviskar 2011). The street vending spaces in Kolkata, where this work is empirically positioned, had become a contested arena following 'Operation Sunshine' in 1996, the biggest drive in the city to 'clean' specific locations of hawkers by evicting thousands of them who encroached landmark pavements of the city. Such physical reproduction of urban spaces towards visible improvements of its 'quality' embeds nature in political economy and power relations, revealing how structural and institutional contexts influence resource users' claims to space (Veron 2006). This critical line of inquiry will be centrally addressed in this work. In doing so, we would broadly trace a route to investigate urban nature as a socio-political rather than a linearly ecological category, where street-based livelihood activities, despite being popularly seen as a 'city hazard' formatively proliferates through powerfully shaped strategies of politics and governmentality. The conceptual focus of the paper would be on the urban environment as being linked to domains of informality, rights, class structures, citizenship and politics. We would then empirically explore how street vending as a prevalent economic activity positions itself within strategic engagements with urban environmentalism, often through 'a state of exception that it embodies' (Roy 2005, p. 147). Through an immersed ethnographic description, the plight of the street vendors today, as we show, adds rigour to the neat epistemic contours of middle-class environmentalism in the city through an elaboration of the role of contemporary political society. In the discussions, we would offer an exploration around an effective investigation of the urban environment as a sociological-political category.

Informality, City Streets and Environmental Framings

A promising range of urban history in different places of South Asia has witnessed the engineering of removal of much of the working class from the city centres and how urbanisation has a crucial role to play in the very absorption of capital surpluses (Harvey 2008). Often by demolishing informal settlements and seizing the land, the state can privatise public spaces and thereby creates and recreates these shifting categories of 'legal' and 'illegal' to suit the needs of corporate groups and for private profit (Baviskar 2011). In contemporary times, Roy (2009) encourages us to think about 'new geographies of imagination' that would enable us to understand multiple forms of metropolitan modernity produced out of the capital surpluses in third-world cities. A work drawing on Chatterjee (2004) captures this idea on modernity: 'often dismissed as the rumblings of 'the street', popular politics is where political modernity is being formed today'.[1] As an instance, Shaw and Colombijn (2009) mention that Kolkata lies at the intersection of two kinds of modernities. Historically precolonial towns were frequently conquered and transformed to fulfil European colonial powers' need. In a similar light, Kolkata, the colonial capital at one point in history, was transformed to suit the needs of the British Raj. But after independence, the city is being remoulded differently to suit the needs of the dominant sections of society and is exhibiting a new form of metropolitan modernity. Nevertheless, today's city still bears considerable remnants of the city's colonial past (Shaw and Colombijn 2009). Scholars have now become interested in theorising 'global cities' or investing in the world cities approach, which generally seeks to understand the position of cities within the world economy. But the problem is that many cities are excluded based on being 'economically irrelevant' (Robinson 2002). These methodologies have a bias towards Western cities, and if one is to break free from these classifications, steps must be taken to decolonise the area of urban studies.

Urban informality has become a way of life in numerous cities across the globe where there are high rates of urbanisation and poverty (Birch 2019). Scholarly writing on 'informality' as a concept can be traced back to the work of Keith Hart, an anthropologist associated with the International Labour Organisation (ILO). In 1973, during his visit to Ghana, he came across workers who came to the city from villages to offer their services as day labourers. This was quite different from the organised markets of England, which he was used to seeing, and it prompted him to distinguish the formal from the informal. Hart also believed that certain features like low skill level, easy entry, low wages and an immigrant workforce characterised the informal sector. Informality has become a common feature in the post-colonial Third World due to systemic borrowing of urban planning techniques from the developed world and then trying to fit the same design as successful tropes of urbanisation modelling. Roy (2005, p. 148) suggests that it is useful to think about informality as 'a mode of urbanisation'. She transcends the formal/informal dichotomy and sees it as 'a series of transactions that connect different economies and spaces to one another' (Roy 2005, p. 148).

There are two dominant views when it comes to informality. Informality is either presented as a problem or celebrated in debates (Banks et al. 2020). It is often considered an unplanned reality that needs to be regulated. Otherwise, it is seen as a celebration of marginalised groups who exist amidst social, economic, political and geographical exclusion. As illustrated in the work later, street vendors have been seen to negotiate their terms of informality by adopting innovative strategies for their survival. In China, for example, the term 'informality' is constantly being

[1] http://cup.columbia.edu/book/the-politics-of-the-governed/9780231130639.

redefined to meet the government's political objectives (Xue and Huang 2015)—here, street vending is not prohibited, but it has a relatively unstable status that is tolerated selectively. The need for maintaining an attractive city image and the necessity to address people's livelihood are managed through the act of permitting and prohibiting hawking in various locations. The extent to which a social practice like street vending is permissible depends on what the state desires at that time. Another instance is given by Crossa (2009), who writes about the Entrepreneurial Urban Governance (EUG) in Mexico City, which aims to revitalise and enhance the streets, buildings and the central plaza of the city's Historic Center. However, the EUG creates socio-spatial exclusions, such as the construction of gated communities and the commercialisation of public space, raising serious concerns regarding citizens' right to the city. Although violent struggles have taken place, the street vendors of Mexico City have shown a unique method of resistance called 'torear'. Against the backdrop of the displacement that has taken place of the hawkers from the Historic Center, some vendors have returned to the streets by engaging in 'torear'. Torear is what bullfighters do to tease or deceive the bull. So, rather than erecting a metal stall on the street and making one's presence visible, street vendors sell goods on the same street by becoming mobile. These examples are crucial as they allow us to examine the boundaries of informality in the global south and if they can be stretched to lay claim to urban environmental politics, which has become one of its strengths.

The claim-making to streets, city spaces and, most importantly, class-driven urban environments provide a context for this study. According to Fernandes and Heller (2006), the new middle class in India may be seen as a class-in-practice, meaning that it is characterised by its politics and everyday actions, which allow it to reproduce its privileged position. They argue that the dominating segment of the middle class plays a crucial role in the politics of hegemony. Baviskar (2011) uses the term 'bourgeois environmentalism' to conceptualise the middle-class pursuit of order, hygiene and ecological conservation. She explores how the urban elite claims to speak for the entire city through the discourses of public interest and citizenship. This activism which is neither guided by ecological sustainability nor social justice produces a form of exclusionary urbanism (Sahoo 2016). A very similar understanding is put forward by Ghertner (2015), who writes about 'nuisance talk'. The everyday depictions of informal settlements as dirty, uncivil and out of place through speech acts or sensory vocabulary construct particular objects as a 'nuisance'. The urban elite thus try to eliminate the poor whom they consider to be a 'nuisance' and construct them as obstacles to the 'world-city' making process. In his work, the 'culture of illegality' is significant as being a part of the nuisance talk that associates the squatters, hawkers and other sections of the urban poor with vote bank politics. Anjaria (2009) talks about how resident welfare associations formed by the Indian middle class render the political claims of street hawkers 'illegitimate' and reconfigure the nature of citizenship. Public Interest Litigations (PIL) filed by elite residents in Delhi High courts have also started to play a significant role in shaping urban environmental transformations. PILs have the power to reconfigure the nature of citizenship of slum dwellers by constructing them as dishonest citizens who do not have to pay for land or a flat (Bhan 2009). In a similar vein, Brosius (2010), citing the example of Delhi, examines how contemporary urban India might be studied within this context of leisure, aspirations and modes of consumption. Sanyal's influential work on *Rethinking Capitalist Development* provides a strong argument to substantiate how underdevelopment, expulsions and exclusions are 'castaways of development'—it is an essential condition of capital's existence and exercise of specific technologies of power to the detriment of the underprivileged (2007, p. 47).

But are environmental concerns indeed only the domain of the middle class? There is a view that the poor may be too preoccupied with meeting their basic needs for subsistence to worry about environmental concerns (Bell 2020, p. 140). Bell (2020) states that Inglehart's post-materialist values theory, the 'affluence hypotheses', and the Environmental Kuznets Curve (EKC) serve only to reinforce these ideas. However, the poor have a long, hidden history of protecting the environment. They have always defended the environment because they know their livelihoods, welfare and survival depend on it. Environmental classism has given us a very narrow definition of the environment. For example, the more affluent sections of the society might focus on recycling and buying green for the greater good of the environment. But the poor are able to consume fewer resources and generate a significantly lower amount of waste than the upper or middle class. They are not environmentalists in need but 'environmentalists in deed' (Bell 2020, p. 145). In the case of street vendors, we notice how these groups also interact with the environment in exciting ways. Scholarly writing often overlooks street vendors' and hawkers' relations with the urban ecosystem. Green spaces in the city provide hawkers with spiritual, economic and cultural functions (Basu and Nagendra 2020). Access to trees and availability of shade make their strenuous livelihoods more bearable in the summer months. So, what is at stake is not simply the 'right to the city' but also the 'right to shade'. It is not unusual to see a barber who sets up his salon by attaching a mirror to a tree trunk in the streets of Kolkata. Street trees thus help the vendors in many direct and indirect ways. Often, trees are used to hang signs with sale prices to attract customers. The branches and the trunks are also used to display goods. Working in the same spot for years, they tend to develop an emotional connection with the trees. Some species of trees are considered lucky for business growth by these vendors. In this context, what becomes important is how hawkers attach a sense of place to their built environment. Gieryn (2000) describes how 'place' has three essential characteristics: its geographical location, material form and its associated meaning. Understanding the difference between space and place is critical because space is what a place becomes when its distinctive value and meaning are stripped away. When individuals extract a defined, identifiable, meaningful and significant place from a continuous and abstract space, they create a sense of place (Sen and Nagendra 2019). Due to public space enclosures and eviction threats, these sentiments are continually in danger.

However, there are many strategies of popular mass politics that the vendors adopt in their everyday lives to pull back efforts of exclusion and dispossession from the city. One is that of negotiation. Schindler (2014a, b) writes about how street vendors maintain access to public space through negotiation with non-state actors who control space at the micro-scale. He goes on to write about the struggles of the hawkers' claim to space in the face of multiple governance regimes, like the municipality and the civil society organisations, which lay claim to public space to transform Indian cities into world-class cities. Through this theorisation, we realise that power is dispersed and that a diverse range of non-state actors participate in governance regimes and seek to control these 'out-of-place' populations. Another very interesting way that the urban marginals in the developing world fight back and assert their claims is through what Bayat (2000, p. 545) calls 'quiet encroachment of the ordinary'. The notion of quiet encroachment describes the silent way ordinary people encroach on the property of the powerful to survive and improve their lifestyles. One example of this is the tapping of electricity from municipal power poles. This way, the authorities are forced to extend urban services to these neighbourhoods.

Similarly, street vendors encroach on public space and subsequently challenge the idea of the orderly modern city and urban governance imposed on them by the urban elites. What must be remembered is that this act of quiet encroachment is not always political but is done out of necessity. Modernity is costly and unfortunately not everyone can afford to be modern (Bayat 2000). Public space is partly what makes cities (Bodnar 2015). Nevertheless, this experience is now under threat. But as the city becomes more of a 'spectacle', the sense of the city as a body politic gradually gets lost (Harvey 2006). Public streets and sidewalks are all that are left as sites of public expression. They are also sites where poverty and inequality are most visible. It is thus imperative to ask how and why political participation can occur in an urban world where space is privatised, commoditised and segregated.

Field Context and Methodology

In this work, we adopted a qualitative approach since it describes and analyses the quality and substance of human experience in detail (Marvasti 2004) as an imperative to explore links between informality and urban environmental concerns. This methodology would be most suitable for this study as we wish to comprehend how our respondents understand the world around them and give meaning to their subjective experiences. An urban ethnography would be an ideal method for learning and uncovering the dynamics of different marginal groups that inhabit the city. Ethnography is a research method that involves a series of qualitative techniques of social investigation (Imilan and Marquez 2019). Frequently, in-depth interviews and observation are employed by investigators to gather information about the subject. Western societies have practised ethnography for years to understand the 'other' or non-western societies by learning their language, building rapport and staying with the natives in their societies. Urban ethnography has made a distinctive contribution to the analysis of ethnicity and class (Jackson 1985). Although the territorial dimension significantly impacts these groups, the subject's experiences must be examined in the light of how broader urban social institutions intersect with their lives. The context of the city and how it is shaped by different state and non-state actors is crucial for this study. We wish to see through fieldwork how these individuals actively produce space and construct a sense of place, altogether redefining what is meant by the 'urban experience' in cities of the global south.

Using urban ethnography, the first author interviewed 14 street vendors from two prime vending zones in Kolkata—Tollygunge in South Kolkata and College Street in North Kolkata. This fieldwork was conducted in January 2022–February 2022. Another rich data source was the Calcutta Hawker Sangram Committee (HSC), a union of more than 70 local hawkers' associations. Alongside this, the first author spoke to the Calcutta Street Hawker's Union members, which is affiliated to the Centre of Indian Trade Unions (CITU). The interviews were mostly kept unstructured so that respondents could freely express their thoughts and opinions. Respondents were selected based on snowball sampling. A snowball sample is built from subjects who are suggested by previous subjects (Baker 1994). In this way, it is possible to accumulate the names of other people who have the qualities we seek for the work. However, using this method can create difficulty in having an equal representation of men, women, young people and the elderly, which could prove to be one of the limitations of this approach in the long run. This issue can be addressed by a longitudinal approach—repeated visits and protracted involvement with the field actors.

Street Vendors and Articulations Around Urban Environment in Selected Areas of Kolkata

In June 2016, in the Baruipur area, the Railway Protection Force (RPF) was reported to evict several hawkers with 'illegal' shops in and around the station premises. Hindu, a popular Indian daily, reported,[2]

> Protests erupted in the morning when RPF personnel reached the spot. Soon after the eviction started, approximately 1,000 hawkers owing allegiance to the Indian National Trinamool Trade Union Congress (INTTUC), the labour wing of the Trinamool Congress, gathered at the spot. "Things took a violent turn when a Railway official was thrown down to the ground and assaulted allegedly by the protesters".

In 2017, there was a similar eviction drive in the Salt Lake area, where 3000 odd hawkers were evicted from footpaths due to the FIFA U-17 World Cup. However, due to a lack of cooperation from the local MLA, the mayor of Bidhannagar Municipal Corporation was unable to hold back the hawkers for a long time, and they eventually returned.[3] Sometime later in 2021, during the COVID-19 pandemic, there was a mass eviction of hawkers from Kalakar street for systematic traffic movement in the Burrabazar area. As reported by Times of India (TOI), 'the idea is to reclaim the

[2] https://www.thehindu.com/news/cities/kolkata/Hawker-eviction-drive-turns-violent-in-Kolkata/article14384662.ece.

[3] https://www.telegraphindia.com/west-bengal/hawkers-back-in-business-in-salt-lake/cid/1692874.

footpath for pedestrians. This will allow more road space for the traffic. However, it will be a long-term plan and will need some time to be fully executed'.[4]

In one of the interviews with the Hawker Sangram Committee (HSC), one of their grassroots leaders highlighted that,

> Many newspapers, especially the Ananda Bazaar Patrika wrote about how consuming street food is unsafe and unhygienic….that there would be food poisoning, cholera, and typhoid since the food is cooked beside the roads where there is dirt and pollution. So they would use pictures to scare people…so that they do not come to our stalls.

This interview shows us how the middle class, with their representation in media, can effectively use the newspaper to bring about the changes they desire. Baviskar (2018) correctly points out that the power to frame something as a problem, and in this case, a 'health and hygiene concern' does not lie with the marginalised since both social and cultural capital are required to articulate and legitimise something as a 'problem'. This particular way of the middle class helps them avoid a direct confrontation and is more subtle and insidious in nature. While the urban populations of the informal sector organise themselves through what Chatterjee (2004) calls the 'political society', the urban elite take the apolitical route of civil society (Chatterji and Roy 2016).

Evictions of street vendors from numerous such streets of Kolkata have been reasonably frequent. On a particular day, during the commencement of the fieldwork, the first author on her way back, sat down to have some lemon tea, and started talking with the vendor casually. It was a spontaneous conversation, and he wanted to remain anonymous after knowing about the research. He mentioned that he might be the oldest hawker on that footpath right now by profession. However, the very stall was not there initially.

> You must have heard of *Sulabh Apartments* – I used to have my stall there. One day, we heard that the roads were being remade and there would be concrete pavements for that apartment complex. For that reason, I was evicted. There was no one to help me and I moved because I had to move. After that I came here, now my stall is shabby and small – nothing compared to what I had. During the pandemic – I was not able to give my payments here for three months - then the union people cut the black plastic sheets above my head and took the small stools. The protectors often prey on us ('*Jara rokhok tarai toh bhokhok*'). I'm not afraid to talk about these union folks like others. This is a slow and painful torture for me ('*Eta ke na ami ekta slow otyachar mone kori*'). It is not that one day I will come and find that my stall has disappeared - rather little by little, items will go missing, my stall will be vandalised and then I will be either forced to pay up or leave the area. Also, these sheets and stools are quite expensive and only I know how I can still be able to make ends meet. None of my family members have studied that much – out of them one is a 'neuro patient' whose treatment had to be stopped due to lack of funds. During the Amphan cyclone, I got no ration or money. Some people here got money or gas cylinder for cooking. But I did not get anything. Therefore, I believe that compared to the other vendors here - I am quite weak because I do not have much power ('*Ami nijeke komjor mone kori*').

[4] https://timesofindia.indiatimes.com/city/kolkata/cops-on-hawker-eviction-drive-at-kalakarstreet/articleshow/86149610.cms.

Interviews like these expose the realities behind the neat articulations of conflict that presumably exist within the larger discourses of informality. A large part of these ‘street rumblings’, as Chatterjee (2004) writes, are evocations of mass politics operating outside the ‘formal legal institutions of the state’ (ibid.). In another instance, the first author interviewed another vendor having a family of three who has been vending since 1996 and is a registered member of the local vending union. When asked about governmental assistance, he mentioned that they are getting ration for free, and sometimes the union would give some rice and potatoes. Once the government promised them 2000 rupees—while some people did receive the amount, the majority did not. During the pandemic, as he mentioned, he subsisted by borrowing money or loaning money. He said,

> We have to eat. My daughter’s school fees also had to be paid. We borrowed money from our relative but are paying our dues back slowly.

He mentioned that vending spaces in these areas could only be established with the Union’s permission. They must write a letter and then acquire permission and then can one set up a stall in that area. He said earlier, during the 1990s, vendors like him faced regular eviction. ‘*Police would come at night and we would have to pack all our stuff and take everything back with us. Now it is not there’*.

When asked about any complaints that they might have received regarding encroachment of public space, the respondent mentioned,

> See this footpath may be a public space but we maintain it very well. There is a good distance between our stalls and the pedestrians. Like in Gariahat and Kudhghat – they don’t do it very well. They occupy too much space. But we can balance it well. We leave a lot of space in between for people to walk in.

During a discussion about the instances of road-widening and hawkers’ evictions from the footpaths of Kolkata, he said,

> We can’t say for sure what will happen then. The government will talk with the unions before they make such a move. Whatever negotiations they make – we will not be able to know. But if they remove my stall from here – My world will drown (‘*Amar Shongshar ta bheshe jabe’)* I have been here all my life. I am 50+. I cannot do anything – I can’t cycle – since with age our ability for physical labour also goes away…after all.
>
> If the government wants to keep a beautiful and clean environment in the city, they have to keep us in that environment too. (‘*Shob kichu rekhe cholte hobe kintu’*)
>
> I do not understand the concept of ruining someone’s life and livelihood for city beautification. Who will be left to see your beautiful city if you evict so many people? (‘*Karor shonshar nosto kore poribesh sundor korata ami bujhina. Ei je eto lok ke tule diye shohor je sundor korcho – tahole dekhbe kara?’*)
>
> These people are now coming and buying things- after this extended lockdown – they are chatting, having tea & cigarettes, some people are having egg roll & chowmein. If beautification happens – all these things will disappear. There will only be bright lights – but this crowd will not be there– people will get robbed – things will get stolen. (‘*Light jolbe shudhu ar kebol Churi Chintai barbe’*.)
>
> Keep everyone and make the city beautiful. (‘*Shobai ke rekhe sundor koro*’.)

Feelings of uncertainty, insecurity and marginalisation in otherwise spectacular cities are often dealt with through constant political negotiations around the claims towards space. The respondent also echoes the words of Jane Jacobs (2015) where she highlighted how sidewalks perform many other functions besides carrying pedestrians. She believed that lively streets make a city attractive—the 'eyes on the street' creates safe spaces, especially for women and children. On the other hand, the problem is most serious, in fact, in genteel-looking 'quiet residential areas' (Jacobs 2015).

A hawker who sells readymade garments in Bhawanipore mentioned that he has been in this profession for 40 years. During the pandemic lockdown COVID-19 lockdown, he had to close his business. He said, '*They were not letting us open our shops. In the beginning, we were trying to sell masks and then we were harassed. The police seized all the items we were selling. We got little help from our unions, but that's about it. We had no money*'. He adds:

> This has been happening from a long time back. For example, in Harish Mukherjee Road near PG Hospital, we were given no notice and then forced to leave one day. When the West Bengal Government first came to power, within one year, the then- Chief Minister came and stood in front of Gokhale Memorial and threatened the hawkers by saying that with his power, if he wished to clean up the streets, it would take him just a day to do so. ('*Ami Bagher bacha, proyojon mone korle ek din e puro rasta saf kore dite pari!*') Then we protested by *Gherao*– you will find this in the papers. We did win that battle which is why you will still find hawkers in that area.

The first author asked him to elaborate on his idea of the environment, and he responded:

> By this, we mean our surroundings. We want to be free from the smoke of cars and factories – this is what we want in our environment. In Kalighat, there is a *shoshan* (crematorium), and smoke comes from there. I grew up in Bhawanipore & at night when we were growing up – we used to live in an area where we used to get that smell all night – of dead bodies being cremated.

A 50-year-old stationary vendor whose tea stall is located in the locality of Jubilee Park, Tollygunge, said that he had recently shifted to this profession, and he is the first in his family to become a hawker. He supports a family of four by selling grocery items, tea, tiffin and cigarettes in his shop. When asked, whether the police had ever come and caused trouble for him, he replied, 'there were obstacles—but those were created by the people who lived here—not the police'. He was hesitant to talk about which residents had harassed him when he was putting up his stall and informed that he cannot disclose or take names as it might create problems for him. For him, 'public' means '*sarkarer*' (it belongs to the government) and a place is private if it is rented to someone. It must be mentioned here that this seemed to be the dominant notion in most of the interviews. A 36-year-old vegetable vendor who was having tea at his stall joined the discussion enthusiastically, and he said,

> This tea stall we are sitting at is a public place, and what is inside that building (pointing to an apartment nearby) is private.

He added that he was allowed to sell his vegetables near the pavement of a massive apartment complex in that area but was never allowed to enter through its gate. It was challenging to figure out who permitted the tea stall owner to put up his shop in that locality since he mentioned that he had no union registration. Although he was unwilling to take anyone's name, the residents of that area did not shy away from mentioning that his stall was put up by some local 'dada' of the All-India Trinamool Congress party. On being asked what he understood by the word 'environment'—he said that he believed that the environment is something that is associated with the feelings of good or bad—like '*bhalo poribesh'* (good environment) or '*kharap poribesh'* (bad environment). Before leaving, he mentioned that he received many threats while setting up the stall and that now things are better—but in the future, he could be evicted—and he could not say with certainty that he was out of danger.

Discussions

While many of the interviews speak about the competing environmental agendas, where we see many of the street vendors understand city environments as a part of their everyday lives, most of them, even when licenced, speak about everyday challenges like workplace insecurity, harassment, confiscation of merchandise and assets (Roever and Skinner 2016, p. 359). However, analysing these interviews was a particularly fascinating composition of the 'everydayness' of their struggles amidst cities in their progress for 'worlding' and environmental order. These struggles, while not exclusionary, are constituted by dominant political explanations—supplication and patron-clientelism are critical and integral ingredients of their powerful strategies to roll back wide-scale evictions and harassments, as many mentioned upfront. A locally powerful nexus of authorities and predominant political patronage networks integrally linked to electorally driven mandates draw together broader approaches to understand the plight of informality and their positions in the growing megacities of India (Roever and Skinner 2016, pp. 364–365). In a fascinating article, Cuvi (2016) writes about the case of the survival of street vendors of Sao Paulo as an 'informal constituency' (p. 396)—how the street vendors earn 'tolerances' or 'forbearance' by paying bribes to street-level officials as well as to certain mid-ranking administrators and how in other cases they resort to supporting local candidates with votes and rallies during electoral campaigns (p. 398).

Regarding environmental questions, most cases of environmental restoration targeted spectacular pedestrian experiences in the cities of Kolkata and were achieved through cleaning the visible nuisance sights, like those of pavement dwellings and street vendors. However, a hierarchy also prevents all hawkers from having equal access to green and open spaces. Due to multiple redevelopment projects and gentrification, street trees are seen getting enclosed within the walls of private property—spaces that were once preferred and used by vendors. As a result, trees have become a rare and private resource, and those with power can access them more easily. This also tells us that urban redevelopment always has winners and losers (Banks et al. 2020).

Our goal was to understand how the city's middle-class citizens and hawkers are drawn together on questions on the environment, the impacts of such environmental concerns and what would count as 'environment' for different classes within the city. We must rethink who the 'urban and civic public' are and how they lay claims to city spaces. Through our study, we can derive that what comes under regulation concerning the hawkers is the 'spatial' aspect and not the trade aspect (Bandyopadhyay 2015). It is not the profession, but the public space that one settles down on that becomes the object of contestation. It needs to be mentioned here that the word 'public' does not have a literal translation in Bengali, as many interviews suggest. The most important concept that the middle-class elites learned from the British was the distinction between the public and private (Kaviraj 1997). The distinction that the Bengali community was familiar with was that of Ghare/Baire which was the 'home' and 'the outside'. Social space was thus used to map inside/outside and the public/private. However, in the minds of the poor, as the interviews show, anything that was not private was 'public'. This meant that places from where they could not be evicted by somebody's right to property could potentially become public spaces, where they could settle in. However, it needs to be acknowledged that beyond the political battles of the informal workers against the elite-driven evictions, the formal economy and the growing middle and upper-middle class need the informal sector. Multiple street food stalls around the '*office para*' (neighbourhoods of various offices) in Kolkata and roadside shops of consumer goods pull in a large segment of the demand from the domain of the seemingly 'informal', catering to the middle class itself. Schindler (2014a, b) explains how the poor help enable Delhi's transformation into a world-class city. In fact, the new middle class needs the informal service sector (ISS) to sustain their affluent lifestyles. In this way, the urban poor have been pulled into the ISS as drivers, security guards and maids so that the middle class can exhibit their economic capital and affirm their class membership.

Similarly, Parthasarathy's work (2017) demonstrates how global flows of capital and economic shifts may give marginalised people new opportunities that could have emancipatory or empowering implications on them. For instance, business process outsourcing (BPO) and software firms, where the majority of employees work at night and serve clients in various time zones, have opened up new avenues for street vendors. The street vendors now modify their timings to provide services at particular hours according to the changing demands. According to him, 'new vendors and hawkers are gaining economic opportunities as the 'time–space compression' at a global level may lead to a 'time–space expansion' locally. (Parthasarathy 2017, p.44)'.

Conclusions

To sum up, this chapter helped us to re-examine politics as an agency and dimension in spaces where environmental claims around urban public spaces are evidently exclusionary. In several instances of city beautification, a technical aestheticised focus on urban greening has undermined local community livelihoods (Sen et al. 2021, pp. 120–121). Related to this is the imagination of a relatively homogenous urban community possessing shared aspirations and interests, which needs a reversal. Urban communities in the global south are far more heterogeneous and discourses around rights to the urban environment require engagement with these ideas of complexity, disparity, inequity and power imbalance.

References

Anjaria JS (2009) Guardians of the Bourgeois city: citizenship, public space, and middle-class activism in Mumbai. City Community 8(4):391–406

Baker TL (1994) Doing social research. McGraw Hill Inc, New York

Bandyopadhyay R (2011) Politics of archiving: Hawkers and pavement dwellers in Calcutta. Dialect Anthropol 35(3):295–316

Bandyopadhyay R (2015) Institutionalizing Informality: the Hawkers' question in post-colonial Calcutta. Mod Asian Stud 50(2):675–717

Banks N, Lombard M, Mitlin D (2020) Urban informality as a site of critical analysis. J Dev Stud 56(2):223–238

Basu S, Nagendra H (2020) The street as workspace: assessing street vendors' rights to trees in Hyderabad, India. Landscape Urban Plann 199:103818

Baviskar A (2011) Cows, cars and cycle-rickshaws: bourgeois environmentalists and the battle for Delhi's streets. In: Baviskar A, Ray R (eds) Elite and everyman: the cultural politics of the Indian middle classes. Routledge, London, pp 391–449

Baviskar A (2018) City limits. In: Lele S et al (eds) Rethinking environmentalism, pp 85–97, Strungmann Forum Reports. Bayat A (2000) From dangerous classes to quiet rebels' politics of the urban subaltern in the global south. Int Sociol 15(3):533–557

Bayat A (2000) From dangerous classes to quiet rebels' politics of the urban subaltern in the global south. Int Sociol 15(3):533–557

Bell K (2020) Working-class environmentalism: an agenda for a just and fair transition to sustainability. Springer Nature

Bhan G (2009) This is no longer the city I once knew. Evictions, the urban poor and the right to the city in millennial Delhi. Environ Urbanization 21(1):127–142

Birch E (2019) Informality as a way of life. In: Workshop of the Penn IUR series on urban informality. Institute for Urban Research, University of Pennsylvania, vol 24, pp 1–5

Bodnar J (2015) Reclaiming public space. Urban Stud 52(12):2090–2104

Brosius C (2010) India's middle class: new forms of urban leisure, consumption and prosperity. Routledge, New Delhi

Chatterjee P (2004) The politics of the governed: reflections on popular politics in most of the world. Columbia University Press

Chatterji T, Roy S (2016) From margin to mainstream: informal street vendors and local politics in Kolkata, India. L'espace Politique Revue En Ligne De Géographie Politique Et De Géopolitique 29:1–18

Crossa V (2009) Resisting the entrepreneurial city: street vendors' struggle in Mexico City's historic center. Int J Urban Reg Res 33(1):43–63
Cuvi J (2016) The politics of field destruction and the survival of Sao Paulo's street vendors. Soc Probl 63(3):395–412
Fernandes L, Heller P (2006) Hegemonic aspirations. Crit Asian Stud 38(4):495–522
Ghertner DA (2015) Rule by aesthetics: world-class city making in Delhi. Oxford University Press
Gieryn TF (2000) A space for place in sociology. Ann Rev Sociol 26(1):463–496
Harvey D (2006) The political economy of public space. Politics Public Space 17:34
Harvey D (2008) The right to the city. New Left Rev 53:23–40
Harvey D (2009) Social justice and the city. University of Georgia Press, Athens
Heynen N, Perkins HA, Roy P (2006) The political ecology of uneven urban green space: the impact of political economy on race and ethnicity in producing environmental inequality in Milwaukee. Urban Aff Rev 42(1):3–25
Imilan W, Marquez F (2019) Urban ethnography. In: Orum A (ed) The Wiley Blackwell encyclopedia of urban and regional studies. Wiley, New York, pp 1–15
Jackson P (1985) Urban ethnography. In: Progress in human geography, pp 157–176
Jacobs J (2015) The uses of sidewalks: safety. In: LeGates RT, Stout F (eds) The city reader. Routledge, pp 149–153
Kashwan PM, MacLean L, García-López GA (2019) Rethinking power and institutions in the shadows of neoliberalism: (an introduction to a special issue of world development). World Dev 120:133–146
Kaviraj S (1997) Filth and the public sphere: concepts and practices about space in Calcutta. Publ Cult 10(1):83–113
Marvasti AB (2004) Qualitative research in sociology. Sage Publications, London
Mawdsley E (2004) India's middle classes and the environment. Dev Chang 35(1):79–103
Onodugo VA, Ezeadichie NH, Onwuneme CA, Anosike AE (2016) The dilemma of managing the challenges of street vending in public spaces: the case of Enugu City, Nigeria. Cities 59:95–101
Pakalapati UV (2010) Hi-tech Hyderabad and the urban poor: reformed out of the system. In: Banerjee-Guha S (eds) Accumulation by dispossession-transformative cities in the new global order. Sage, New Delhi, pp 125–150
Parthasarathy D (2017) Global flows or rural–urban connections? Temporality, public spaces and heterotopias in globalising Mumbai. In: Social dynamics of the urban. Springer, New Delhi, pp 33–59
Robinson J (2002) Global and world cities: a view from off the map. Int J Urban Reg Res 26(3):531–554
Roever S, Skinner C (2016) Street vendors and cities. Environ Urban 48(2):359–374
Roy A (2005) Urban informality: toward an epistemology of planning. J Am Plann Assoc 71(2):147–158
Roy A (2009) The 21st-century metropolis: new geographies of theory. Reg Stud 43(6):819–830
Sahoo N (2016) A tale of three cities: India's exclusionary urbanisation. ORF Issue Brief 156(4)
Sanyal K (2007) Rethinking capitalist development: primitive accumulation, governmentality and post-colonial capitalism. Routledge, New Delhi
Schindler S (2014a) Producing and contesting the formal/informal divide: regulating street hawking in Delhi, India. Urban Stud 51(12):2596–2612
Schindler S (2014b) The making of "world-class" Delhi: relations between street hawkers and the new middle class. Antipode 46(2):557–573
Sen A, Nagendra H (2019) The role of environmental placemaking in shaping contemporary environmentalism and understanding land change. J Land Use Sci 14(4–6):410–424
Sen A, Unnikrishnan H, Nagendra H (2021) Restoration of urban water commons: navigating social-ecological fault lines and inequities. Special issue on 'Restoration For Whom, By Whom' (Edited by Marlène Elias, Deepa Joshi, Ruth Meinzen-Dick). Ecol Restoration 39(1&2):120–129

Shaw A, Colombijn F (2009) Introduction—decolonization and urban change in the Asian City1. Urban Geogr 30(8):809–814
Veron R (2006) Remaking urban environments: the political ecology of air pollution in Delhi. Environ Plan 38:2093–2109
Xue D, Huang G (2015) Informality and the state's ambivalence in the regulation of street vending in transforming Guangzhou, China. Geoforum 62:156–165

Chapter 8
Polycentric Urbanism and the Growth of New Economic Hubs in Mumbai, India

Sujayita Bhattacharjee and Madhuri Sharma

Abstract Polycentric urban growth has become a common feature of most urban spaces in post-Fordist times. Cities that were originally monocentric have adopted polycentric patterns of urban growth, which have been largely fuelled by economic decentralisation and globalisation of centres of production and consumption, with far looser connections to the central business districts (CBDs). Especially since the 1990s, as the developing economies have gradually integrated into the globalised free market, several developing-world cities have also transitioned into polycentric functionalities. Mumbai, the financial capital of India, was fast to transition due to its economic functionality along with the central business districts becoming enormously unaffordable for the middle class. Nariman Point, Mumbai's once-hyped CBD, has now been eclipsed by the newly emerging economic hubs in the suburbia—transitioning the metropolis into a world-class polycentric entity. This has changed the concentration of economic and commercial activities across Mumbai, thereby influencing its housing patterns and commute behaviour. This study explores Mumbai's history of transition from a monocentric to a polycentric existence and compares the declining functionality of its original CBD with the newly emerging economic growth centres. Our data comprises secondary sources, along with personal reconnaissance and lived-in histories and observations during field surveys that were employed to acquire better insights into the nature of economic and business operations in Mumbai. Through the employment of descriptive qualitative and textual analysis, we find the increasing role of newly developing polycentric-urban centres and their influence on the changing residential and urban communities of Mumbai.

Keywords Post-Fordist · Monocentric · Polycentric · Globalisation · Economic decentralisation · Central business district · Mumbai

---

S. Bhattacharjee
Post-Doctoral Candidate, International Institute for Population Sciences (IIPS), Mumbai, Maharashtra, India
e-mail: sujayita100@gmail.com

M. Sharma (✉)
Department of Geography and Sustainability, University of Tennessee, Knoxville, TN, USA
e-mail: msharma3@utk.edu

U. Chatterjee et al. (eds.), *Urban Commons, Future Smart Cities and Sustainability*, Springer Geography, https://doi.org/10.1007/978-3-031-24767-5_8

Introduction

Polycentricity is a crucial aspect of urban-spatial structure (Wu et al. 2021). Since spatial configurations exert a significant influence on the nature of development that takes place in an area (Zhuo and Liu 2020), studies on polycentricity have gained considerable significance in recent times. Metropolitan regions appear to be transitioning to polycentric systems, in which urban operations are dispersed among a number of (sub)centres (Van Criekingen et al. 2007). Cities today are transitioning towards polycentricity either as an outcome of planned initiative or because of the unprecedented urban growth, largely driven by the post-Fordist economy, that has stretched cities far and wide.

Polycentric urban growth is not only reconfiguring cities around the world; instead, its transformation of the intra-metropolitan geographies of economic activities is no less dramatic' (Van Criekingen et al. 2007). Polycentric urban forms have come to be viewed as a means of addressing growing urban problems such as traffic, congestion, pollution and shortage of affordable housing, as well as contributing to the environmental and social sustainability of urban development (Liu and Liu 2018). In the organisation of urban systems, the notion of polycentricity addresses the existence of numerous functional centres and widespread links between them (Khiali-Miab et al. 2019). Meijers (2007) attributes the benefits of polycentricity to the synergistic linkages that exist between the urban centres of a metropolitan area. Several monocentric cities of the developing world have been noted to have transitioned towards polycentricity (Salvati et al. 2016; Burger et al. 2013). Van Criekingen et al. (2007) note that the economies of agglomeration earlier concentrated in the central business districts (CBDs) of the monocentric cities have expanded and diversified beyond the city cores to areas further beyond in suburbia and exurbia. This is evident in the case of Mumbai, where polycentric growth has given rise to many economic hubs far away from the original CBD. This chapter delves into the transition of Mumbai from a monocentric character to a polycentric existence and the emergence of new economic hubs. The polycentric characteristics acquired by Mumbai in recent times are evaluated through the lens of urban theory to make empirical observations on the emerging urban-spatial patterns.

Literature Review

Polycentricity is a dynamic concept used for defining and describing spatial extent from diverse perspectives (Kwon and Seo 2018; Liu and Liu 2018; Liu et al. 2017; Taylor 2008). The notion of polycentric growth is preceded by the idea of monocentric growth from which cities move towards polycentricity. Sat (2018) notes that the monocentric city, first proposed by Alonso in 1964, is based mostly on the principles of Burgess and Park's 'concentric zone theory'. The morphology of a city, as per the concentric zone theory of Burgess forwarded in 1925, is characterised by certain functionally distinct zones, which together form some concentric rings, namely the CBD, the zone of transition, the working-class zone, the residential zone and the commuter zone (Sat 2018). This theory positively correlated the socio-economic status of households with the distance from the CBD, eventually the better off being settled in farther zones intermixing with the host society. Extending Burgess's theory further, Hoyt propounded the sectoral theory in 1939, which classified the structure of cities into five basic sections—Sector 1: a CBD, Sector 2: high-income housing, Sector 3: middle-income housing, Sector 4: low-income housing and Sector 5: a wholesale sector (Bruyns 2018). The concentric zone theory stresses on the demand-side mechanisms while the sectoral theory emphasises on the supply-side mechanisms (Pacione 2009). Both the theories were over-simplistic in their conceptualisation of urban structure. This problem was addressed by Harris and Ullman's multiple nuclei theory in 1945, where they emphasised that most major cities developed through the gradual merger of a number of independent nuclei, rather than growing around a single CBD (Pacione 2009). It states that when a city expands and grows, its CBD may not be able to meet the needs of the new areas, resulting in the creation of new nuclei as Secondary Business Districts (SBDs) to meet the needs of these new areas (Ross et al. 2000). Thus, the multiple nuclei theory basically emphasises the polycentric growth of urban centres that are dispersed across a typical metropolitan area with different functions and features.

By the mid-twentieth century, however, as information and communication technology advanced, employment opportunities in CBDs began to dwindle and disperse to newly emergent growth centres beyond the CBD (Borsdorf et al. 2016; Sat 2018). Thus, the monocentric existence of cities with a single employment centre was challenged by the emergence of multiple employment subcentres as a part of the transformation to a polycentric urban form (Mcmillen and Mcdonald 1998; Glaeser 2001; Liu and Liu 2018). This is often explained from the view of new urban economic theory, which contends that the struggle between 'agglomeration economies' and 'agglomeration diseconomies' drives the emergence of employment subcentres (Richardson 1995; White 1990; Liu and Liu 2018). Abozeid and AboElatta (2021) note that polycentricity in the literature encompasses two major sets of explanations—morphological and functional. Morphological polycentricity takes into account the aspects of population and employment for describing the spatial distribution of cities (Beckmann 1958; Parr 2004; Liu and Liu 2018; Wu et al. 2021), whereas functional polycentricity takes into account the interaction between places in terms of people, goods and information flows based on knowledge (van der Laan 1998; Limtanakool et al. 2007; Liu and Liu 2018; Wu et al. 2021).

Based on these theoretical underpinnings, various studies on polycentricity have been carried out in different parts of the world. The earlier studies on polycentricity mostly focused on the urban areas of the developed world (Kunzmann and Wegener 1991; Bovaird 1993; Hall 1993; McDonald and Prather 1994; Song 1994; Suarez-Villa and Walrod 1997). Along similar lines, Kloosterman and Musterd (2001) termed polycentricity as a defining feature of urban scapes in the developed economies. However, with the fast urbanisation in the global south, the academic attention on polycentric urbanism in the developing world has gained attention. Recent urban literature focused on polycentric urbanism in the developing world have discussed it from varying perspectives (Rocco 2006; Wang 2020; Suárez and Delgado 2009; Sinclair-Smith 2014; Liu and Liu 2018; Yang et al. 2019). Some attempts at studying polycentric urban growth in India have been (van Duijne and Nijman 2019; Kumar et al. 2021), however, limited in number and their scope and coverage, making it necessary to add more work through deeper exploration on the emerging aspects of polycentricity in the urban areas of a developing economy as that of India.

Materials and Methods

The Study Area

The study area is the metropolis of Mumbai, located in the state of Maharashtra in India. Until 1500, Mumbai (earlier known as Bombay) existed as a small fishing hamlet, but its fate began to change after the East India Company received its procession in 1668 (Census of India 2011a, b, c). Bombay grew as a trade centre under the British rule. Ashcroft (2011) terms Bombay as an 'invention of colonialism'. Although Mumbai today stands mostly as a continuous landmass, it originally existed as an archipelago of seven islands, namely the isles of Bombay, Colaba, Old Woman's Island, Worli, Parel, Mahim and Mazagaon. Prior to their reclamation, these islands existed as inconspicuous rocky outcrops disconnected from one another by shallow, swampy creeks during low tide (Lentin 2021). The present configuration of Mumbai is an outcome of a series of reclamation schemes. Initially, an island city, Mumbai's growth and expansion led to its northward (suburban) growth. Today the island city area, also known as South Mumbai, exists as the core of the metropolis, but the city has spread far and wide encompassing the southern half of the Salsette Island. Administratively, present Mumbai (city and suburbs) comprises of two districts, namely the Mumbai City District and the Mumbai Suburban District, which fall under the jurisdiction of the Municipal Corporation of Greater Mumbai (MCGM). Mumbai lies at the heart of the Mumbai Metropolitan Region (MMR).

Data and Research Instruments

Data for this study is collected from secondary sources such as books, journals, news articles, government documents and property web portals. Along with this, personal reconnaissance, and lived-in histories, as well as observations made during field surveys were used to gain a deeper understanding of the nature of Mumbai's economic and business operations. We employ a mix of textual analysis along with other secondary sources, coupled with personal reconnaissance to make sense of the place and its economic integration through the transitioning of Mumbai. Thus, our research design in this study is primarily descriptive qualitative research—a well-known research paradigm that has been regarded as vital and suitable for research endeavours that are aimed at determining *who, what* and *where* of events or experiences, as well as gathering insights about a poorly understood phenomenon (Kim et al. 2017) (Fig. 8.1).

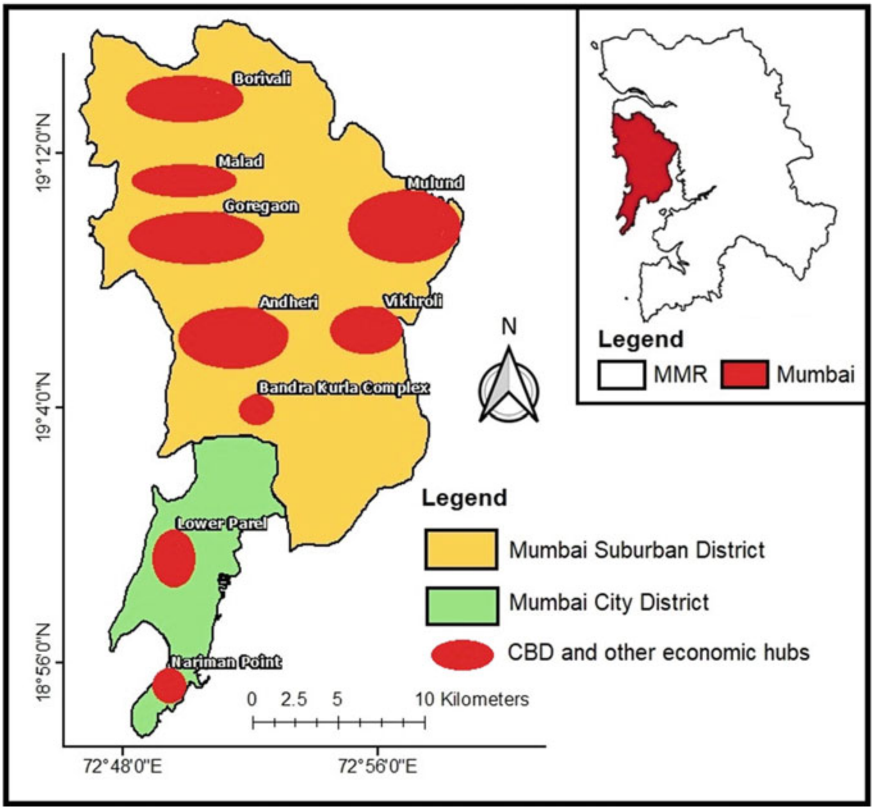


Fig. 8.1 Study area (*Source* Prepared using QGIS 3.22 software)

Results and Discussion

Mumbai's Transition from a Monocentric to a Polycentric Paradigm

Over the last century, the internal geographies of cities all over the globe have changed drastically, with classic monocentric concentrations being replaced by a range of decentralised configurations (Goswami and Lall 2019). Mumbai, the financial capital of India, too has witnessed its fair share of changes, which led to its establishment as a polycentric metropolis, both in terms of urbanisation and economic functions and business practices. One of the most significant changes in this regard was the restructuring of Mumbai's economy at the dawn of the neoliberal era. Following liberalisation, the original central business district (CBD) of Mumbai began to relinquish its grip on its business and commercial operations, allowing various other business hubs to emerge. Pradhan (2009) notes that the CBD is the economic core of a city. It acts as the nucleus or downtown of an urban area containing the main concentration of commercial land, with the highest percentage of retail shops, offices and services such as banking and finance (McColl 2014).

Nariman Point, located in South Mumbai on a plot of land reclaimed from the sea Back Bay, emerged as the CBD of Mumbai prior to the economic liberalisation in the 1990s. Pendleton (2014) terms it as India's first CBD and the financial heart of Mumbai. However, Nariman Point was not the first business hub of Mumbai. The earliest business centre of Mumbai was Ballard Estate (during late eighteenth and early nineteenth centuries), followed by the rise of the Fort area as a business hub (in the mid-nineteenth century), and as the city kept growing, Nariman point was developed (in the 1970s) to accommodate small businesses and establishments (Padmanabhan 2012). Nariman Point continued to function as the main centre of business and commerce in Mumbai until this monocentric pattern started getting challenged by its declining functionality. Although Nariman Point suffered from an inherent drawback of being surrounded by water bodies on its three sides, which strictly undermined its expansion, this issue didn't pose much concern until forces of globalisation started making impact.

When the policy of economic liberalisation was implemented in 1991, India became subject to global economic influences. According to Nijman (2011), things have begun to change since the early 1990s, when exceptional liberalisation measures aided the globalisation of the Indian economy. Mumbai, being a major economic centre, started witnessing an inflow of multinational corporations. Almost every major bank or corporation that entered India set up a liaison office at Nariman Point (Mumbai Mirror 2012). Massive employment opportunities arose in finance, ICT and services, among other fields, with spillover impacts in industries such as film, music and tourism (Clark and Moonen 2014). An ever-increasing struggle for space and higher rental values resulted from growing population and expanding businesses. Within half a decade from 1991, prices in the Nariman Point area increased four to six times of the previous levels (Nijman 2000, 2002). According to Deshpande and

Deshpande (2017), in 1990, the property price in Nariman Point was Rs. 3500/sq. ft, which rose to Rs. 29,500/sq. ft by 1995. Although this trend did not continue for too long, by June 1996, office rents had risen to more than twice the ongoing rate in Paris or Frankfurt and were far above the cost of office space in established high-cost centres such as New York, London, Tokyo or Hong Kong (Nijman 2000, 2002). Also, the prevalence of multiple ownership patterns in Nariman point complicated the functioning of the businesses (Padmanabhan 2012). Upon occupying even a single floor of a building in Nariman Point, companies were required to deal with multiple landlords, where one landlord would insist them on paying higher rent, while the other would ask them to vacate the building (Mumbai Mirror 2012). The replacement of the Bombay Rent Control Act of 1947 by the Maharashtra Rent Control Act of 2000 further complicated matters for Nariman Point. This meant the landlords were now required to pay taxes based on the value of their building leading to a 112% increase in property tax over the rent of these properties, and this made the landlords pass on this burden to the tenants (Mumbai Mirror 2012). Also, most of the buildings located in Nariman point were at least three decades old, with no new supply in the market, making these structures obsolete, especially for the newer economy corporates and multinational companies (Chadha 2012). Thus, Nariman Point started losing its value and significance as a business district. Consequently, most of the businesses and corporations that used to operate in Nariman Point started relocating to these emerging commercial hubs in mid-town Mumbai and the suburbs (Tandon 2015).

The Emergence of New Economic Hubs

Several economic centres have emerged in Mumbai. Some important ones among these centres include Bandra Kurla Complex (BKC), Lower Parel, Goregaon, Malad, Andheri, Vikhroli and Mulund. However, the growth of these economic hubs didn't happen only within Mumbai, but, also far beyond in other areas of the MMR, which have not been covered here, given the focus of this chapter on Mumbai. The emergence of the new economic hubs is associated with the suburban expansion of Mumbai and the growth of transport. The congestion of the island city led to suburban expansion. In 1951, the first Census India county after its independence, the total population of Mumbai District was 2,329,020, whereas this statistic for the Mumbai Suburban district was merely 665,424 people (Census of India 2011a, b, c). However, with the saturation of the population of the former and the accelerated growth of population in the latter, by 2011, the population in the Mumbai District stood at 3,085,411, whereas in the Mumbai Suburban District, population rose to 9,356,962 (Census of India 2011a, b, c) (Table 8.1).

The urban sprawl of Mumbai began profoundly in the 1970s, following the government's declaration of the policies of decongestion and deindustrialisation (Nallathiga 2007). Further, the formulation of the Development Control Regulation of 1991 set the development density on a parcel of land at an extremely low level, resulting

Table 8.1 Population growth in Mumbai city district and Mumbai Suburban District from 1951 to 2011

Census year	Mumbai City District			Mumbai Suburban District		
	Population	Decadal variation	Percentage decadal variation	Population	Decadal variation	Percentage decadal variation
1951	2,329,020	–	–	665,424	–	–
1961	2,771,933	442,913	19	1,380,123	714,699	107.4
1971	3,070,378	298,445	10.8	2,900,197	1,520,074	110.1
1981	3,285,040	214,662	7	4,958,365	2,058,168	71
1991	3,174,889	−110,151	−3.4	6,751,002	1,792,637	36.2
2001	3,338,031	163,142	5.1	8,640,419	1,889,417	28
2011	3,085,411	−252,620	−7.6	9,356,962	716,543	8.3

Source Census of India, District Census Handbook—Mumbai District and Mumbai Suburban District (2011)

in population dispersal, shifting of economic activities and urban sprawl along the transport corridors (Nallathiga 2007). In addition to this, The Mumbai Development Plan of 1991 was crucial in implementing key infrastructure projects aimed at decongesting the core and encouraging a transit-oriented development pattern (Bhatia 2014). With this, the road and rail network of Mumbai and its surrounding areas, that together comprise the MMR, has developed and strengthened much better in the recent times. Greater Mumbai's population share in MMR has decreased from 77% in 1971 to 63% in 2001, thus reducing its congestion, whereas MMR's total population share in Maharashtra has climbed from 15% in 1971–20% in 2001 (MMRDA 2003). Everyday commute to Mumbai from different areas of the MMR for work is a common trend, given the significantly improved transport connectivity in the region. All of these factors have collectively made Mumbai the choicest place to live and work for multi-generations.

Mumbai Suburban Railway serves as the lifeline of the city connecting Mumbai to many far-flung areas. More than 80% of the vehicular travels in the MMR are carried out on public buses and railway services, of which more than 50% of the public transport travels take place on railways (Varshney 2018). More than 7.34 million people across the MMR commute daily on the Mumbai Suburban Railways, from Church Gate to Virar (served by the western railway) and Chhatrapati Shivaji Terminus to Kasara, Khopoli and Panvel (served by the central railway) (MMRDA 2021). In addition, the construction of the arterial roads connecting Mumbai with its suburbs such as the Eastern Express Highway (connecting Mumbai and Thane), the Western Express Highway (connecting Mira Road to Bandra) and the Sion-Panvel Expressway (Connecting Panvel to Sion) have led to greater connectivity. Thus, railways and roadways have connected many distant areas of the MMR with the economic hubs of Mumbai (Fig. 8.2). Besides roads and railway network, the monorail and metro connectivity has also boosted mobility within Mumbai as well as with the MMR. A brief account on these new economic hubs of Mumbai is given below.

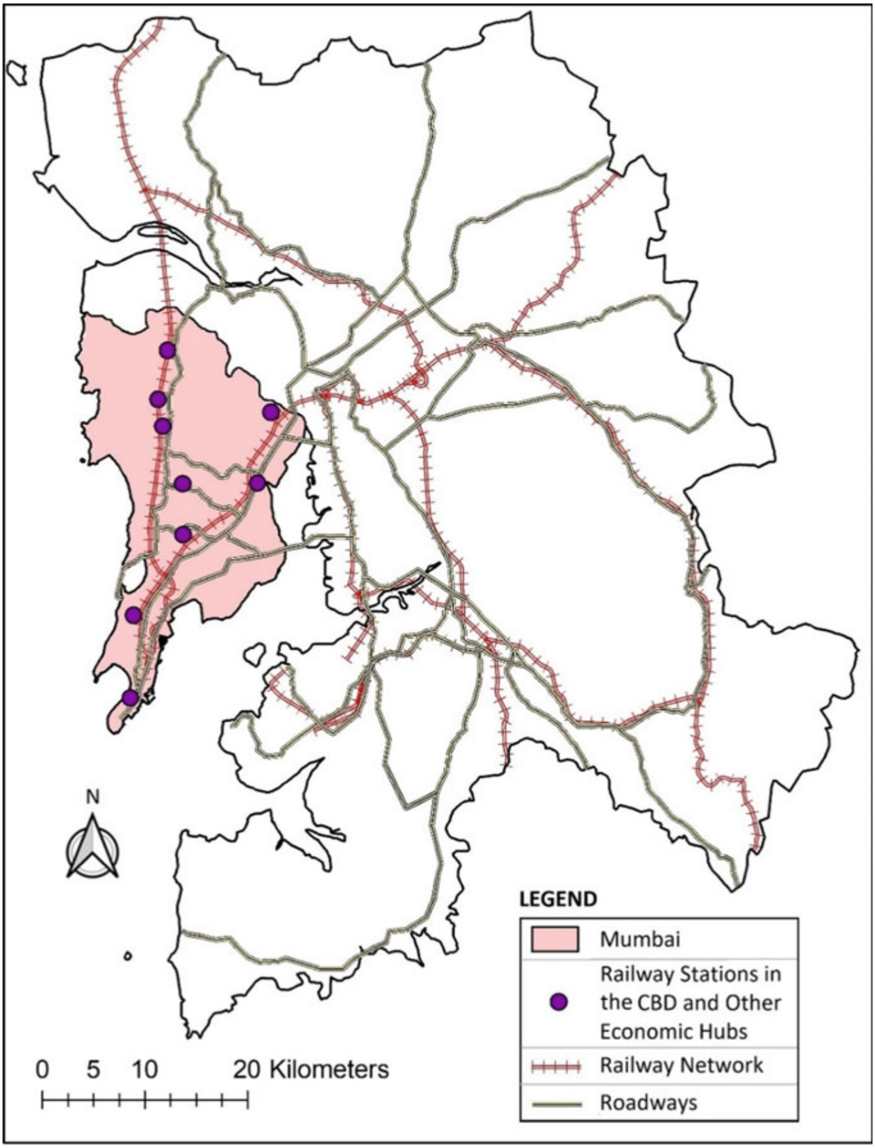


Fig. 8.2 Major roads and railway connectivity in MMR—connecting far-flung areas to the CBD and other economic hubs of Mumbai (*Source* Prepared using QGIS 3.22 software)

Bandra Kurla Complex (BKC) came to be planned as an alternative to the original CBD. For its planning and development, the Mumbai Metropolitan Region Development Authority (MMRDA) was charged with the Special Planning Authority in 1977 (MMRDA n.d.). BKC came to be developed on a strip of swamp land along the Mithi River between Bandra and Kurla. Prior to the economic liberalisation, not many companies were willing to locate to this area. However, by the dawn of the 1990s, the price of land in BKC progressively increased, with liberalisation changing its fortunes dramatically (Lewis 2018). As liberalisation and globalisation made the declining functionality value of Nariman Point apparent, companies gradually started moving out to other areas, especially the BKC. Thus, by the year 2009, BKC had established itself as the *de-facto* CBD of Mumbai (Mumbai Mirror 2012). BKC at present houses several Indian and International companies including Amazon, Reliance, Netflix, National Stock Exchange, SEBI, ICICI, GIA, Bank of America, Google, Edelweiss, Novartis, Kotak Bank and ONGC. Though BKC proved to be a viable alternative to Nariman Point, it was far from the only one. BKC is also not free from problems. It is known for the longer commuting hours, high real-estate prices and severe traffic issues in its vicinity. These have further contributed to the emergence of new economic hubs in Mumbai (Fig. 8.2).

Lower Parel used to be a prominent textile mill centre of Mumbai during the industrial phase. After deindustrialisation and liberalisation, it underwent a wave of transformation. The mill lands have been transformed into a plethora of high-end residential and commercial properties, including stylish hotels, great restaurants, entertainment and retail outlets (Lower Parel–Worli belt, an upmarket residential neighbourhood in South Central Mumbai 2020). The prime location of Lower Parel along with the availability of the vacant mill parcels served as a pull factor attracting real-estate developers to the area (Babar 2012). Its proximity to Nariman Point was another factor that contributed to its transformation. Tulsi Pipe Road and NM Joshi Marg, as well as the Mumbai Monorail and the Suburban Railway Line, connect Lower Parel with the rest of Mumbai. Currently, Lower Parel stands as a corporate hub, housing various domestic and international corporations. Peninsula Business Park, Peninsula Tower, the Empire Business Centre and One Indiabulls Centre are some of the office and business zones that have sprung up here. Also, several commercial spaces have emerged in the erstwhile mills located in the area. Such transformed mills include Raghuvanshi Mills Compound, Kamala Mills Compound Sun Mill Compound and Empire Mills.

Goregaon has seen a lot of commercialisation in the last several years (Goregaon—The Right Place to Invest In 2018). Goregaon's economic boom, combined with infrastructure improvement, has made it a sought-after Mumbai neighbourhood (Goregaon—The Right Place to Invest In 2018). It is connected to the residential and commercial areas of Mumbai through road and rail. The western express highway connects Goregaon to Andheri and BKC, while the Jogeshwari-Vikhroli Link Road connects it to upmarket areas of Powai and Vikhroli (Achary 2021). The improved connectivity of Goregaon has boosted the growth of its commercial real estate. Several office and business areas such as the Synergy Business Park, Vakratunda Corporate Park, IRIS Business Park, ACME Business Park, Orchard

Corporate Park, Mungekar Industrial Estate, Nigos Industrial Estate and Sainath Industrial Estate have emerged as the centres of economic activity in Goregaon.

Malad is located adjacent to Goregaon. It has witnessed immense growth in business and commerce in recent times. Its main office and business hubs are Lotus Business Park, DLH Park, Parth Business Plaza, Niman Industrial Estate, Sterling Industrial Estate, Orbit Industrial estate, Mehta Industrial Estate, Synergy Business Park, Paras Industrial Estate and Infinity IT Park. The western express highway and the suburban railway service provide it with ample connectivity, which has contributed to its economic growth.

Andheri has grown into a thriving commercial hub of Mumbai. Its proximity to the Eastern and Western Express Highways renders it great connectivity, as well as it also benefits immensely from its closeness to commercial hubs such as BKC and Lower Parel (Andheri: Rapidly Expanding Business District of Mumbai 2022). Also, through metro and train connections, it is well-connected to various areas of the Mumbai Metropolitan Region. The eastern half of Andheri has emerged as a prominent area for business and commerce with several MNCs functioning in Saki Naka, Mumbai Industrial Development Corporation (MIDC), and Santacruz Electronic and Export Promotion Zone (SEEPZ) (Sharma 2018). The western hub of Andheri, which began as a residential area, has steadily climbed the commercial real-estate ladder, aided by a combination of a favourable business climate, the mushrooming boom of the IT sector and a slew of infrastructural developments that have bode well for commercial real-estate growth in this well-functioning market (Why Andheri West is being preferred by commercial real-estate developers—Media Bulletins 2021). Andheri West has emerged as a centre for creative industries. Various film and TV studios, editing studios and production centres can be found here (Sharma 2018). Corporate preferences for large-sized office spaces and a constant increase in the number of companies opting for Andheri to centralise their activities have increased the area's potential for future commercial expansion (Why Andheri West is being preferred by commercial real-estate developers—Media Bulletins 2021). Several office and business hubs have come up across Andheri to accommodate the emerging office spaces and other commercial spaces in them. The major business parks of Andheri include Pinnacle Business Park, Dynasty Business Park, Prime Corporate Park, ATL Corporate Park, Elegant Business Park, Peninsula Business Park, IRIS Business Park and Neelkanth Corporate Park.

Vikhroli is another economic hub of Mumbai. The Eastern Express Highway, the Lal Bahadur Shastri Road and the suburban railway line connect it with the rest of the country. It has eased commuting to and from Vikhroli. Many organisations such as Accenture, WNS, TCS and others have flocked to the Godrej Business District, which offers over a million square feet of office space (Mumbai's emerging business hubs 2014). Multinationals and Indian companies with diverse requirements from sectors such as Information Technology and Consulting, Information Hospitality, Pharmaceutical, Consulting, Technology Enabled Services, Retail, Chemical, BFSI, Energy and Power, Engineering and others are among the clients at Godrej Business District (Godrej Real Estate | Godrej-Business-District n.d.). Nearby lies the HCC Real Estate-developed 247 Park, which has notable tenants such as Future Group, Tata Consulting Engineers, DHL and others (Mumbai's emerging business hubs 2014).

Mulund, with its business areas, office complexes and new-age retail stores, is effectively competing with the other economic hubs of Mumbai. Ecstasy Business Park, O2 Business Commercial Park, Nirmal Corporate Centre, 360 Degree Business Park and Avior Corporate Park are some of its important office and business areas. Mulund's ascent as a business hub began only in the late 1990s, and it has grown rapidly since then. Old factories were replaced by modern malls, multiplexes and towers as it expanded into a retail centre. Eventually, the service centre too found its way to Mulund, turning it into an economic hub. Its central location with the city of Thane in the north, Navi-Mumbai in the east and South Mumbai in the south made it suitable for the growth of business and commerce. Mulund has also witnessed improvement in rail and road connectivity in the recent times. The construction of the Lal Bahadur Shastri Road, Mulund-Airoli Link Road and Eastern Express Highway has rendered immense connectivity to Mulund (Kashyap 2014). Mulund has emerged as a favourable location for new businesses seeking to establish themselves. Mulund's commercial office space is popular among start-ups because of its lower rents.

Implications of the Polycentric Growth of Economic Hubs

The polycentric growth of economic hubs across Mumbai brought about several changes bearing both positive and negative connotations. These implications are as follows:

1. The growth of the new economic hubs has lowered the burden of the CBD. Advantages offered by the new economic hubs such as the availability of larger office premises at lower rent/price, lower travel time for employees, modern infrastructure with improved facilities and so on have given the companies enough reasons to look beyond the CBD while deciding from where to operate their business. For example, (a) as per a report published in the Deccan Chronicle (2017), the average floor plate size in the new economic hubs of Mumbai is around 22,000 sq. ft as compared to 12,000 sq. ft in the CBD; (b) the average price of commercial office space in Nariman Point stood at Rs. 35,180/sq. ft from October to December 2021, whereas, during the same period the average price of commercial office space in Mulund and Goregaon stood at Rs. 17,805/sq. ft and Rs. 16,894/sq. ft, respectively (Commercial Property Rates in Mumbai n.d.).
2. It has created the opportunity for organisations to select from multiple locations for operating their business. Start-ups venturing into the world of business are especially choosing from among the new economic hubs to set up their business due to their comparatively low property rates. Also, in recent years, several large corporations have relocated from the CBD to other economic hubs of Mumbai (Sinha 2017). For example, Bank of America recently relocated from Nariman Point to BKC (Sinha 2017).

3. As the growth of new economic hubs has contributed not only to the growth of commercial property in these localities, it has also led to continued growth in property prices. For instance, in Lower Parel, the average price of commercial office space was Rs. 14,409/sq. ft from October to December 2009, whereas, between October to December 2021, it increased to Rs. 25,243/sq. ft (Commercial Property Rates in Mumbai n.d.).
4. These new economic hubs with employment opportunities and improved connectivity are also attracting home buyers to these localities. This has given impetus to the growth of residential real estate in these areas as well as moving-in of people from different areas. For instance, in Goregaon, the average price of multi-storey apartments was Rs. 16,491/sq. ft from October to December 2017, whereas, by October to December 2021, it increased to Rs. 18,013/sq. ft (Residential Property Rates in Mumbai n.d.).
5. With the growth in business and commercial activities along with the moving-in of people, these economic hubs have witnessed a rise in the number of people residing there as well as people commuting to work on a daily basis. This has added to the traffic woes in most of these areas.
6. Sharma and Abhay (2022) have observed that the large urban centres in developing countries are overburdened because of unplanned and unsustainable rural–urban migration fuelled by urban economic hubs. Mumbai is no exception to this. The growth of the new economic hubs has opened up new opportunities for employment and has been playing a crucial role in attracting migrants to Mumbai from across India. This has contributed to the growing pressure of population in the area.
7. Mitra and Murayama (2009) and Sharma (2017) in their prior analysis of the National Capital of Delhi have discussed elaborately the pro-urban biases and how that impacts the quality of life of the rural–urban migrants, trying to make a living from various types of informal activities. The opportunities to engage in one or the other type of informal economy, while not enough to push the migrants out of poverty, is still a lifestyle that many such migrants have learned to live with. Mumbai is no exception as many people from all over the country simply want to live and make a life for themselves in Mumbai.

Conclusions and Recommendations

The discussion made so far reveals that the growing pace of economic activities under the impact of neoliberal forces preceded by the process of deindustrialisation marked the post-Fordist economic turn of Mumbai. It was the phase when MNCs started pouring into Mumbai and the space constraint in the existing CBD paved way for the polycentric growth of new economic hubs in Mumbai. There has been a noted increase in the prices of property, both commercial and residential in the suburban and polycentric locations over recent years. This has served well for those who already own a piece of land or property as this has ultimately added to their accumulation of wealth. This has also created a motivation for suburban and decentralised living wherein people can maintain better quality of lives with better quality of air and reduced burdens to land and natural resources.

Finally, we conclude that polycentric urban growth and development has been the most feasible way to accommodate the ever-expanding desires of humans, especially in the context of developing economies such as India, where the total urbanisation is still below 35%. At the same time, the pro-urban biases and the urban-centric economic investment and growth—a widely practiced policy by the Indian government (Mitra and Murayama 2009; Sharma 2017), is a natural booster to rural–urban migration, and the results so far from our textual analysis suggest that polycentric urbanisation is an ideal way to cope up with both—work and life balance—by providing decent life to all. In terms of our academic approaches to doing this analysis, while we have attempted to conduct a descriptive and textual analysis to complete this work, we are aware of its limitations. Given the fact that the Census 2021 has not yet been completed in India due to the unforeseen circumstances of the COVID-19 pandemic, we could not delve into time series or in-depth census-based analysis. The lack of availability of intra-ward data from other secondary sources is another limitation. Also, an empirical approach to studying the causes of urban expansion and economic growth would be an ideal way to add nuanced insights into these processes, and we hope to accomplish some of these in the recent future.

References

Abozeid ASM, AboElatta TA (2021) Polycentric vs monocentric urban structure contribution to national development. J Eng Appl Sci 68(11):1–18. https://doi.org/10.1186/s44147-021-00011-1

Achary N (2021) Malad-Goregaon has become the most sought after real estate destination. Business news this week. business news this week. Retrieved 19 Mar 2022, from http://businessnewsthisweek.com/business/malad-goregaon-has-become-the-most-sought-after-real-estate-destination/

Andheri: Rapidly Expanding Business District of Mumbai (2022) Navi Mumbai Houses. Retrieved 18 Mar 2022, from https://navimumbaihouses.com/blog/news/andheri-rapidly-expanding-business-district-of-mumbai/

Ashcroft B (2011) Urbanism, mobility and Bombay: reading the postcolonial city. J Postcolonial Writ 47(5):497–509. https://doi.org/10.1080/17449855.2011.614774

Babar K (2012) Mumbai's lower parel: one of the most coveted piece of real estate in the country's financial capital hard to sell. The Economic Times. Retrieved 10 Apr 2022, from https://economictimes.indiatimes.com/wealth/personal-finance-news/mumbais-lower-parel-one-of-the-most-coveted-piece-of-real-estate-in-the-countrys-financial-capital-hard-to-sell/articleshow/13066443.cms

Beckmann M (1958) City hierarchies and the distribution of city size. Econ Dev Cult Change 6(3):243–248. https://doi.org/10.1086/449769

Bhatia N (2014) Mumbai's eastern suburbs: infrastructure leads development. The Indian Express. Retrieved 9 Apr 2022, from https://indianexpress.com/article/india/india-others/mumbais-eastern-suburbs-infrastructure-leads-development/

Borsdorf A, Hildalgo R, Vidal-Koppmann S (2016) Social segregation and gated communities in Santiago de Chile and Buenos Aires. A comparison. Habitat Int 54:18–27. https://doi.org/10.1016/j.habitatint.2015.11.033

Bovaird T (1993) Analysing urban economic development. Urban Stud 30(4–5):631–658. https://doi.org/10.1080/00420989320081851
Bruyns G (2018) The social and the spatial, urban models as morphologies for a ‘Lived’ approach to planning. Cub J 1(1):52–73. https://doi.org/10.31182/cubic.2018.1.003
Burger M, Meijers E, Van Oort F (2013) Regional spatial structure and retail amenities in the Netherlands. Reg Stud 48(12):1972–1992. https://doi.org/10.1080/00343404.2013.783693
Census of India (2011a) District census handbook Mumbai, 8–10. Retrieved from https://censusindia.gov.in/2011census/dchb/2723_PART_B_DCHB_%20MUMBAI.pdf
Census of India (2011b) District census handbook Mumbai, 36. Retrieved from https://censusindia.gov.in/2011census/dchb/DCHB_A/27/2723_PART_A_DCHB_MUMBAI.pdf
Census of India (2011c) District census handbook Mumbai suburban, 33. Retrieved from https://www.censusindia.gov.in/2011census/dchb/DCHB_A/27/2722_PART_A_DCHB_MUMBAI%20SUBURBAN.pdf
Chadha S (2012) The slow but steady death of nariman point-business news. Firstpost. Retrieved 4 Mar 2022, from https://www.firstpost.com/business/economy/the-slow-but-steady-death-of-nariman-point-562877.html
Clark G, Mooney T (2014) Mumbai: India’s global city. Brookings JPMorgan Chase 1–32
Commercial Property Rates in Mumbai. Magicbricks. Retrieved 25 Mar 2022, from https://www.magicbricks.com/Property-Rates-Trends/ALL-COMMERCIAL-rates-in-Mumbai
Deccan Chronicle (2017) Secondary business districts winning the realty race. Retrieved 21 Feb 2022, from https://www.deccanchronicle.com/business/in-other-news/060717/secondary-business-districts-winning-the-realty-race.html
Deshpande S, Deshpande L (2017) Real estate market in Mumbai—a crawl to convergence. In: Segbers K, Raiser S, Volkmann K (eds) Public problems—private solutions? Globalizing cities in the south. Routledge, London, UK. https://doi.org/10.4324/9781351151009
Glaeser EL, Kahn ME (2001) Decentralized employment and the transformation of the American City; Nber Working Paper No. 8117; NBER: Cambridge, MA, USA, pp 1–63
Godrej Real Estate | Godrej-Business-District. Godrej.com. (n.d.) Retrieved 21 Mar 2022, from https://www.godrej.com/p/real-estate/Leasing/Godrej-Business-District
Goregaon—The Right Place to Invest In. Omkar.com. (2018) Retrieved 19 Mar 2022, from https://www.omkar.com/blogs/goregaon-right-place-to-invest
Goswami A, Lall S (2019) Jobs and land use within cities: a survey of theory, evidence, and policy. The World Bank Res Obs 34(2):198–238. https://doi.org/10.1093/wbro/lkz004
Hall P (1993) Forces shaping urban Europe. Urban Studies 30(6):883–898. https://doi.org/10.1080/00420989320080831
Kashyap N (2014) Mulund thrives on demand for housing and connectivity to Mumbai suburbs. Retrieved 30 Dec 2019, from https://www.99acres.com/articles/mulund-thrives-on-demand-for-housing-and-connectivity-to-mumbai-suburbs.html
Khiali-Miab A, van Strien MJ, Axhausen KW, Grêt-Regamey A (2019) Combining urban scaling and polycentricity to explain socio-economic status of urban regions. PLoS ONE 14(6):e0218022. https://doi.org/10.1371/journal.pone.0218022
Kim H, Sefcik JS, Bradway C (2017) Characteristics of qualitative descriptive studies: a systematic review. Res Nurs Health 40(1):23–42. https://doi.org/10.1002/nur.21768
Kloosterman R, Musterd S (2001) The polycentric urban region: towards a research Agenda. Urban Stud 38(4):623–633. https://doi.org/10.1080/00420980120035259
Kumar S, Ghosh S, Singh S (2021) Polycentric urban growth and identification of urban hot spots in Faridabad, the million-plus metropolitan city of Haryana, India: a zonal assessment using spatial metrics and GIS. Environ Dev Sustain 24(6):8246–8286. https://doi.org/10.1007/s10668-021-01782-6
Kunzmann KR, Wegener M (1991) The pattern of urbanization in Western Europe. Ekistics 58(350/351):282–291. http://www.jstor.org/stable/43646772
Kwon K, Seo M (2018) Does the polycentric urban region contribute to economic performance? The case of Korea. Sustainability 10(11):4157. https://doi.org/10.3390/su10114157

Lentin S (2021) Mercantile Bombay: a journey of trade, finance and enterprise. Taylor & Francis, India

Lewis C (2018) BKC: wasteland to landmark of Mumbai. The Times of India. Retrieved 1 Mar 2022, from https://timesofindia.indiatimes.com/city/mumbai/bkc-wasteland-to-landmark-of-mumbai/articleshow/66531407.cms

Limtanakool N, Dijst M, Schwanen TA (2007) Theoretical framework and methodology for characterising national urban systems on the basis of flows of people: empirical evidence for France and Germany. Urban Stud 44:2123–2145

Liu Z, Liu S (2018) Polycentric development and the role of urban polycentric planning in China's mega cities: an examination of Beijing's metropolitan area. Sustainability 10(5):1588. https://doi.org/10.3390/su10051588

Liu X, Derudder B, Wang M (2017b) Polycentric urban development in China: a multi-scale analysis. Environ Plann B: Urban Analyt City Sci 45(5):953–972. https://doi.org/10.1177/2399808317690155

Lower parel–worli belt, an upmarket residential neighbourhood in South Central Mumbai (2020) The economic times. Retrieved from https://economictimes.indiatimes.com/wealth/real-estate/lower-parelworli-belt-an-upmarket-residential-neighbourhood-in-south-central-mumbai/articleshow/74209970.cms

McColl R (2014) Encyclopedia of world geography, vol 1. Infobase Publishing, New York, p 159

McDonald JF, Prather PJ (1994) Suburban employment centres: the case of Chicago. Urban Stud 31(2):201–218. http://www.jstor.org/stable/43196088

Mcmillen DP, Mcdonald JF (1998) Suburban subcenters and employment density in metropolitan Chicago. J Urban Econ 43:157–180

Meijers E (2007) Synergy in polycentric urban regions: complementarity, organising capacity and critical mass. IOS Press, Sustainable Urban Areas, Delft

Mumbai Mirror (2012) Why Nariman point is running on empty. Retrieved 1 Mar 2022, from https://mumbaimirror.indiatimes.com/mumbai/other/why-nariman-point-is-running-on-empty/articleshow/17863545.cms

Mitra A, Murayama M (2009) Rural to urban migration: a district-level analysis for India. Int J Migr Health Soc Care. 5(2):35–52

MMRDA (2003) Population and employment profile of Mumbai metropolitan Region. Mumbai, 1–34

MMRDA (2021) Final regional plan for Mumbai metropolitan region, 1–197. Retrieved 1 Mar 2022, from http://shorturl.at/aCDP4

MMRDA (n.d.) Retrieved 1 Mar 2022, from https://mmrda.maharashtra.gov.in/development-of-bandra-kurla-complex

Mumbai's emerging business hubs. Business Today (2014) Retrieved 21 Mar 2022, from https://www.businesstoday.in/in-the-news/photo/mumbai-developing-business-hubs-4741-2014-05-09-1

Nallathiga R (2007) Compact city and smart growth as policy guiding models for achieving sustainable city development: the case for Mumbai metropolis. The ICFAI J Urban Pol 42–59

Nijman J (2000) Mumbai's real estate market in 1990s: de-regulation, global money and casino capitalism. Econom Polit Wkly 35(7):575–582. http://www.jstor.org/stable/4408936

Nijman J (2002) The effects of economic globalization: land use and land values in Mumbai, India. In: Grant R, Short J (eds) Globalization and the margins. International political economy series. Palgrave Macmillan, pp 150–169. Retrieved from https://doi.org/10.1057/9781403918482_10

Nijman J (2011) Mumbai as a global city: a theoretical essay. In: Derudder B, Hoyler M, Taylor P, Witlox F (eds) International handbook of globalization and world cities, vol 1. Edward Elgar Publishing Limited, pp 447–454

Pacione M (2009) Urban geography a global perspective, 3rd edn. Routledge, New York, p 143

Padmanabhan K (2012) Why Nariman Point is running on empty. Pune Mirror. Retrieved from https://punemirror.indiatimes.com/pune/cover-story/why-nariman-point-is-running-on-empty/articleshow/31507750.cms

Parr J (2004) The polycentric urban region: a closer inspection. Reg Stud 38(3):231–240. https://doi.org/10.1080/0034340042000211114

Pendleton D (2014) Jungle firestorm. Worldwide Library, p 222

Pradhan S (2009) Retailing management. McGraw-Hill Education (India), New Delhi, pp 168–169

Residential property rates in Mumbai. Magicbricks. Retrieved 3 Apr 2022, from https://www.magicbricks.com/Property-Rates-Trends/Multistorey-Apartment-rates-Goregaon-in-Mumbai

Richardson HW (1995) Economies and diseconomies of agglomeration. Springer, Berlin/Heidelberg, Germany

Rocco R (2006) Towards a polycentric metropolis. Global strategies and unequal development in São Paulo. Urbani Izziv 17(1–2):193–198. https://doi.org/10.5379/urbani-izziv-en-2006-17-01-02-005

Ross S, Morgan J, Heelas R (2000) Essential AS geography. S. Thornes, Cheltenham

Salvati L, Venanzoni G, Serra P, Carlucci M (2016) Scattered or polycentric? Untangling urban growth in three southern European metropolitan regions through exploratory spatial data analysis. Ann Reg Sci 57(1):1–29. https://doi.org/10.1007/s00168-016-0758-5

Sat N (2018) Polycentricity in a developing world: a micro-regional analysis for morphological polycentricity in Turkey. Geoscape 12(2):64–75. https://doi.org/10.2478/geosc-2018-0007

Sharma M, Abhay R (2022) Urban growth and quality of life: inter-district and intra-district analysis of housing in NCT-Delhi, 2001–2011–2020. GeoJournal. https://doi.org/10.1007/s10708-021-10570-8

Sharma M (2017) Quality of life of labor engaged in informal economy in the national capital territory of Delhi. India. Khoj: Int Peer Rev J Geogr 4:14–25. https://doi.org/10.5958/2455-6963.2017.00002.9

Sharma P (2018) Andheri: a prime residential and commercial hub in Mumbai | Housing News. Housing News. Retrieved 18 Mar 2022, from https://housing.com/news/andheri-prime-residential-commercial-hub-mumbai/

Sinclair-Smith K (2014) Polycentric development in the cape town city-region: empirical assessment and consideration of spatial policy implications. Dev South Afr 32(2):131–150. https://doi.org/10.1080/0376835x.2014.984378

Sinha A (2017) Move over central business districts. BW Businessworld. Retrieved 25 Mar 2022, from https://www.businessworld.in/article/Move-Over-Central-Business-Districts/17-07-2017-122283/.

Song S (1994) Modelling worker residence distribution in the Los Angeles region. Urban Stud 31(9):1533–1544. https://doi.org/10.1080/00420989420081411

Suárez M, Delgado J (2009) Is Mexico city polycentric? a trip attraction capacity approach. Urban Stud 46(10):2187–2211. https://doi.org/10.1177/0042098009339429

Suarez-Villa L, Walrod W (1997) The Donald Robertson memorial prizewinner 1997: operational strategy, R&D and intra-metropolitan clustering in a polycentric structure: the advanced electronics industries of the Los Angeles basin. Urban Stud 34(9):1343–1380. https://doi.org/10.1080/0042098975466

Tandon S (2015) Why rents for premium Mumbai office space are falling | The financial express. Financialexpress.com. Retrieved from https://www.financialexpress.com/economy/rents-for-premium-mumbai-office-space-come-off/116483/

Taylor P, Evans D, Pain K (2008) Application of the interlocking network model to Mega-City-Regions: measuring polycentricity within and beyond city-regions. Reg Stud 42(8):1079–1093. https://doi.org/10.1080/00343400701874214

Van Criekingen M, Bachmann M, Guisset C, Lennert M (2007) Towards polycentric cities. An investigation into the restructuring of intra-metropolitan spatial configurations in Europe. Belgeo 1:31–50. https://doi.org/10.4000/belgeo.11629

van der Laan L (1998) Changing Urban systems: an empirical analysis at two spatial levels. Reg Stud 32(3):235–247. https://doi.org/10.1080/00343409850119733

van Duijne R, Nijman J (2019) India's Emergent urban formations. Ann Am Assoc Geogr 109(6):1978–1998. https://doi.org/10.1080/24694452.2019.1587285

Varshney M (2018) Mumbai transportation system transformation, innovative governance of large urban systems. Retrieved 11 Mar 2022, from https://iglus.org/mumbai-transportation-system-transformation/#:~:text=Over%20the%20past%205%20years,changed%20significantly%20during%20the%20period

Wang M (2020) Polycentric urban development and urban amenities: evidence from Chinese cities. Environ Plann B: Urban Analy City Sci 48(3):400–416. https://doi.org/10.1177/2399808320951205

Why Andheri west is being preferred by commercial real estate developers—Media bulletins. Media Bulletins (2021) Retrieved 18 Mar 2022, from http://mediabulletins.com/business-world/why-andheri-west-is-being-preferred-by-commercial-real-estate-developers/.

White MJ (1990) Urban areas with decentralized employment: theory and empirical work. In: Mills ES, Cheshire P (eds) Handbook of regional and urban economics, vol 3. pp 1375–1412

Wu C, Smith D, Wang M (2021) Simulating the urban spatial structure with spatial interaction: a case study of urban polycentricity under different scenarios. Comput Environ Urban Syst 89:101677. https://doi.org/10.1016/j.compenvurbsys.2021.101677

Yang T, Jin Y, Yan L, Pei P (2019) Aspirations and realities of polycentric development: Insights from multi-source data into the emerging urban form of Shanghai. Environ Plann B: Urban Analyt City Sci 46(7):1264–1280. https://doi.org/10.1177/2399808319864972

Zhuo Y, LIU T (2020) Polycentric city and region: a review and appraisal. Progress Geogr 39(8):1385–1396. https://doi.org/10.18306/dlkxjz.2020.08.012

Chapter 9
Estimate the Urban Landscape Dynamics in Balichak Census Town, West Bengal, for Integrated Spatial Monitoring

Manishree Mondal and Nilay Kanti Barman

Abstract Mainly the countries of rapidly growing economies have experienced the unceasing, unplanned and unsystematic transformation from physical environment of rural areas into the cultural milieu of urban areas over the modern eras. The escalation of anthropological activities within the metropolitan vicinity has been directed for serving the altered drill of land use within and outside of metropolitan area with mark effects of ecosystem. Urban sprawling can be identified by continuous urban growth. Balichak is one of the emerging forms of census town in terms of economic activities, settlement, transport and administrative centre in Paschim Medinipur District. This present attempt tried to estimate the spatio-temporal alterations of urban land use dynamics at Balichak census town where the land use and cove pattern are altering vigorously. It is crucial to include the various indicators liable to vigorous practice and create complex relationships among them in order to achieve the sustainable development. In this concern, some technologies and tools such as geospatial modelling and system dynamics framework as well as perception survey of local residents suggest sufficient prospects in spatial and temporal aspects to understand quantify and monitor the urban dynamics. Operation research approaches and multi-agent system approaches have been able to apprehend the dynamism of the landscape alterations scheme and also be treated as a convenient tool to predict the potential upcoming alterations. Therefore, this study tried to measure the accelerating difficulties of sprawling in Balichak area with the incorporation of remotely sensed techniques and Geographical Information System methods to efficiently consider, appraise and evaluate the different strategy formulation for maintaining the sustainability and integrated spatial monitoring of this unplanned growth of urban landscape.

Keywords Urban sprawling · Land use dynamics · Geospatial modelling · Perception survey · Strategy · Sustainability · Integrated spatial monitoring

M. Mondal (✉) · N. K. Barman
Department of Geography, Midnapore College (Autonomous), Paschim Medinipur, Midnapore 721101, India
e-mail: manishree72@gmail.com

U. Chatterjee et al. (eds.), *Urban Commons, Future Smart Cities and Sustainability*, Springer Geography, https://doi.org/10.1007/978-3-031-24767-5_9

Introduction

The definition of an urban area depends on factors like the concentration of population, the percentage of inhabitants who are not completely reliant on cultivation, and also the availability of amenities and facilities for the general public. In India, a region is said to as an urban area if it has over and above 5000 inhabitants and has a density of populace above 400 person per square kilometre; on the other hand, 75% of its residents work in non-agricultural professions (Shashidhar 2001). Census of India, 2011, exhibits that the urbanisation rate in India is near about 31.16% which is very rapid in nature.

Urban sprawl could potentially be seen as a warning sign to reach the sustainable urbanisation. Consequently, it is essential to comprehend the issue of urban sprawl, especially from the perspective of growing nations Misra and Mishra (2017). Additionally, it is determined that the challenges posed by urban expansion are caused by poor planning, a lack of effective methods and a lack of worthy leadership for a number of reasons (Chandramouli 2011). The deficiency of adequate materials regarding the spatial indices contributes to scheduling mechanism's ongoing inability to anticipate realistic sprawl extents and its advancement (Batty et al. 2004). Additionally, the planning and management are unable of anticipating the results of various assessments, mostly due to the lack of dynamic spatial models with feedback systems (Cheng and Masser 2003). Additionally, the lack of a method to appraise for various strategy inferences and the deficiency of spatial planning support system to endorse and validate various planning procedures are contributing to sprawl (Dewan and Yamaguchi 2009).

In order to achieve sustainable development, it is essential to take into account a number of factors that drive dynamic growth and construct complex relationships between them (Deng et al. 2009). Geospatial technologies offer promising opportunities for analysing, monitoring and tracking urban plans simultaneously in spatial and temporal dimensions. To manage dynamic geographic simulations, however, geospatial modelling is still inept (Sharifi and Rodriges 2002).

Using a systems approach and multi-agent systems to comprehend and quantify urban structures will enable one to comprehend the alteration aspects of the scheme and make it simple to predict probable future deviations (Parsa and Salehi 2016). Thus, the tasks of future study will be to achieve an incorporated spatial planning support system to successfully design, evaluate and estimate the diverse strategy options while the dynamism intricate in Debra-Balichak census town's expanding urban sprawl (Rawat et al. 2013).

As a result, the measures and methods used to calculate sprawl are still not exact, much like the studies and descriptions of urban sprawl. This calls for developing appropriate measures to address the difficulties of sprawling while considering the levels of urbanisation, population densities, as well as the combined spatial ranges of urban regions (Jat et al. 2008). Therefore, it is crucial for any study to take into account the issue of sprawling in an emerging nation like India while arriving at useful metrics.

One of the most recently developed census town forms is Balichak, which is the transportation, administrative and centre of commerce for the Paschim Medinipur District. The landscape configuration has changed as a result of the previous times (Haregeweyn et al. 2012). However, the majority of research activities have been centred in Kolkata, the state capital of West Bengal. However, the spatio-temporal dynamism of urban expansion and changes to the land use and land cover of Balichak census town have received less attention. Balichak census town's land use land cover and its alteration over time were thus the focus of this investigation.

Urban sprawling, which is the result of unchecked and haphazard urban growth, is the spatial expansion of urban areas (Bera and Chaterjee 2019). Sprawl is also thought to be an unintentional development of urban regions adjacent to cities, along roads, and adjacent to routes leading into cities (Sovani 1966). Numerous townships and metropolises are expanding as a result of unplanned planning and decision-making processes, with changes to the land use lateral to highways and in the close vicinity of the cities (Sjoberg 1965; Sikdar 2001). Sprawl typically refers to a specific kind of improvement with effects including the squeeze of cultivated land, courtyards and environmentally delicate housing peripheral areas of metropolitan centres. Due to unanticipated growth, a deficiency preceding evidence, and inaccurate expansion estimates made in the time of planning, strategy and decision-making, these provinces lack essential facilities.

Urban sprawl is an extremely dynamic phenomenon (Allen 1979). Even though it is regularly observed, the phenomenon affects the layout and development of any metropolitan or urban area. Urban sprawl is well-known to be caused by the rise of outskirts with augmented population explosion and also with the expansion of infrastructural services surroundings of the urban unit (Allen 1986). Some techniques and strategies from the domains of engineering, management, geospatial science and artificial intelligence are being applied to detect the delinquent of modelling urban systems. The system dynamics framework, operations research techniques, geographic modelling with GIS tools, and in very recent times, the utilisation of agent-based models in concurrence with geospatial models to study the dynamism and demonstrating the sprawling of urban unit are some of the important methodologies (Besussi 2002). In order to quantify urban sprawl, its effects, and to assure sustainable urbanisation, the operation research (OR) approach, the system dynamics (SD) framework, and simulation models have also been widely employed in the development of the Integrated Spatial Support System.

It is very imperious to have a powerful spatial planning support system (SPSS) in order to effectively supervise, test various hypotheses, structure, and visualise scenarios in order to address the delinquent of urban sprawl (Couclelis 1987). An ideal SPSS would support the management of the required system as well as its planning, organisation, coordination, monitoring and evaluation. These plans include geo-information technological tools which were predominantly created to upkeep various planning processes, including deficient analysis, spatio-temporal data collection, demonstrating of data, extraction of data and mining, data display and visualisation and also scenario creation, formulation and estimation of plan, preparation of projection plane, improved participation and cooperative decision-making and report writing (Geertman and Stillwell 2004).

UrbanSim and OBEUS are now the two most well-known contexts and secondary correspondences for the modelling of integrated urban system. Under the Open Platform for Urban Simulation, UrbanSim runs as a collection of correspondences (OPUS) (Waddell et al. 2003). However, this is rather widespread in order to its rationality for taking into account the variables related to land use, transportation, finances, demography, and the environment. One big drawback of this module is its 'data hungry'. Additionally, the concerned environment does not sustenance for active future predictions. The OBEUS is becoming more capable and has a growing propensity to incorporate various advancements as agent-based model to predict them spatially.

Most nations today face a significant difficulty in 'sustaining' their financial growth rates while having minimal environmental impact (Meadows 1998). Urbanisation and 'development' have practically become synonymous in modern times, particularly in developing countries. Additionally, the term 'development' is typically associated with financial development, which the majority of countries pledge to offer to their population (Rao and Karmeshu 1989). The majority of rising nations are experiencing the common phenomena of urbanisation, which has led to the growth of massive metropolises along with their slums and trespassers. In addition to the widening gaps between urban and rural areas, a number of ecological and socioeconomic variables have contributed to the considerable problems of the modern era. These include declining natural resources, rising pollution levels and related natural dangers (Khawas 2003). So, it is very indispensable for specialists involved with governing and supervising metropolitan growth to adopt integrated planning philosophies that take into account the needs of their clients and achieve the goals in a sustainable manner (Brush 1962). It needs appropriate planning in order to achieve the growth of urban areas, relieve the compression on natural resources and also the environment, and meet the demands of the economy that endures these metropolitan regions (Greetman and Stillwell 2004). It is the point of view that establishes sustainable development as fundamentally addressing for achieving the state of equilibrium of environment and economic progression, for the forthcoming peers. Urban expansion configurations that result in urban sprawling are 'unsustainable' because they contribute to the loss of natural resources for future populations as well as the current depletion of a region's carrying capacity. The need to control urban sprawl arises from a global concern with achieving sustainable urbanisation. Sustainable urbanisation is an active, multifaceted process that addresses ecological, societal, financial and organisational viability.

A system of cosmopolitan development known as urbanisation is a response to the often poorly understood interplay between technical, financial, societal and political pressures as well as to the physical characteristics of a certain degree (Grubler 1994). For example, unintended urbanisation and succeeding urban expansion, often known as sprawling of urban areas, are perceived as disrupting the land use of any kind of spatial unit predisposed to widespread urban growth and the squeeze of valuable cultivation land rather than being considered as a warning to the environment or development (Davis 1965). Keeping all the above discussions in mind the present work aims with the following objectives-

- To estimate the spread out of urbanisation over temporal extent.
- To assess the systematic sense regarding the life cycle of urban area.
- To analyse the degree of susceptibility produced by urban sprawling.
- To formulate the strategies for sustainable urban sprawling management.

Study Area

According to the census of 2011, Balichak is classified as a census town due to its potential for population growth, financial situation and amenities for human comfort, educational opportunities and other factors. Balichak had a total population of 13,784 people in 2011, of which 6.735 (49%) were men and 7049 (51%) were women. There were 1261 people in the 0- to 6-year-old age bracket. There were 10.944 literate people in Balichak overall (87.39% of the population over 6 years). The overall size of this study region has been rapidly expanding in space over time (Fig. 9.1). The current study area lacks the identity of a suitable urban or town area; instead, it is being developed in a rural–urban or r-urban manner, with the maximum expanses of land being consecutively covered with cultivation land, settlement area, vegetation, unoccupied land, and wetland.

Materials and Methods

A particular idea for a geographical database for metropolitan areas is where the geneses of GIS can also be sketched back to the late 1960s. Urban sprawl mapping delivers a ‘snapshot’ of the areas wherever the concerned kind of urban expansion is taking place. Moreover, it is an aid in identifying the natural and environmental resources that are endangered by it and propose the proposed urban sprawling prediction and contours of urban sprawling (Lata et al. 2001). Understanding the nature and growth of this phenomenon, it will be fruitful to examine the sprawl across time. The use of GIS technologies and satellite remote sensing data are validated for studying sprawl. The use of remotely sensed satellite imageries allows for the consideration and supervision of landscape arrangements for urban sprawling over temporal aspects. They can also be used to extract the patterns of urban expansion from spatial dimensional aspects as well as temporal aspects. These types of aids are very needful in defining the linear expansion and radial growth patterns that characterise urban sprawl.

The current project is enhanced with many primary and secondary databases. While several data from secondary source like the government census report, BDO, BL&LRO, Gram Panchayat office, etc., have been incorporated for ground truth

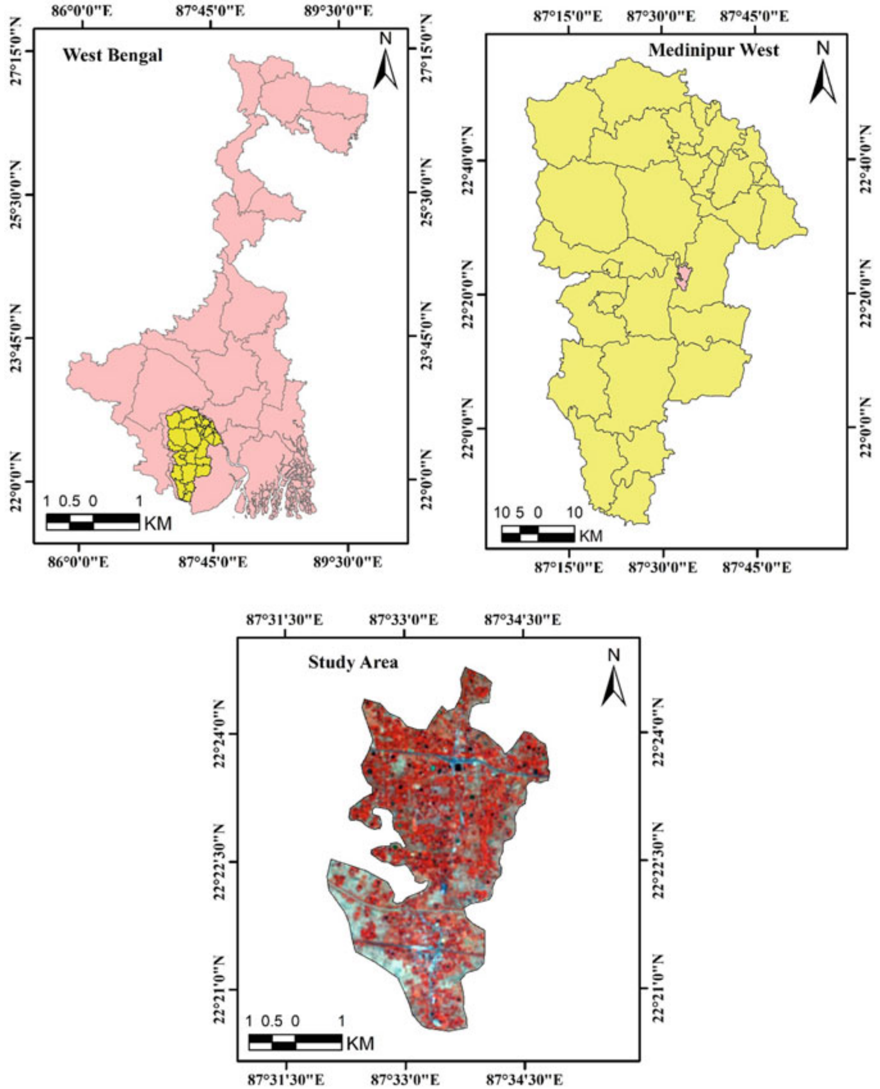


Fig. 9.1 Study area is being increasing hurriedly in terms of spatial expansion over time

verification. Mouza maps, Landsat 4 and Landsat 8 satellite pictures, and the images from Google Earth have been integrated for mapping analysis.

Landsat 4 and Landsat 8 satellite photographs are mostly used for the LULC 2001, 2011 and 2021. The band composition process has been completed first, followed by the extraction of the study area from the composite band and the classification of the photos using the Arcgis-10.4.1 software. Besides this, the extensive fieldwork and Google Maps both are successfully recognised for the analysis of spatial growth.

On the basis of the rapid spatial growth in the form of development of the settlement site as well as the transformation of agricultural land into the non-agricultural purpose, the present chapter also recommends some strategic actions to cope with this rapid changeability of land use pattern as well as the ecological aspects also. During the entire study, researchers have considered some urban demands-related parameters which are highly accentuated by the rapid urban growth processes. Based on these urban demand parameters, researchers have set up some goals by which they have also identified some problems which are largely prevailed in the studied area and closely connected with this rapid urban sprawling. The recommendations to cope with these alterations of land use pattern are completely based on these identified problems through vigorous field study and human perception study. Further, the present study has also given some light on the expected result which can be yielded to perform the prescribed actions.

Approximation of Sprawling Susceptibility

An intensive perception survey has been carried out among 300 local respondents selected by stratified random sampling procedure basically to know the changes of this census town between pre- and post-sprawling situation for assessing the susceptibility. Potential susceptible groups of every economic class are the main target for this study. Evidences essential for susceptibility exploration are precisely presented in Table 9.1. Here, only structure of the table has been presented. It highlights on five clusters that are projected to have minimum security in respect to urban sprawl. Nature and conformation of such extremely susceptible clusters may differ from spatial dimension as well as situation also. The differences among the susceptible clusters are retrieving of four types of possessions (agricultural land, water body, settlement and vegetation) in considering socio-economic susceptibility of a community due to this sprawling event. The signs are utilised to indicate whether a specific cluster is probable to enrich (+), condense (−) or remain the same (0) in its condition in retrieving the belongings. But the ‘0’s (no changes) are not considered during calculation since; they have no significance with respect to susceptibility. If the investigator comprehends that there is actually no variation in any variable in the appearance of sprawling, then he can put ‘0’ in computing susceptibility.

It is perceptible that the information is in ordinal scaled and not normally disseminated. Hence, the contemporaneous investigator practises the principle of binomial test (as functional in sign test) for determinative the probability of progressive or destructive alterations in between pre and post sprawling circumstances in respect to every designated variables. The probability for the k number of progressive or destructive clarifications is given by.

Table 9.1 Variables and calculations for determining sprawling susceptibility

<table>
<tr><td rowspan="4">Access to</td><td colspan="18">Potential susceptible clusters</td></tr>
<tr><td colspan="10">Poorest (33%)</td><td colspan="4">Middle (33%)</td><td colspan="4">Richest (33%)</td></tr>
<tr><td colspan="3">Women</td><td colspan="4">Child</td><td colspan="2">Elder</td><td>Minority</td><td>Women</td><td>Child</td><td>Elder</td><td>Minority</td><td>Women</td><td>Child</td><td>Elder</td><td>Minority</td></tr>
<tr><td colspan="18">Respondent’s perception in regard to change in condition between pre and post sprawling event</td></tr>
<tr><td>Responses</td><td>+</td><td>–</td><td colspan="2">0</td><td>+</td><td>–</td><td colspan="2">0</td><td colspan="10"></td></tr>
<tr><td>Agricultural land</td><td></td><td></td><td colspan="2"></td><td></td><td></td><td colspan="2"></td><td colspan="10"></td></tr>
<tr><td>water bodies</td><td></td><td></td><td colspan="2"></td><td></td><td></td><td colspan="2"></td><td colspan="10"></td></tr>
<tr><td>Settlement</td><td></td><td></td><td colspan="2"></td><td></td><td></td><td colspan="2"></td><td colspan="10"></td></tr>
<tr><td>Vegetation</td><td></td><td></td><td colspan="2"></td><td></td><td></td><td colspan="2"></td><td colspan="10"></td></tr>
</table>

Probability Mass Function in Sprawling Impacts Analysis

In general, if the random variable X follows the binomial distribution with parameters n and p, it is written as $X \sim B(n, p)$. The probability of receiving accurately k successes in n trials is given by the probability mass function:

$$f = (k; n, p) = \Pr(X = k) = \binom{n}{k} p^k (1 - p)^{n-k} \tag{9.1}$$

for $k = 0, 1, 2, \ldots, n$, where

$$\binom{n}{k} = \frac{n!}{k!(n - k)!} \tag{9.2}$$

This is the binomial coefficient, hence the name of the distribution. The formula can be assumed as follows: it is k successes (p^k) and $n - k$ failures $(1 - p)^{n-k}$.

However, the k successes can occur everywhere among the n trials and there are $\binom{n}{k}$ different ways of distributing k successes in a sequence of n trials.

In constructing reference tables for binomial distribution probability, generally the table is completed in up to $n/2$ values. It is because for $k > n/2$, the probability can be calculated by its supplement as

$$f(k, n, p) = f(n - k, n, 1 - p). \tag{9.3}$$

Considering at the appearance $f(k, n, p)$ as a function of k, there is a k value that makes the most of it. This k value can be initiated by computing

$$\frac{f(k + 1, n, p)}{f(k, n, p)} = \frac{(n - k)p}{(k + 1)(1 - p)} \tag{9.4}$$

and comparing it to 1. There is continually an integer M that gratifies

$$(n + 1)p - 1 \leq M < (n + 1)p. \tag{9.5}$$

$f(k, n, p)$ is monotone growing for $k < M$ and monotone diminishing for $k > M$ with the exemption of the instance where $(n + 1)p$ is an integer. In this case, there are two values for which f are maximal: $(n + 1)p$ and $(n + 1)p - 1$. M is the most probable (most likely) outcome of the Bernoulli trials (Papoulis 1984) and is called the mode. Note that the probability of it occurring can be fairly small.

Cumulative Distribution Function

The cumulative distribution function can be expressed as:

$$F(k; n, n) = \Pr(X \leq k) = \sum_{i=0}^{k} \binom{n}{i} p^i (1-p)^{n-i} \quad (9.6)$$

where, $q = (1 - p)$

where $\lfloor k \rfloor$ is the 'floor' under k, i.e. the greatest integer less than or equal to k. It can also be signified in expressions of the normalised inadequate beta function as follows:

$$\begin{aligned} F(k; n, n) &= \Pr(X \leq k) \\ &= I_{1-p}(n-k, k+1) \\ &= (n-k)\binom{n}{k} \int_{0}^{1-p} t^{n-k-1}(1-t)^k \mathrm{d}t. \end{aligned} \quad (9.7)$$

where $n =$ number of observations, $p = 0.5$ probability of positive changes and $q = 0.5$ probability of negative changes. Thus, reflected probabilities may be expressed in zero to unity. The test is to be directed for each and every of the variables under every resource type and values attained are to be supplemented to get the probability of susceptibility of a specific cluster in a particular spatial unit (here CBD and distance from CBD). Spatial unit-wise calculated susceptibility can be determined by multiplied the adding up value of probability of susceptibility of a specific cluster in a particular spatial unit with its total population.

Result and Discussion

The main objective of this study is to estimate the urban sprawling, perception of local residents about the impact of this sprawling and formulate a strategy for sustainable management. The results are discussed in detail in the following subsections.

The following maps (Fig. 9.3) were created using satellite pictures and Google Earth imagery to reflect the socio-temporal changes in the research area's growth centres. The 2001, 2011 and 2021 years have been incorporated for map preparation of the present work to estimate the growth pole sprawling through time. The land use scenarios for 2001, 2011 and 2021 are shown into the land use land cover map and related database (Figs. 9.2 and 9.3). Debra-Balichak census town's expansive size and extent have been calculated using digital methods and mapping analyses.

This metropolitan region was only a growth centre or point in its early stages of development. There were hardly any modern metropolitan facilities or services

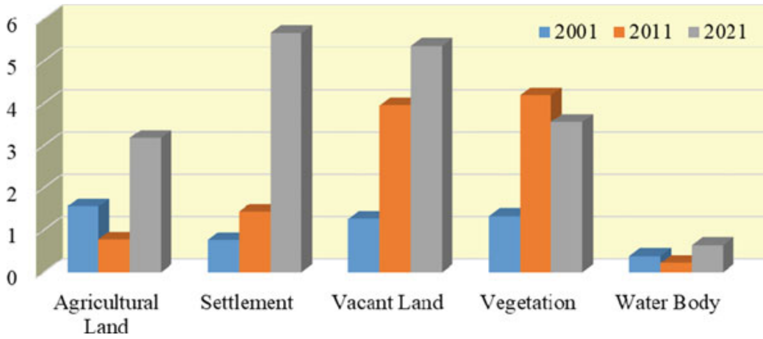


Fig. 9.2 Major land use pattern and their alteration scenario over time

found in this region. According to the tabulated synthesising data, agricultural land (29.391%) has the largest percentage of land use, followed by empty land (25.143%), vegetation (23.819%), settlement (14.450%) and water body (07.197%) (Table 9.2). It should be noted that the agro-economy was present in the current research region up to 2001. The development during the period was mostly dependent on the transportation system.

While the vegetation cover is clearly the highest in magnitude (39.538%) into the land use and land cover map of 2011, followed by inhabited areas (13.585%), undeveloped land (37.376%), agricultural land (7.347%) and aquatic bodies (02.054%). The main point is that due to the spatial expansion of urban area, the amount of vegetation cover and vacant land area also increased following the settlement expansion from its previous amount and presence. This land use scenario reflects the pre-stage situation of land uses of this census town (2011), which indicates the gradual declining scenario of agricultural land, water body, wetlands, etc.

The land use forecast for 2021 is, nevertheless, reflected in the LULC map and the relevant data table. The combined data reveals that in the research region, settlements now account for 30.765% of all land use occupied features, followed by vegetation (19.326%), agricultural land (17.274%), and water body (03.501%). As a result of the transition of market construction and the extension and rehabilitation of new roads, the amount of vacant land is almost at its maximum. But it is also obvious that many anthropogenic activities, such as market development, road construction and settlement growth, have significantly diminished the vegetation cover.

Any metropolitan or growth pole location will typically exhibit sprawling. This is likewise not unique in the case of the current research. However, the velocity and size of the Balichak area's expansion are directed in various ways along various channels. The Khargpur and Debra-Panskura routes both have extremely high growth rates. It is also very notable since following its designation as a census town, in Debra block, Balichak has greatly sped southward along the Balichak-Debra route (Fig. 9.4). Urban sprawl's scope and characteristics are significantly different in industrialised countries than they are in India, a rapidly developing and predominantly rural-agrarian country. After reaching saturation levels of development, the challenges of sprawl

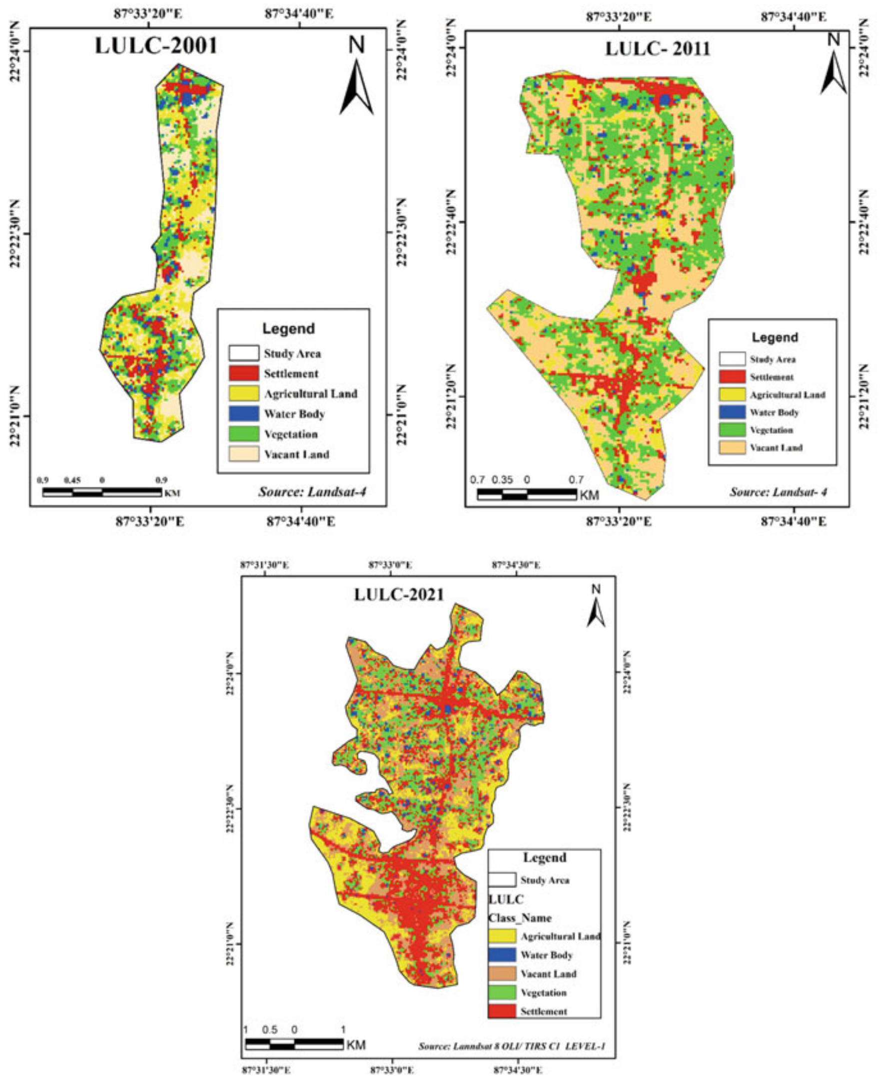


Fig. 9.3 Land use land cover map of 2001, 2011 and 2021

are extreme in developed nations. On the other hand, most emerging and underdeveloped nations are rapidly expanses today and are previously predisposed to the sprawl delinquent to a greater level. Population concentrations are a key difference between the urbanisation patterns of industrialised and developing nations. Nearly 42% of people in the Balichak area live in newly developed areas, and these areas are expanding at a rate never seen before due to a lack of services like transport network, drinking water supply, proper sanitation system and energy supply framework with

Table 9.2 Major land use pattern and their alteration scenario over time

S. No.	Major land use pattern	2001		2011		2021	
		Area (in km^2)	% of land use	Area (in km^2)	% of land use	Area (in km^2)	% of land use
1.	Agricultural land	1.556	29.391	0.776	7.347	3.177	17.274
2.	Settlement	0.765	14.450	1.435	13.585	5.659	30.765
3.	Vacant land	1.261	23.819	3.948	37.376	5.359	29.134
4.	Vegetation	1.331	25.143	4.187	39.638	3.555	19.326
5.	Water body	0.381	07.197	0.217	02.054	0.644	03.501
Total		5.294	100	10.563	100	18.394	100

a reasonable level of commercial activities, huge populace in disorganised occupational divisions, and insufficient accommodation, the intensification of shanty towns and trespassers in these built-up expanses appears unavoidable. Focused commercial development in a selected few regions suggests that rural-to-urban migrations cause growth to be skewed (Bogue and Zachariah 1962). The planning apparatus and administrators of today are also not as much of prepared to evaluate and estimate any kind of strategy assessments vigorously in order to anticipate the prospective effects of a strategy instruction as well as the sections of impending spread as well as to solve the issues of sprawling. Future research must support a thorough consideration of the sprawling of urban phenomenon, understanding the dynamism, model the dynamism and formulate a spatial planning support system to assess, estimate and appraise the different strategy options in order to have an operational approach. In this perspective, to take corrective actions for diminishing the effects, the planning apparatus and administrators need to be cognisant of the expected extents of sprawl.

Probability of Changes

The principle of binomial coefficient (as applied in sign test) has been used for defining the probability of progressive or destructive alterations between pre- and post-sprawling situations in respect to each of the selected variables/parameters. The result showed that the probability of susceptibility is very high (0.245–0.394) in just peripheral area of CBD regions for their congested situation where any types of evil intensity and magnitude regarding selected parameters are very high in nature. Alternatively according to the distance from the CBD, the probability of susceptibility reflects very low (0–0.22) in nature. The CBD belongs to the erstwhile intermediate probability of susceptibility classes according to the probability of susceptibility.

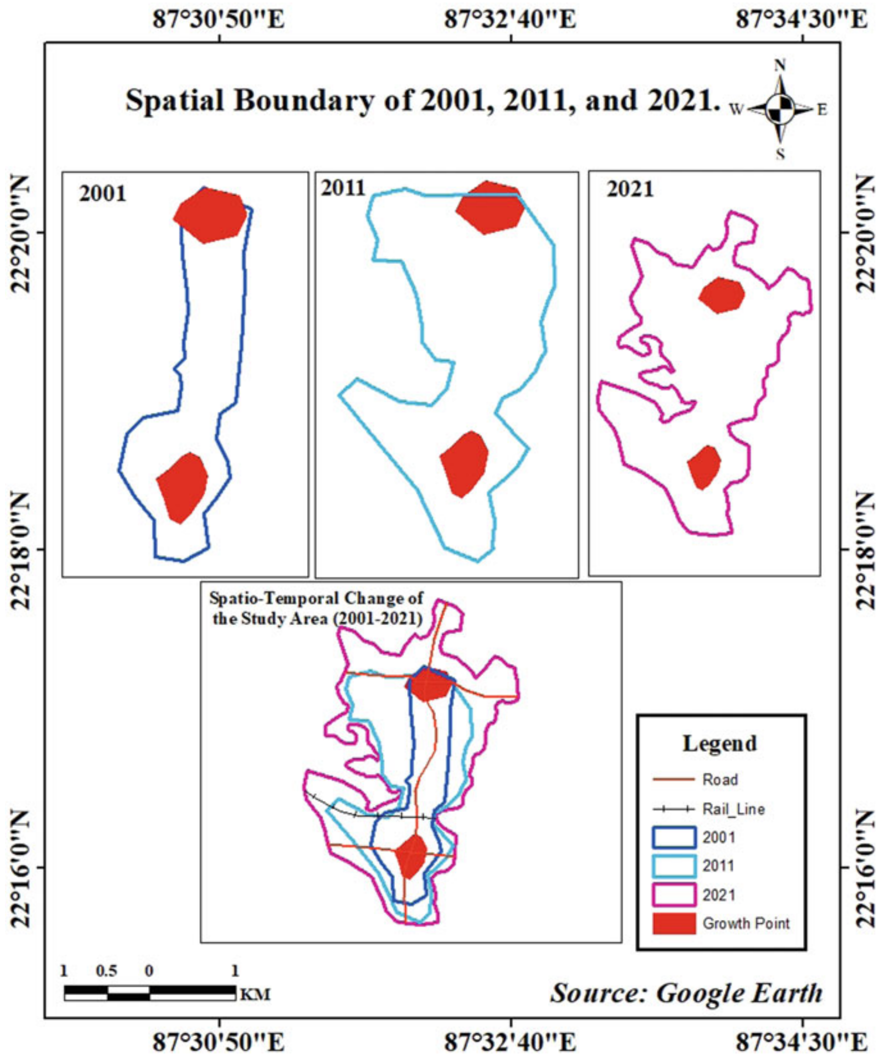


Fig. 9.4 Spatial expansion of the study area over time

Susceptibility Score

From the above methodology, susceptibilities have been considered and the outcome noticeably exhibited that susceptibility is not ever linearly be influenced by the probability of susceptibility rather it determined by population density of a particular region. The peripheral vicinities are experiences very high sprawling susceptibility scores (6275.52–16241.40) only because the population density is very high in this part than the other part of the study area.

On the other hand, the fringe areas experience very low sprawling susceptibility score (151.92–1520.27). Rest portion of the studied area belonged to the erstwhile intermediate vulnerability classes, according to the sprawling susceptibility score.

Recommendations for Sustainable Coping Strategy

Sustainable management of urban sprawling is a very difficult challenge for any urban unit. Unplanned and unscientific urban growth has generated various severe threats to human wellbeing and environment. In the present census town, the economy and transport play as key role rather than spatial planning and urban design (Batty 2008). Now this town acts as a pull factor for the surrounding rural areas due to the availability of rural facilities and urban amenities. Rural–urban migration is another serious problem. The haphazard mushrooming of settlement, market and traffic congestion have had many adverse impacts for future development like drainage and sanitation.

Constraining the unlawful land use alteration to maintain the land use policy in accordance with government rules and regulation is necessary. Confining the illegitimate intrusion and influential apprehending of water bodies, green cover areas, wasteland, cultivated land, etc., for random expansion of the growth pole is required. Preventing the supremacy of developers and extenders in connection with commercialisation of land properties should be prohibited.

Action should be taken for remedying the administration and administrative negligence regarding unintended and irrational urban sprawl. It will make sure that the effort for preservation of the ecological-footprint and reducing land use vulnerability due to free frog expansion of urban growth should not be stopped. Modernising and revolutionising the urban landscape and growth pole scenario amending in accordance with its functional capability are also the effective tools for sustainable management of urban growth. Combination of different strategy, community and design for supportable progression and enlargement of growth pole expanse should be done accordingly. An explicit guideline is necessary for resolving the accommodation issues of migratory people in study area.

A sustainable development strategy and implementation of proper action plan are urgent necessity for planning and wise future of this census town. For this, the authors have suggested a road map of sustainable strategies for urban sprawling management (Fig. 9.5).

Conclusion

Urban sprawl may be seen as a cautionary sign for achieving sustainable urbanisation. Therefore, understanding the issue of urban sprawl is crucial, especially from the perspective of a growing nation. In the end, this would help in the development

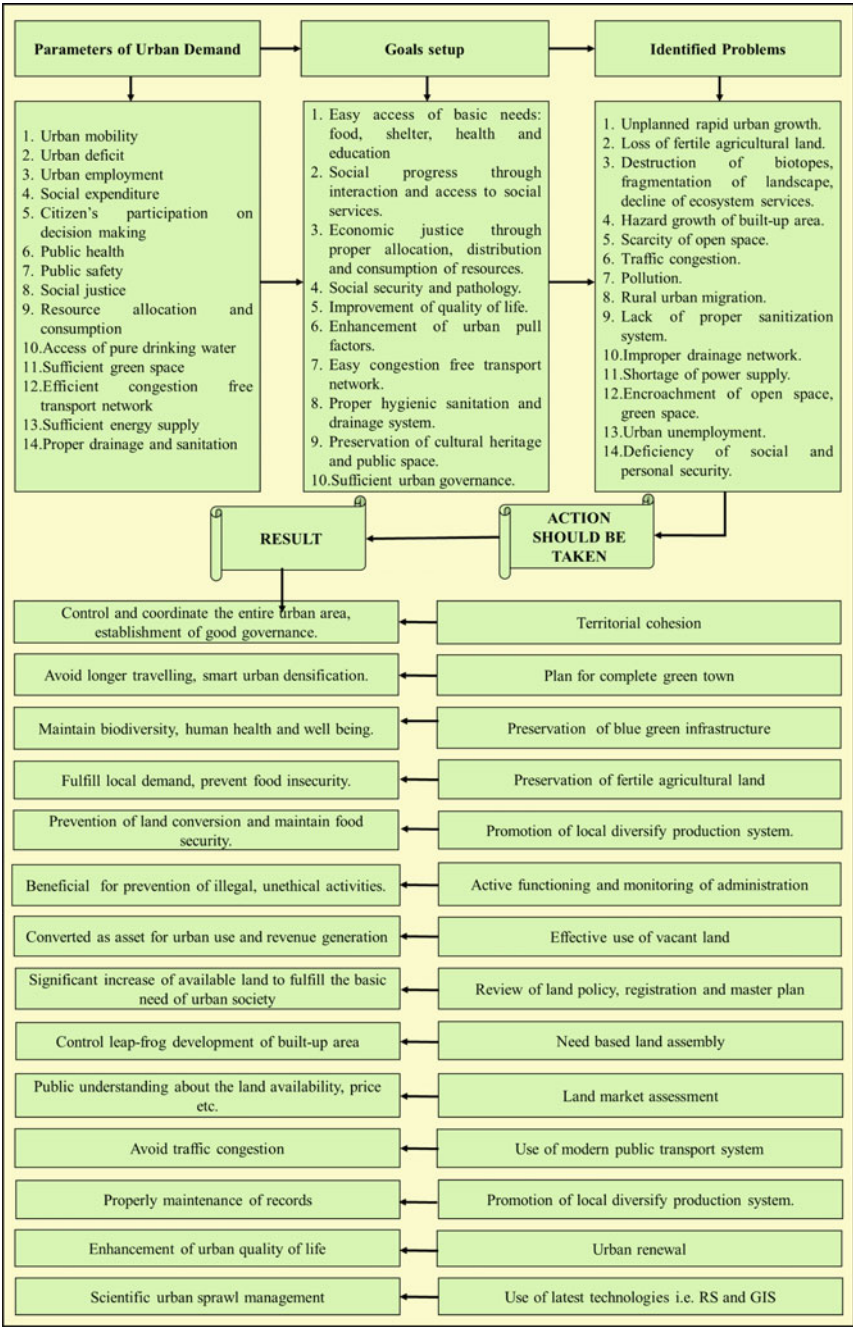


Fig. 9.5 Road map of coping strategies for development and sustainable planning

of any management possibilities and strategies for effectively resolving the urban sprawl issue. Furthermore, due to a variety of factors, it is believed that poor planning, weak policies and a lack of competent administration are to blame for the growth of urban sprawl. The deficiency of suitable information regarding spatial extent and spatial signs accounts for the planning machinery's inability to foresee potential sprawl extents and growth. In addition, planning and administration are fundamentally unable to anticipate the effects of various actions due to the absence of sufficient spatial model with response systems. Additionally, poor strategy choices are causing additional sprawling because there is no such method to appraise various strategy interpretations and no system of support for spatial planning to validate various policy preferences.

Therefore, the challenges for future research in the current situation with the intensifying delinquency of urban sprawling are to achieve at an integrated spatial planning support system to efficiently design, analyse, and apprise the various strategy possibilities while apprehending the dynamism intricate. So, the current endeavour also advises against stopping urban or growth centre sprawling and instead suggests introducing some useful tactics and planning procedures to manage this bad process.

So, the following suggestions for anti-sprawl urban strategy may be used to advance the study of sprawling pattern. The suggested actions are listed below.

- Constraining the improper land use alteration to maintain the land use policy in accordance with ecological equilibrium aspects as well as government rules and regulation.
- Confining the illegitimate intrusion and influential apprehending of water bodies, green cover areas, wasteland, cultivated land, etc., for random expansion of the growth pole (Myrdal 1957).
- Preventing the supremacy of developers and extenders in connection with commercialisation of land properties.
- Remedying the administration and administrative negligence regarding unintended and irrational urban sprawl.
- Preserving the ecological-footprint and land use vulnerability for free frog expansion of urban growth (Riebsame et al. 1994).
- Modernising and revolutionising the urban landscape and growth pole scenario amending in accordance with its functional capability.
- Combination of different strategy, community and design for supportable progression and enlargement of growth pole expanse.
- Offering the explicit guidelines to resolve the accommodation issues of migratory people in study area (Aijaz 2019).

Finally, it can be said that each and every functional characteristics, comprises with regular people, local administration, local agents, officials, strategy formulator, industrialist, manufacturer and other concerned character have to be revealed into a very specific exertion related to functional characters for not only widespread but also sustainable development of any potential urban growth centre.

References

Aijaz R (2019) India's peri-urban regions: the need for policy and the challenges of governance. ORF Issue Brief No. 285, Observer Research Foundation

Allen PM, Engelen G, Sanglier M (1986) Self-organizing systems and the 'laws of socio economic geography'. Eur J Operat Res 25(1):127–140

Allen PM, Sanglier M (1979) A dynamic model of urban growth: II. J Soc Biolog Syst 2(4):269–278

Basham AL (1967) The wonder that was India: a survey of the history culture of the Indian subcontinent before the coming of the Muslims. Sidgwick Jacksohn Ltd., London

Batty M (2008) The size, scale and shape of cities. Science 319:769–771

Batty M, Besussi E, Chin N (2004) Traffic, urban growth and suburban sprawl. Centre for advanced spatial analysis, University College London, Working Paper Series, Paper 70

Bera S, Chatterjee ND (2019) Mappingand monitoring of land use dynamics with their change hotspot in North 24-Parganas district, India: a geospatial and statistical based approach. Model Earth Syst Environ 5(3):1529–1551. https://doi.org/10.1007/s40808019-00601-2

Besussi E (2002) System analysis of urban sprawl by experts, in the case cities. Sprawling cities and transport: from evaluation to recommendations (SCATTER), Work package 2, Version 1.0

Bogue DJ, Zachariah KC (1962) Urbanisation and Migration in India. In: Turner R (ed) India's urban future. Oxford University Press, Bombay

Brush JE (1962) The morphology of Indian cities. In: Turner R (ed) India's urban future. Oxford University Press, Bombay

Chandramouli C (2011) Census of India: rural urban distribution of population census of India 2011 (Provisional population totals)-our census, our future, Ministry of Home Affairs New Delhi, pp 5

Cheng J, Masser I (2003) Urban growth pattern modelling: a case study of Wuhan City, PR China. Landscape Urban Plan 62:199–217

Couclelis H (1987) Cellular dynamics: how individual decisions lead to global urban change. Eur J Oper Res 30(3):344–346

Davis K (1965) The urbanization of the human population. Sci Am 213(3):40–53

Deng JS, Wang K, Hong Y, Qi JG (2009) Spatiotemporal dynamics and evolution of land use change and landscape pattern in response to rapid urbanization. Landsc Urban Plan 92(3–4):187–198

Dewan AM, Yamaguchi Y (2009) Using remote sensing and GIS to detect and monitor land use and land cover change in Dhaka metropolitan of Bangladesh during 1960–2005. Environ Monit Assess 150(1–4):237–249

Epstein J, Payne K, Kramer E (2002) Techniques for mapping suburban sprawl. Photogrammetr. Eng. Remote Sens. 63(9):913–918

Geertman S, Stillwell J (2004) Planning support systems: an inventory of current practice. Comput Environ Urban Syst 28:291–310

Grubler A (1994) Technology. In: Meyer WB, Turner II BL (eds) Changes in land use and land cover: a global perspective. Cambridge University Press, Cambridge, UK

Haregeweyn N, Fikadu G, Tsunekawa A, Tsubo M, Tsegaye DM (2012) The dynamics of urban expansion and its impacts on land use/land cover change and smallscale farmers living near the urban fringe: a case study of Bahir Dar, Ethiopia. Landsc Urban Plann 106(2):149–157

Jat MK, Garg PK, Khare D (2008) Monitoring and modeling of urban sprawl using remote sensing and GIS techniques. Int J Appl Earth Obs Geoinf 10(1):26–43

Khawas V (2003) Trend in urbanization and urban growth in the North Eastern Indian hills—the case of Manipur, Sikkim and Tripura. Centre for Environmental Planning and Technology, Ahmedabad India

Lata KM, Sankar Rao CH, Krishna Prasad V, Badrinath KVS, Raghavaswamy V (2001) Measuring urban sprawl: a case study of Hyderabad. GIS Dev 5(12)

Meadows D (1998) Indicators and information systems for sustainable development. Report to the Balton Group, The Sustainability Institute, Hartland, USA

Misra HN, Mishra A (2017) Role of small and intermediate towns in regional development: a case study of Raebareli, Sultanpur and Pratapgarh Districts of Uttar Pradesh, India. Environ Socio-economic Stud 12 5(4)

Myrdal G (1957) Rich lands and poor. Harper and Row, New York

Papoulis A (1984) Bernoulli trials. Probability, random variables, and stochastic processes (2nd ed). Mc Graw-Hill, New York, pp 57–63

Parsa VA, Salehi E (2016) Spatio-temporal analysis and simulation pattern of land use/cover changes case study Naghadeh Iran. J Urban Manag 5(2):43–51

Rao DN, Karmeshu, Jain VP (1989) Dynamics of urbanisation: the empirical validation of the replacement hypothesis. Environ Plann B 16:289–295

Rawat JS, Biswas V, Kumar M (2013) Changes in land use/cover using geospatial techniques: a case study of Ramnagar town area, district Nainital, Uttarakhand, India. Egypt J Remote Sens Space Sci 16(1):111–117. https://doi.org/10.1016/j.ejrs.2013.04.002

Riebsame WE, Meyer WB, Turner BL (1994) Modeling land-use and cover as part of global environmental change. Clim Change 28(1–2):45–64

Sharifi MA, and Rodriges E (2002) Design and development of a planning support system for policy formulation in water resources rehabilitation: the case of Alcázar De San Juan District in the Aquifer 23, La Mancha, Spain. Int J Hydroinf

Shashidhar H (2001) Provisional population totals: rural-urban distribution of population. Paper 2 of 2001, Series-30, Directorate of Census Operations, Bangalore, Karnataka

Sikdar PK (2001) A framework for evaluation of transport development and management options using pollution profile technique. Paper presented at the workshop on transportation, land use and the environment, organized by the Harvard University centre for environment and hosted by central Institute for road transport (CIRT). Pune, India

Sjoberg G (1965) The origin and evolution of cities. Sci Am 213(3):54–63

Sovani NV (1966) Urbanisation and urban India. Asia Publishing House, Bombay

Waddell P, Borning A, Noth M, Freier N, Becke M, Ulfarsson G (2003) UrbanSim: A simulation system for land use and transportation. Netw Spat Econ 3:(43–67)

Chapter 10
Determination of Urban Sprawl Using Shannon Entropy Model in GIS: A Study of Bardhaman City of West Bengal, India

Amlan Ghosh, Sandipan Das, and Deb Prakash Pahari

Abstract Rapid urbanisation and expansion of the urban area are leading to spatial change and uneven growth around the cities. The changing land use pattern inside and outside of the city area is a concern where the land conversion is happening with an increase in the built-up area and a decrease in the land under other utilisation. This study has incorporated the spatial expansion of Bardhaman city of West Bengal, India, between the time period of 2001, 2011 and 2021. The expansion of the urban area is determined by the changes in the land use land cover between the time period. The Shannon Entropy model is used for showing the changes around the centre of the city towards the outside. The result shows that there is a rapid increase in the built-up area specifically in certain directions. The land is being converted from agriculture to built-up areas in the periphery of the city. New townships and the development of large projects are taking the agricultural land.

Keywords Urban sprawl · Shannon entropy · Urbanisation · Land use land cover · Bardhaman city

Introduction

Urban Sprawl is the result of uneven growth in the area and population in the urban spaces (Al-shalabi et al. 2012; Sharma and Joshi 2012). The urban growth resulting from the expansion of city space is often not restricted by the administrative boundaries. The economic activity and urbanisation processes that affect the peri-urban areas with the transformation in the city space are also essential here with the continuous population pressure within the limited geographical space. The transformation in the peri-urban areas often leads to converting the land from natural vegetation

A. Ghosh · S. Das (✉)
Symbiosis Institute of Geo-Informatics, Symbiosis International (Deemed University), Pune, Maharashtra 411016, India
e-mail: sandipanraj2002@gmail.com

D. P. Pahari
Department of Geography, The University of Burdwan, Bardhaman, West Bengal 713104, India

U. Chatterjee et al. (eds.), *Urban Commons, Future Smart Cities and Sustainability*, Springer Geography, https://doi.org/10.1007/978-3-031-24767-5_10

or agriculture to urban use (Dadashpoor and Nateghi 2017; Feng et al. 2016). The process is not limited even to physical phenomena. It overflows the idea of physical space and sets the boundaries towards affecting the economy and livelihood of the people. There are studies about the urban expansion and conversion of land cover classes, but it is essential to see the linkages between spatial phenomena and human activities (Dasgupta et al. 2013). There is a need for the particular development of the city further entitled to the proper management within the city space and the peri-urban villages. There is lacking basic amenities or facilities in different locations within the city or outwards.

Urbanisation is the process of increasing the urban area by size and population. The process is influenced by the growth and expansion of the economic factor within the city space. The outward development of the urban area is often associated with the strategy behind causing the land use change and changes in economic activities. Being a significant contributor to the population in third-world countries, India has emerged as an urban study with its dynamics. Some studies have raised the issues related to the processes and forms of urbanisation in the cities of India. Mohan and Dasgupta (2004) studied that urbanisation was rapid around the globe in the last century. Still, India did not face an urban explosion, as did many regions, and in the Americas. The level of urbanisation in India is increased from 17.6% in 1951 to 23.7% in 1981 and 27.8% in 2001. Kundu (2011) suggested that the processes of urban development in India are not always positive as it has been associated with the accentuation of regional and interpersonal inequality and, unfortunately, with slight poverty reduction. The study by Kundu (2011) also argued that the recent data from the population census cast severe doubt on this joint proposition of rapid urban growth in India. As a result, the urbanisation in India is top-heavy, oriented towards large cities as demographic growth and in-migration impact the growth and investments. The uneven distribution of the new assets has impacted the regional development and investment in the large cities since the early nineties. That has made the urban core where the growth is based on automobile production, consumer electronics, consumer electronics, computer software and information technology, chemicals, petrochemicals and steel production (Shaw 1999). The regions grown in this time mentioned in the study by the author were the Ahmedabad–Pune urban corridor, the southern urban triangle of Bangalore–Chennai–Coimbatore, Delhi and the surrounding areas in Rajasthan and Punjab and new hubs of growth in the south such as Hyderabad, Vishakhapatnam and Kochi.

The unbalanced growth of the cities in India created a top-heavy condition. With more million-plus towns, a small number of cities account for the largest share of the urban population, resulting in distorted regional economic development (Shaban et al. 2020). The hierarchical order is causing less financial return to the small- and medium-sized town in India lacking civic infrastructure and amenities. The three aspects that are important here for sustainability are economy, equity and environment. These components are spatial and can link urban areas and spatial modelling.

Many studies have used spatial data for showing urban growth and modelling different components (Bihamta et al. 2015; Zhang et al. 2015; Hashem and Balakrishnan 2014). The survey by Mondal et al. (2019) performed UGMs, viz. MCCA-MC and SLEUTH model to show the dissimilarity mechanism between the machine learning and rule-based procedure in urban modelling in Udaipur city. The study shows that in the context of urban sustainability, any single model is not sufficient to observe future urban growth patterns as each model serves a specific purpose. Another study by Dutta and Guchhait (2020) shows the changes in the land use and land cover affected by the urban growth in the Kanksa C. D block of Paschim Bardhaman district of West Bengal. The study has shown the changes in the built-up area associated with the rapid development in the areas near industries. The locational impact developed the transport and other facilities to the region and transformed the agricultural land and other lands to the urban.

The state of West Bengal has experienced a high level of urbanisation during 2001–2011 though high inter-district disparity exists in urban population distribution (Ghosh and Chakma 2014). The district Bardhaman is one of the most urbanised districts where the level of urbanisation is high compared to West Bengal and India (Rahaman 2018). The district has played an essential role in the growth of industrial locations and urban centres. The Western Bardhaman comprised of Durgapur-Asansol development area is industrialised and developed the infrastructure. The present condition of the Eastern part and western parts are separate districts, namely Paschim Bardhaman and Purba Bardhaman. The city Bardhaman is located in the eastern part that is Purba Bardhaman district of West Bengal. The study by Arif and Gupta (2020) shows that the municipality Bardhaman is changing rapidly with its effect on the peri-urban spaces. The impact of the city growth has transformed the rural areas in the peri-urban region by affecting the facilities available. The increase and development due to urban expansion in the peri-urban region modify the socio-economic condition and the governance. Monitoring of land use changes is essential to assessing urban growth trends at the local and regional levels for urban planners. The research presented in this paper focused on utilising, multi-temporal satellite data to study the spatial and temporal dynamics of LULC change for Bardhaman City of West Bengal, India.

Study Area

The city Bardhaman (23° 13′ N to 23° 16′ N and 87° 49′ E to 87° 53′ E) is located in Purba Bardhaman district of West Bengal, India (Fig. 10.1). It has been developed on the bank of the Damodar River with historical importance. The city is transformed through the processes of urbanisation from the traditional kinship to the modern. The historical lineage of different rajas in the town enriched the city space with changing economic behaviour in and outside the city area.

The growth of the city area is very rapid with the changing scenario in the infrastructure. The surrounding city blocks of the city area are also experiencing the change

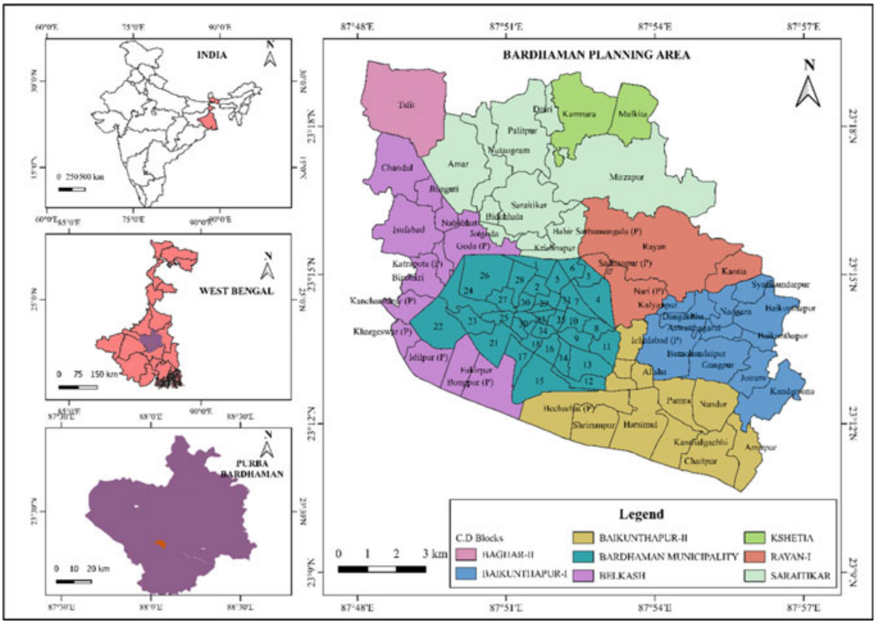


Fig. 10.1 Location map of the study area

through the changing land use and livelihood pattern. The study has chosen the area under Bardhaman planning area demarcated by Bardhaman Development authority. There are 35 wards of 2011 census within the given region and the surrounding 52 villages under different C. D Blocks (Fig. 10.1). The villages are the adjacent peri-urban lands associated with greater connectivity with Bardhaman city. The whole region is demarcated by Bardhaman Development Authority for better management and planning. The centre of the planning area is covered by Bardhaman Municipality. Bardhaman city is 105 km away from the nearest metro-city Kolkata. The connectivity of the region is good with the accessibility of roads and railways. The location and connectivity through the transport network are maintained. It is connected to Kolkata from the south-eastern part and to Durgapur-Asansol to the north-western part. This map shows the location of Burdwan Municipality at the centre and the gram panchayats under Bardhaman Planning Area. There are wards in the municipality and villages under the gram panchayats.

Materials and Methods

For this work, the secondary data have been collected from the following sources (Table 10.1). Burdwan Development Authority has prepared the planning area with Bardhaman Municipality and associated villages (Fig. 10.1). The study area is selected by the area demarcated. Satellite data for Landsat 7, Landsat 5 and Sentinel 2 have been collected from the USGS. Satellite imageries have been classified with supervised classification using the maximum likelihood method. The data of Landsat 5 and Landsat 7 is of 30 m spatial resolution while for Sentinel 2 it is of 10 m. These data have been used for showing the quantitative analysis, and some of the information available from the primary survey has been added to analyse the facts in a better way. The primary survey includes the locations of markets, high-rise buildings, roads and infrastructure of the city in the present context.

The study has incorporated Shannon Entropy methods for showing the changes in the built-up area around the city using geospatial data. In addition to this, the primary survey helped to understand the structure of the city. The structure of the methods is represented in the figure (Fig. 10.2). The study area is demarcated with the map collected from Burdwan Development Authority. The wards under Bardhaman Municipality and surrounding villages of Bardhaman Planning area are selected. To see the change in the built-up, the remote sensing data of 2001, 2011 and 2021 have been used with the method of supervised classification. The increase in the area outside the municipality is shown with the mapping.

Table 10.1 Details of materials used in the study

Source	Particular	Year of survey/imaging	Scale/resolution	Remarks
USGS	Landsat 7 (Path 139, Row 44) Landsat 5 (Path 139, Row 44)	26.10.2001 04.03.2011	30 m 30 m	• Used for supervised classification for 2001 and 2011
USGS	• Sentinel 2 data	24.04.2021	10 m	• Used for supervised classification of 2021
Census of India	• Ward map and villages (Administrative Atlas)	2011	–	• Used for study area map
Burdwan development authority	• Bardhaman Planning Area map	2017	–	• Demarcation of the study area

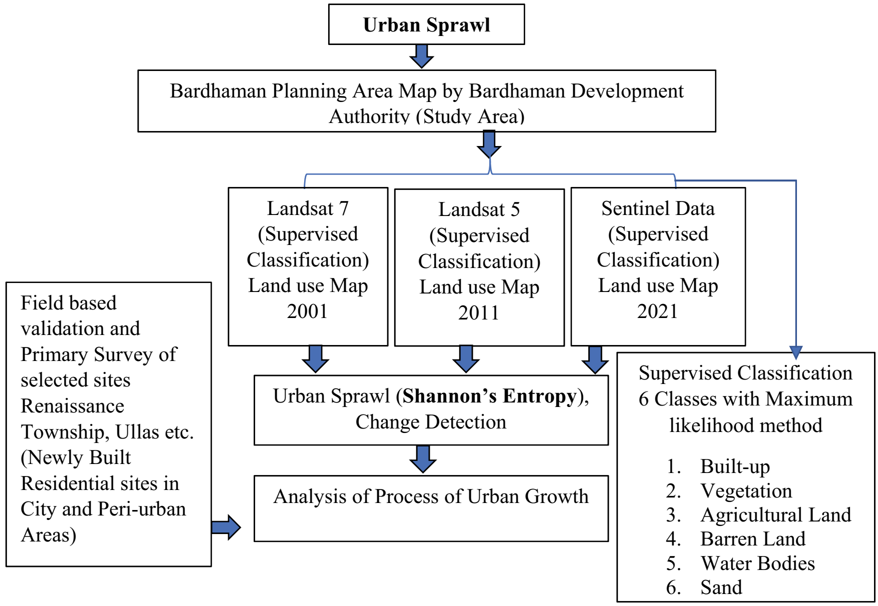


Fig. 10.2 Workflow of the study

Result and Discussion

Changes in the Land Use and Land Cover in Bardhaman Planning Area

Bardhaman Development Authority has demarcated the areas surrounding for future development and planning. The villages under different C. D blocks are in this development planning, covering different aspects. The changes of land use and land cover through the corridor of transport are happening. The land use and land cover analysis of the Bardhaman Planning Area revealed such a picture from the last decades. The total area under Bardhaman Planning Area is 154 km^2 covering the agricultural land primarily as the whole plain of Damodar River is fertile and known for rice cultivation.

The whole area under study is covered with agricultural plains, and rice cultivation is rapid. The land use and land cover analysis show the changes in the built-up area at a rapid rate than the other land use where the area under vegetation is also essential. In the southern end, the location of the Damodar River restricted the growth of the built-up area. The area under agricultural land covered 99.4 km^2 in 2001 and was reduced to 88.8 km^2 in 2021 (Table 10.2). The reduction of the area under agriculture is the process of urbanisation that causes most cases. The land was converted to built-up or kept as barren land for non-agricultural use in future. The map shows that the urban-centric growth of the study area covered the middle of the location, which is the location of Bardhaman city. The surrounding locations are rural areas dominated mainly by agricultural areas (Fig. 10.3). The vegetation cover is 19.8 km^2 (12.9%), barren land is 6.7 km^2 (4.4%), built-up is 14.7 (9.5%), and the rest of the 9% area is covered by water bodies and sand in the year 2001.

In 2011, the built-up is increased to 18.6 km^2 (12.1%) with a slight reduction of agricultural land to 98.4 km^2 (63.7%), an increase of barren land to 8.3 km^2 (5.4%) and the water bodied and sands remained almost identical (Fig. 10.4). In

Table 10.2 Area under different land use land cover categories in Bardhaman planning area in 2001, 2011 and 2021

Land use land cover classes	Area in km^2			Percentage		
	2001	2011	2021	2001	2011	2021
Built-up area	**14.7**	**18.6**	**22.9**	**9.5**	**12.1**	**14.8**
Vegetation	19.8	16.3	16.1	12.9	10.6	10.4
Agricultural land	**99.4**	**98.4**	**88.8**	**64.4**	**63.7**	**57.5**
Barren land	6.7	8.3	12.2	4.4	5.4	7.9
Water bodies	4.0	3.2	4.6	2.6	2.1	3.0
Sand	9.8	9.6	9.8	6.3	6.2	6.4
Total	154.4	154.4	154.4	100	100	100

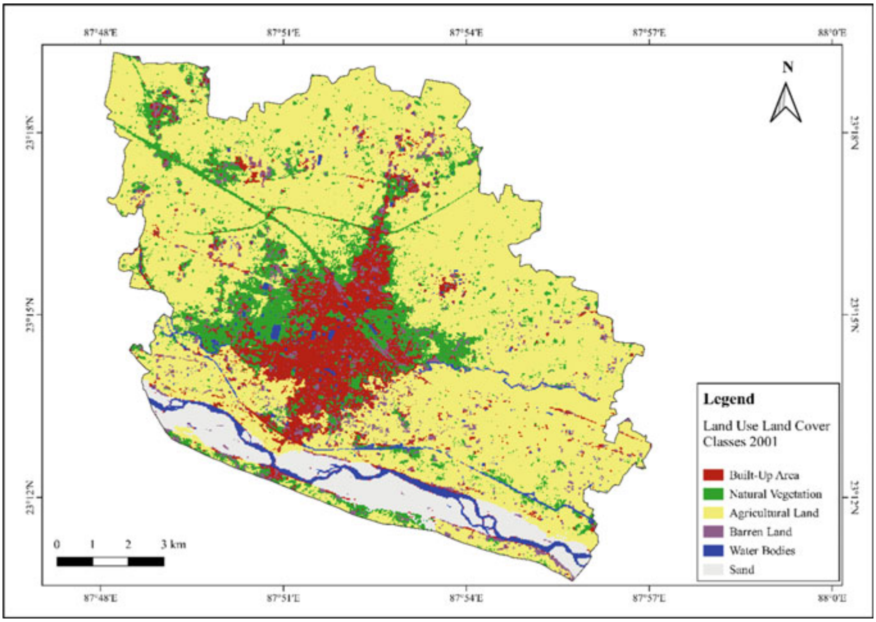


Fig. 10.3 Land use land cover map of Bardhaman planning area 2001

2021, the growth of the built-up area has covered a larger area in this plain. Here, the built-up area grew to 22.9 km^2 (14.8%), vegetation decreased to 16.1 km^2 (10.4%), agricultural area decreased to 88.8 km^2 (57.5%), barren land increased to 12.2 km^2 (7.9%) and the slight increase in the area of water bodied and sand (Table 10.2). The land use land cover map of 2021 shows the reduction of the green areas and increased built-up in the western direction (Fig. 10.5). From the land use maps of 2001, 2011 and 2021, it is clear that the adducent areas to the urban are being converted to built-up areas faster. Some of the lands were kept as barren land in 2011, and those lands were converted into built-up in 2021.

The graph (Fig. 10.6) shows the percentage share of different land use land cover for different years. By considering the total plain of the Bardhaman Planning Area, it is clear that the agricultural land dominates the area, but even there is a reduction in the land used for agriculture. The increase is for built-up and barren land specifically. The rise in the area for barren land is also a concern for the planning of the area. Many builders are buying the lands for construction purposes the way is leading to the reduction of the large plot of agricultural area and converting it into barren land.

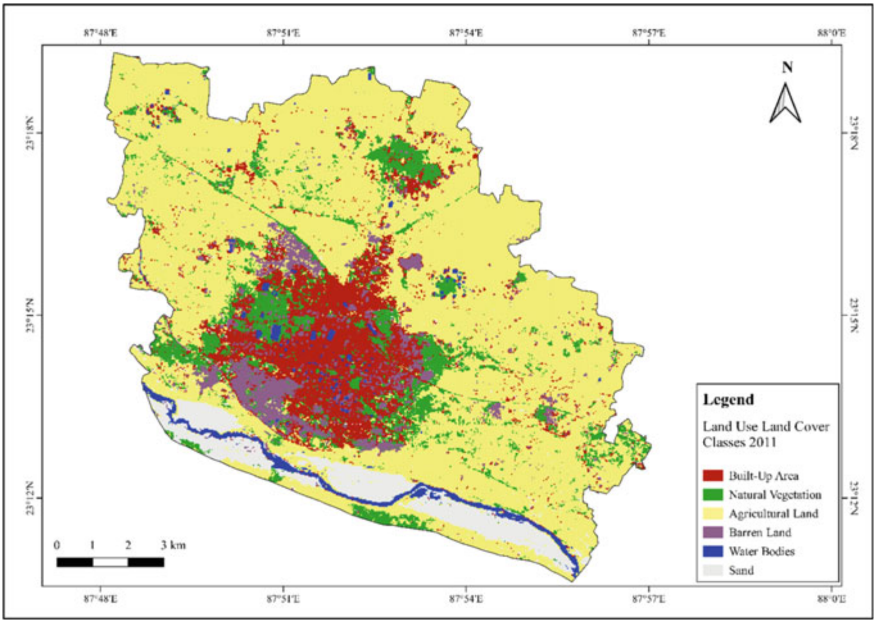


Fig. 10.4 Land use land cover map of Bardhaman planning area 2011

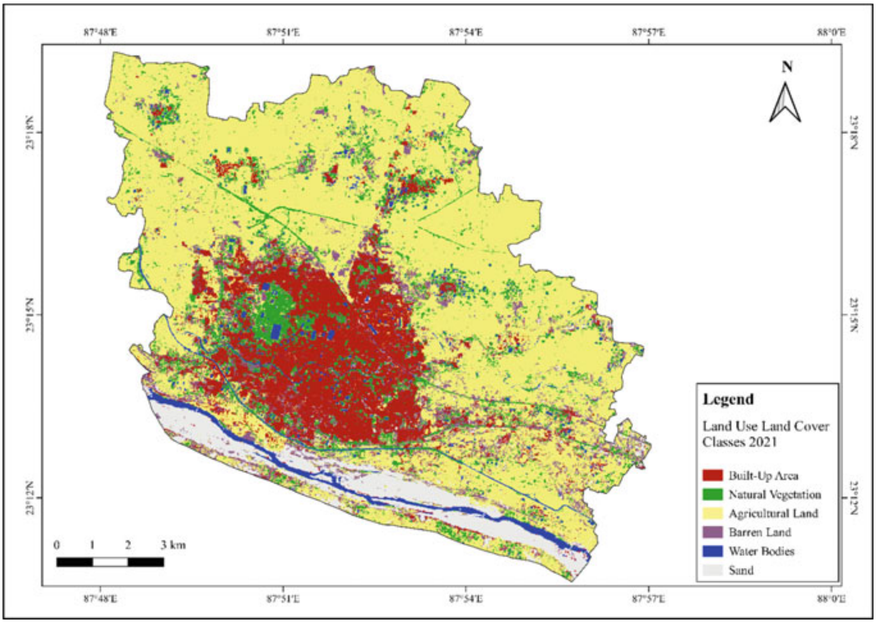
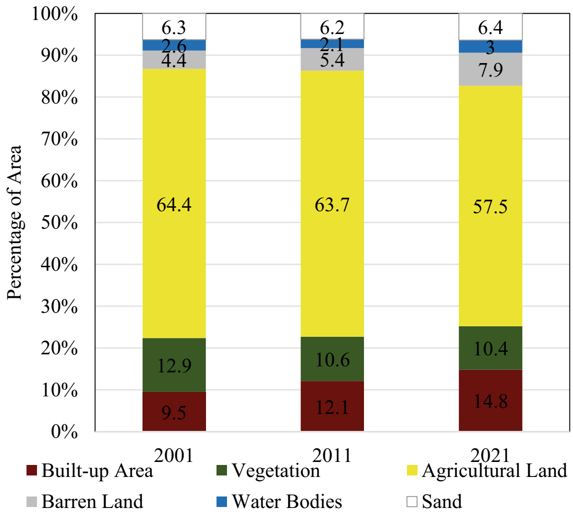


Fig. 10.5 Land use land cover map of Bardhaman planning area 2021

Fig. 10.6 Changes in the percentage of area under different land use and land cover in Bardhaman planning area 2001, 2011 and 2021



Change Detection and Area Converted to Built-Up in Bardhaman Planning Area

The change detection analysis needs to know which lands are converted into the built-up area. As the study focuses on the increasing urban areas, the areas and location change as built-up areas are given preferences. In Fig. 10.8, the areas inside the municipality and in the northern portion changed to built-up mainly from the agricultural land and vegetation. From 2011 to 2021, the barren land has much of the newly built settlement area share. The south-western corner of the municipality is grown from the barren land (Fig. 10.9). By comparing the change from 2001 to 2021, it is clear that mostly the vegetation and agricultural lands are converted. It is converted into a built-up area with some barren land (Fig. 10.10). The land converted to built-up from water bodies and sand is negligible.

In the graph below, the area converted to built-up from different land use categories. The total area added to built-up is coming from vegetation (3 km^2), agricultural land (4.1 km^2) and barren land (1.8 km^2) from 2001 to 2011. As the total area added to build-up increased, the area from different land use land cover converted to built-up also increased. It is from vegetation (3.5 km^2), agricultural land (4.5 km^2) and barren land (3 km^2) from 2011 to 2021 (Fig. 10.7).

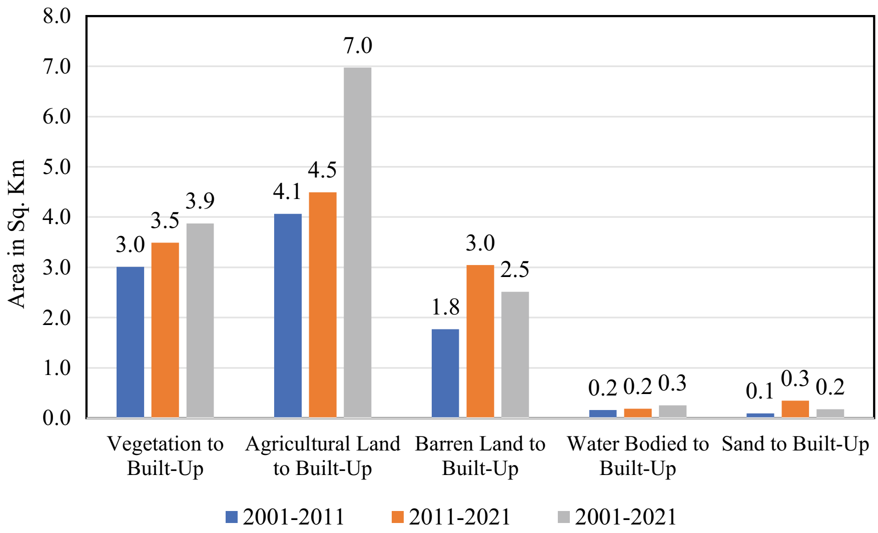


Fig. 10.7 Area converted to built-up (2001–2011–2021) (Agriculture, vegetation and barren land are being converted to built-up where the share of agriculture is at its highest from 2001 to 2011)

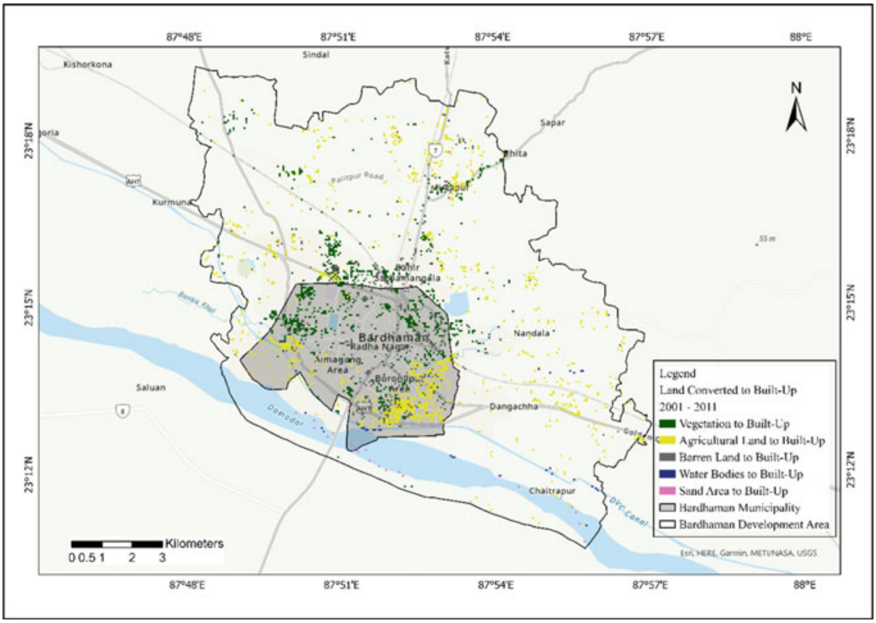


Fig. 10.8 Change detection map (Agricultural land and vegetation to built-up) 2001–2011

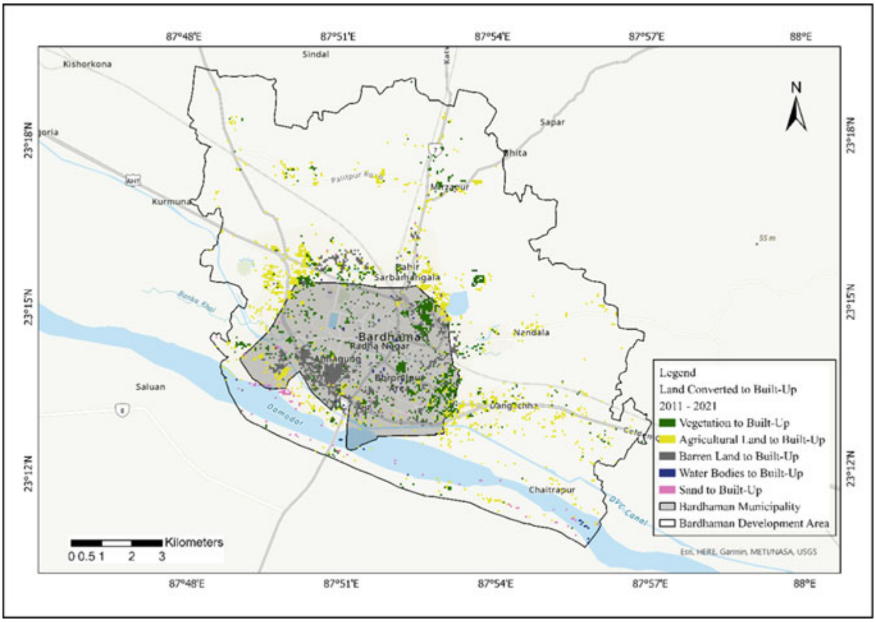


Fig. 10.9 Change detection map (Agriculture and barren land to built-up) 2011–2021

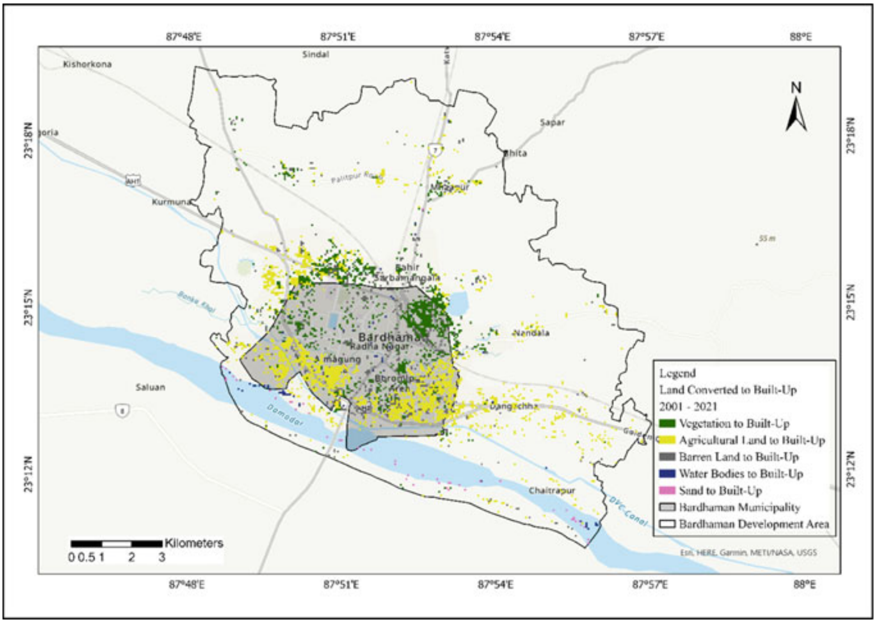


Fig. 10.10 Change detection map (Agricultural land to built-up) 2001–2021

Urban Sprawl and Expansion of the City Area

The studies of Urban sprawl depict some specific scenarios of urban expansion where uneven growth is taking place. Many cities in developing countries have uncontrolled growth in the urban area, which occurs through different processes. The result of the uneven growth often leads to the improper management of resources. The land conversion processes through the urban expansion often led to reducing agricultural land and natural vegetation. The loss of such land use and land cover categories would further need attention. There are many studies which focus on the spatial expansion of the cities covering the peri-urban spaces. Urban growth has direct linkages with the peri-urban landscape. The nearby areas are often connected with the city through which the urban expansion process impacts the spatial elements and livelihood.

The urban expansion in the city is demarcated here in this study. There are locations of the peri-urban spaces surrounding the wards of Bardhaman Municipality. Urban sprawl is seen here in respect of the area increase in built-up. The total area increased is significantly developed through the plain. The built-up area shown in the map with three colours shows the area under built-up in different times, 2001, 2011 and 2021. The red one was the built-up area in 2001, the orange one was the additional area under built-up in 2011, and the green one is the additional area in 2021 (Fig. 10.11). The total area under built-up has grown from 14.7 km^2 in 2001 to 22.9 km^2 in 2021 (Fig. 10.12). The area is increased from 9.5 to 14.8% from 2001 to 2021 (Fig. 10.13). The direction expansion is obstructed by the location of the Damodar River in the

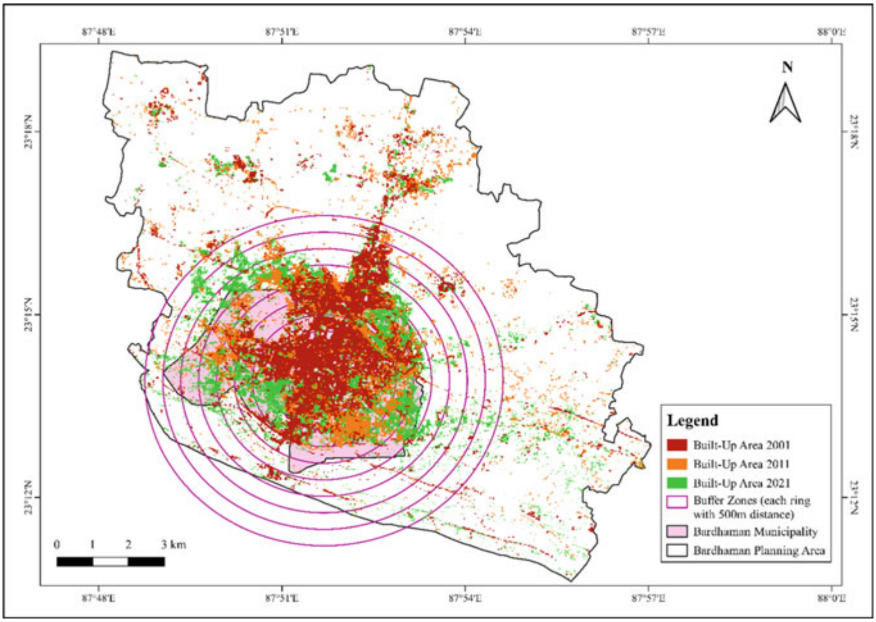


Fig. 10.11 Expansion of urban areas leading to sprawl outside municipality by showing four buffer rings of 500 m distance for the years 2001, 2011 and 2021

southern part of the city. The city thus has grown towards the western and northern portions. From the centre of the city, 1 km of buffer rings has shown the growth pattern in a different direction. In the northern portion, the built-up area has crossed the outer boundary of the municipality. The buffer rings cover the four rings with the 4 km of the outer limit. In the northern and western parts, the built-up area has crossed the fourth ring, which means it is growing faster with the distance away from 4 km from the city centre. It is covering only 2 km of distance in the southern part (Fig. 10.11). The city Bardhaman has grown in the past centuries for its spatial advantage. The city is very much connected to the nearest metropolitan city Kolkata through roads and railways. Education, medical facilities, transportation, marketing and large agro-based industries like rice mills have been the centripetal forces driving this town's urbanisation. Rural–urban dynamics are driven by the massive urban demand to provide basic services and job opportunities close to urban industrial areas.

Shannon's Entropy Index for Urban Sprawl

The increase in the built-up area is seen around the city causing the urban sprawl. For the continuous growth of the built-up, Shannon's Entropy method has been applied with the identification of the concentric ring zones around the city. The rings have

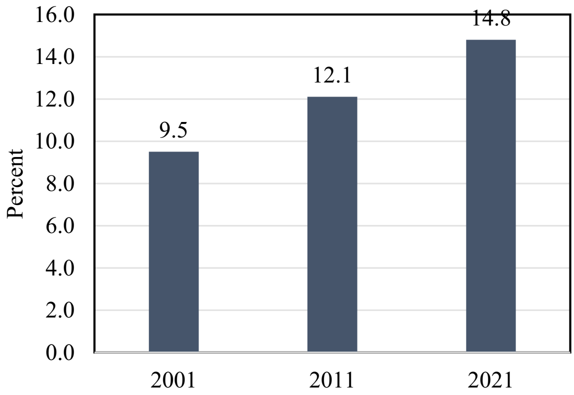


Fig. 10.12 Increase of built-up area in percentage

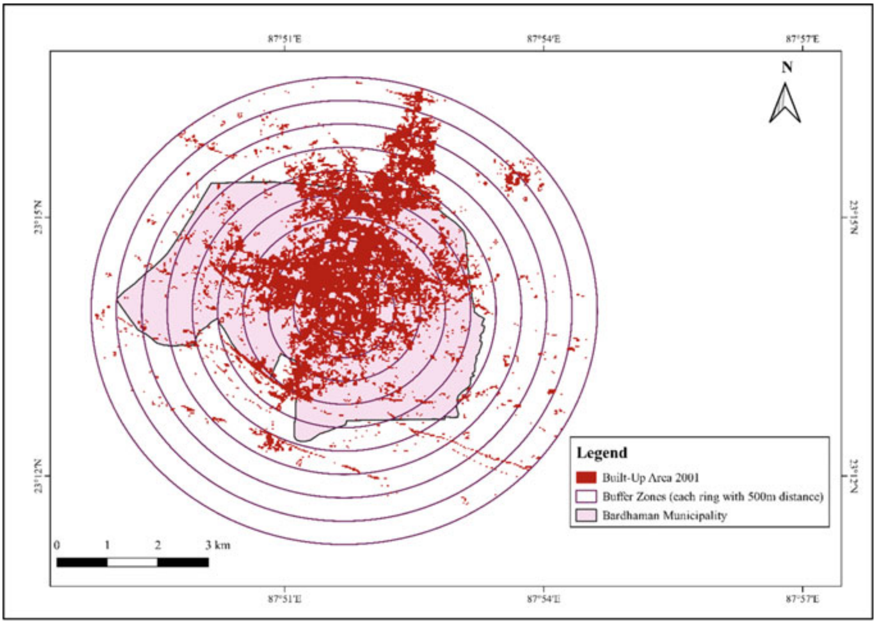


Fig. 10.13 Built-up area in the concentric ring zones for Shannon's entropy 2001

been created with 500 m distance multiple buffer rings, and the proportion of the built-up area has been taken for the calculation. The built-up area in 2001 (Fig. 10.13) is not covering much of the buffer rings whereas in 2011 (Fig. 10.14) the area increased. In 2021 (Fig. 10.15), there is growth in the buffer rings of northern and western side. With the calculation of the area under built-up with Shannon's Entropy, the sprawl area can be demarcated in the buffer zones outside the municipal boundaries. The

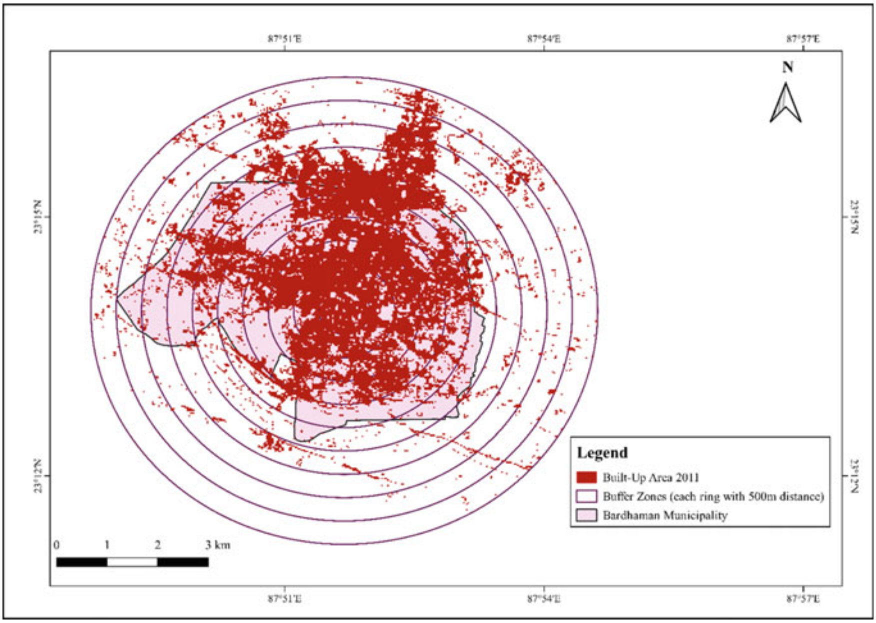


Fig. 10.14 Built-up area in the concentric ring zones for Shannon's entropy 2011

index value of Shannon's Entropy increased from 2.35 to 2.51 from 2001 to 2021 (Table 10.3). The increase in the built-up area across different zones is rapid from 2001 to 2021 where it has been increased from the 1.5 km distance from the centre of the city up to 4.5 km visible in the graph till nineth ring (Fig. 10.16).

$$\text{Shannon's Entropy Hn} = S\ \text{Pi}\log(\text{Pi})$$

Where Pi = Proportion of Built-up area in *i*th Zone.

Total number of zones = 10.

Conclusion

The primary land conversion is clear from the overall analysis of urban sprawl and the land use and land cover change. From this section, the spatial extent of the urban sprawl is measured with the direction of growth. The city's northern and western parts have grown faster, and the land conversion processes depict a specific pattern. In the first stage, the city was restricted in the municipal boundaries with lesser impact in the peri-urban areas. In the second stage, the city has grown to peri-urban spaces

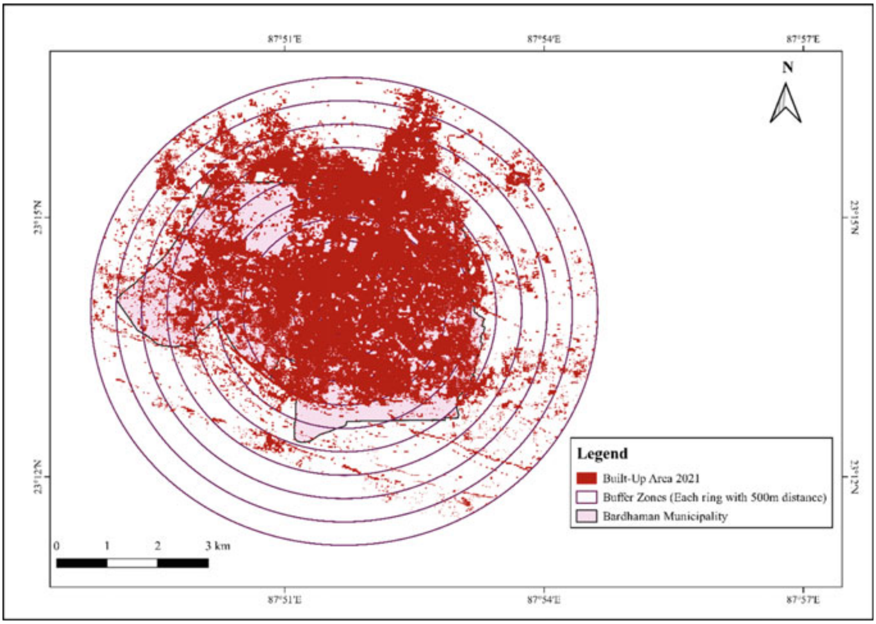


Fig. 10.15 Built-up area in the concentric ring zones for Shannon's entropy 2021

Table 10.3 Shannon's entropy index

Year	2001	2011	2021
Shannon's entropy index	2.353	2.489	2.511

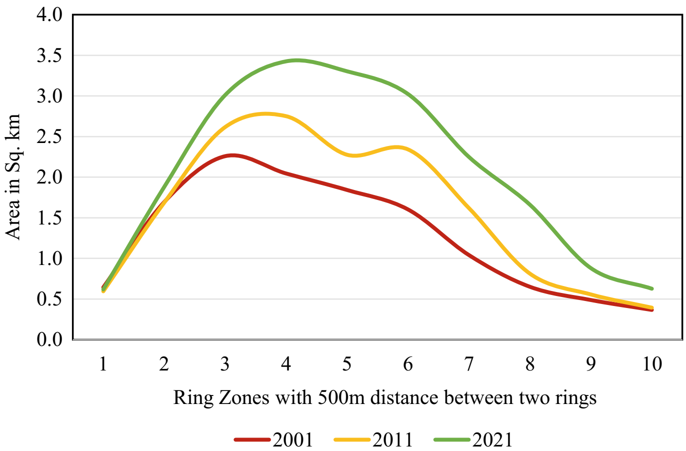


Fig. 10.16 Built-up area in the concentric ring zones for 2001, 2011 and 2021

and modified with the land use transformation. The agricultural lands were bought and kept vacant for years in outward zones. In the third stage, the converted barren lands were used for new built-up. This city has transformed from the earlier stage with the expansion of the built-up area. The process of converting the agricultural land directly for built-up or through the barren to built-up is going on with faster conversion of peri-urban lands to urban use. There are new townships and urban settlements grown outside the city. This growth around the city of Bardhaman is reducing the agricultural land and occupying a large area under different projects. The land conversion is rapid for the city in the last ten years, where the settlement has covered the area in the northern and north-western regions around the concentric rings around the city. The study will aid urban planners, stakeholders, administrators and policymakers in planning regional industrial development and amending the existing policy to better manage sustainable urban development practices. Research from this study may also provide guidance for future studies examining other stressors and how they may affect the local environment.

References

Al-shalabi M, Billa L, Pradhan B, Mansor S, Abubakr A, Al-Sharif A (2012) Modelling urban growth evolution and land-use changes using GIS based cellular automata and SLEUTH models: the case of Sana'a Metropolitan city Yemen. Environ Earth Sci 70:425–437

Arif M, Gupta K (2020) Spatial development planning in peri-urban space of Burdwan City, West Bengal, India: statutory infrastructure as mediating factors, S.N. Appl Sci A Spring Nat J

Bihamta N, Soffianian A, Fakheran S, Gholamalifard M (2015) Using the SLEUTH urban growth model to simulate future urban expansion of the Isfahan metropolitan area Iran. J Ind Soc Remote Sens 43(2):407–414

Dadashpoor H, Nateghi M (2017) Simulating spatial pattern of urban growth using GIS based SLEUTH model: a case study of eastern corridor of Tehran metropolitan region. Iran Environ Dev Sustain 19:527–547

Dasgupta S, Asvani K, Gosain K, Rao S, Roy S, Sarraf M (2013) A megacity in a changing climate: the case of Kolkata. Clim Chang 116:747–766

Dutta S, Guchhait SK (2020) Assessment of land use land cover dynamics and urban growth of Kanksa Block in Paschim Barddhaman District, West Bengal, GeoJournal, Springer

Feng Y, Liu Y, Batty M (2016) Modeling urban growth with GIS based cellular automata and least squares SVM rules: a case study in Qingpu-Songjiang area of Shanghai China. Stoch Env Res Risk A 30:1387–1400

Ghosh B, Chakma N (2014) Urbanisation in West Bengal: an analysis of recent processes, space and culture India 2:2

Hashem N, Balakrishnan P (2014) Change analysis of land use/land cover and modelling urban growth in Greater Doha. Qatar Ann GIS 21(3):233–247

Kundu A (2011) Trends and processes of urbanisation in India, Human settlement group IIED and population and development Branch, UNFPA, Urbanization and Emerging Population Issues-6

Mohan R, Dasgupta S (2004) Urban development in india in the twenty-first century: policies for accelerating urban growth, Stanford center for international development, Working Paper No. 231

Mondal B et al (2019) Evaluation of spatial modelling approaches to simulate urban growth dynamics: a case study on Udaipur city, India, Geocarto International, Taylor and Francis

Rahaman M (2018) Trend of urbanisation in Bardhaman District West Bengal, India. Int J Current Adv Res 7(2):10421–10426

Shaban A et al (2020) India's urban system: sustainability and imbalanced growth of cities. Sustainability, MDPI

Sharma R, Joshi PK (2012) Monitoring urban landscape dynamics over Delhi (India) using remote sensing (1998–2011) inputs. J Ind Soc Remote Sens 41:641–650

Shaw A (1999) Emerging pattern of urban growth in India, economic and political weekly

Zhang H, Jin X, Wang L, Zhou Y, Shu B (2015) Multi-agent based modeling of spatiotemporal dynamical urban growth in developing countries: simulating future scenarios of Lianyungang city, China. Stoch Environ Res Risk Assess 29:63–78

Chapter 11
Urban Sprawl and Landscape Transition in Awutu Senya East Municipal Assembly

Cudjoe Justice and John Manyimadin Kusimi

Abstract The rapid rate at which cities and towns are urbanising is of concern to urban planners globally. Urbanisation has caused urban sprawl and densification of urban landscapes of cities. This chapter is based on a project that has used remote sensing and social survey methods to assess the transformation of the physical landscape into urban landscape in the Awutu Senya East Municipality between 1986 and 2021. Remote sensing analysis entailed image classification and change detection. Social survey involving questionnaire administration and key informant interviews were conducted to ascertain the causes and impacts of declining vegetative cover. Vegetation and barelands were more transformed into urban landscape. Rising population of the locality related to urban sprawl and intensification causing a decrease in vegetal cover and barelands from a coverage of 53.5% and 35.4%, respectively, in 1986 to 15.3% and 13.7%, respectively, in 2021, while built-up environment increased from 9.7% in 1986 to 70.6% in 2021. Most conversions of vegetation were between 1986 and 2002, barelands between 2002 and 2021 while built-up assumed a rising trend throughout the period. The main driving force of vegetal and bareland diminution is urbanisation which caused an increase in the built-up environment. The landscape transformation is perceived to be causing urban heat, urban aesthetic damage, flooding, etc. The study recommends the development and implementation of a land use plan focusing on urban greening to improve upon the ecological services of the municipality.

Keywords Kasoa · Land use and land cover change · Remote sensing analysis · Urban green space · Urbanisation and urban sprawl

C. Justice · J. M. Kusimi (✉)
Department of Geography and Resource Development, University of Ghana, Legon, Accra, Ghana
e-mail: jmkusimi@ug.edu.gh

C. Justice
e-mail: jcudjoe004@st.ug.edu.gh

U. Chatterjee et al. (eds.), *Urban Commons, Future Smart Cities and Sustainability*, Springer Geography, https://doi.org/10.1007/978-3-031-24767-5_11

Introduction

The world is becoming progressively more urbanised. Urbanisation rate is increasing at an unprecedented rate, mostly within the developing countries in sub-Saharan Africa and Asia (United Nations Department of Economic and Social Affairs [UNDESA] 2018). According to UNDESA (2018), as the world urban population continue to increase, cities will further expand to other remote areas and create mega cities culminating into urban sprawl. This global growth in urban population is because of demographic factors mostly rural–urban migration which has seen a surge in recent years in developing countries (Acheampong et al. 2019). About 55.7% of the world population as of 2019 lived in urban areas, as compared to 30% urban population in 1950 with the urban population of developing countries like Ghana, Nigeria, Kenya projected to double by the year 2050 (UNDESA 2018). Addae and Oppelt (2019) have also postulated that about 40% of the population of Africans that lived in urban areas as of 2014 are projected to increase to about 56% by 2050.

The rate at which Ghana is urbanising is very rapid. According to Ghana Statistical Service (2014), the urban population of the country has increased from about 23.1% in 1960 to about 50.9% and has been predicted to further escalate within the next coming years (Owusu 2018). Most of the urban population in Ghana is seen to be concentrated within Accra; the national capital followed by Kumasi and Tamale (Addae and Oppelt 2019). According to Adarkwa (2012), since the pre-colonial era, there has been extensive change in urbanisation and urban infrastructure of Ghana owing to colonial policies and strategies which developed areas of natural resources and national/regional capitals. The bruises of these situation among other factors have ended up with Accra been the most urbanised region in Ghana, having about 90.5% urban population as of 2010 and continuous to urbanise in recent years (Ghana Statistical Service [GSS] 2012).

Urbanisation directly influences and alters vegetation in the world and is a major phenomenon that contributes largely to the alteration of the natural vegetation (Cao and Natuhara 2019; Owusu 2018). The spreading of towns and cities due to the rapid escalation of urban population has also led to the situation where there is a rapid transformation of agricultural land to urban land use (Acheampong et al. 2019). Thus, agricultural lands, vegetative covers and other land use and land cover (LULC) get transformed to residential and commercial space to suit the growing population. Some impacts of urban sprawl include loss in peri-urban lands and environmental pollution, loss of indigenous species of plants and animals, reduced tourism and loss of ecosystem services that are vital to humans (Agyeman 2018; Blay 2019; Cobbinah and Amoako 2012).

Due to the rapid rate at which the Greater Accra Region has urbanised, it has been challenging for the local authorities to manage urban sprawl and the cascading effects (Addae and Oppelt 2019). The Greater Accra Region has sprawled into neighbouring regions like the Central Region where the Awutu Senya East Municipality is located. The Greater Accra Region has the highest migrants of 23,673 people residing in the municipality (Ghana Statistical Service 2012). A respectable number of government employees and businessmen now stay in the Awutu Senya East Municipality and work in Accra. Significant vegetal cover has been converted into open spaces for the sake of livability. The proportion of the population living in urban areas in Awutu Senya Municipality as of 2010 is 94.1% compared to 5.9% in the rural areas (Ghana Statistical Service 2014). The urbanisation of the municipality has caused land cover transformations. The municipality which was known to be highly agricultural and whose land was mainly used to produce food and other agricultural purposes has turned into residential areas to serve the escalated urban population of Accra. There is the need for urban planners to put in measures to curb the indiscriminate destruction of vegetation as a result of urbanisation and urban sprawl due to the several benefits urban vegetation offers: including carbon sequestration, air filtering, reduction of heat, beautification, and recreation, and the stabilisation of the ecosystem and microclimate among others (Owusu 2018). Despite the numerous benefits urban vegetation brings to the cities, protecting vegetation in urban areas has become very difficult to achieve in sprawling cities in the developing worlds like Ghana. Stow et al. (2016) in a study of towns in four regions of southern Ghana between 2000 and 2010 revealed that 1.5% of the study area transitioned to built, an increase of 56% built area since 2000, while population increased by 33%. Anarfi et al. (2020) also showed that urbanisation has been rapid in Kumasi and Obuasi over the years and this has resulted in changes in land cover in the localities between 1986 and 2018. Other studies that analysed the nexus of urbanisation, urban sprawl and land use and land cover changes in Ghana include Owusu (2018), Addae and Oppelt (2019), Acheampong (2019), Blay (2019) among others. What are the urbanisation effects on vegetal cover and what have been the effects of urbanisation on the earth's systems? It becomes very expedient to investigate the changing trends of vegetal cover amidst rapid urbanisation in a developing country like Ghana to contribute to the literature. By employing remote sensing approach, researchers have been able to come out with major findings and suggestions to curb the issue of urbanisation associated with vegetation and other land conversions (Anarfi et al. 2020; Cai et al. 2019; Stow et al. 2016; Yang et al. 2017). Thus, to better understand the scenario of the adverse effects of urbanisation and urban sprawl on the vegetal cover and other landscape elements in the area, the study undertook a spatio-temporal analysis of the land use and land cover changes in the locality between 1986 and 2021 using remote sensing.

Literature Review

Urbanisation and Urban Sprawl

The urban area can be considered as a composite of built-up and the non-built-up (vegetated or bareland) surfaces in urban areas (Zhou et al. 2014a, b). Acheampong et al. (2019) defined urbanisation as the increase in the number of people living in the towns and cities within a particular country. This is when the population of cities increases leading to the expansion of the cities. The total number of inhabitants that qualify a town to be classified as urban is not universal, but it depends on the population criteria for defining urban centres in a particular country. For example, in Denmark, a town with 250 inhabitants can be classified as urban; 1,000 in Greece; and 20,000 in Nigeria (Bodo 2019); while in Ghana, localities with a population of 5,000 are classified as urban (GSS 2014). The increase in population according to Acheampong et al. (2019) could be caused by numerous factors. They stated that countries with high economic growth like China with a low rate of childbearing have their growth in urban population caused by in-migration, while developing countries of sub-Saharan Africa had experienced growth mainly because of natural increase, thus high birth and low mortality rates coupled with rural–urban migration. Glaeser (2014) relates urbanisation to globalisation, agricultural productivity, transport improvements in an open economy. According to modernisation and urban bias theories, rural–urban migration, natural population growth, economic development, infrastructure are the noted driving forces of urbanisation of cities globally; however, some of these factors are not very tenable in the developing countries (Njoh 2003; Park et al. 2017). A resultant effect of urbanisation on peri-urban fringes is urban sprawl.

Urban sprawl has various definitions depending on the context and characteristics pertaining to regions. Urban sprawl according to Cobbinah and Amoako (2012) refers to the unstructured model of development mostly around peri-urban areas. Johnson (2001) also defines urban sprawl as urban development with low-density housing, both residential and commercial, segregated land use and high level of automobile use combined with lack of public transport. Urban sprawl is mostly characterised by scattered, spread out, little planning control of land development and discontinued development (Habibi and Asadi 2011; Liu et al. 2018). Habibi and Asadi (2011) and Liu et al. (2018) have enumerated the characteristics of urban sprawl and among them are low-density residential and commercial settlements, leapfrogging of development, dominance of private transport system, loss of farmlands and income inequality among dwellers. As the population of inner cities increases, the economic, environmental and sanitary problems of urbanisation in these areas also increase pushing the marginalised to urban fringes. Other triggers of urban sprawl comprise high income, high taxation, increase crimes, high land value/land financing in the city centres thus pushing the marginalised to the periphery (Habibi and Asadi 2011; Han 2020). This therefore results in more people choosing to stay on the fringes of the city where the associated impacts cannot be felt. This causes urban sprawl, as is the case of Accra and Kasoa, Kumasi, Obuasi and other cities in Ghana (Cobbinah and Amoako 2012; Blay 2019).

Effects of Urbanisation and Urban Sprawl on Earth's Systems

The benefits of urban vegetation are air purification, carbon storage, biodiversity conservation, enhancement of urban aesthetics and beautification, regulation of storm water and the microclimate (Kabisch et al. 2015; Wolch et al. 2014). These ecosystem services of urban vegetation improve public health, increase the life quality of urban citizens by offering aesthetic enjoyment, recreational opportunities which contribute to the improvements in physical and psychological wellbeing of residents (Dong et al. 2022; Luan and Li 2021; Zhang et al. 2022). The effects of urbanisation and urban sprawl on earth's systems are legion. In developing countries, the direct effect of urbanisation is urban sprawl due to uncontrolled development. Urban expansion results in environmental degradation and pollution and ecosystem transformation of urban periphery and rural areas (Saaty and De Paolo 2017; Xie and Liu 2019). Other effects include urban heat island and the degradation of the many ecological services enumerated (Yang et al. 2017). The impact of urban sprawl on vegetation has therefore been the focus of many scientists like ecologists, urban planners, climatologists among others.

Two differing views have emerged in response to urbanisation: sprawling into peri-urban landscape or densify/compact city through the development of existing urban green space (UGS) (Dallimer et al. 2011). Urban sprawl is noted to threaten the peri-urban and rural areas (Antrop 2004; Haaland and van den Bosch 2015; Swenson and Franklin 2000) while densification leads to green space loss within the cities and threaten urban agriculture and gardening (Haaland and van den Bosch 2015; Zhao et al. 2013). With the projected population of people living in urban areas expected to increase to 68% by 2050 (UNDESA 2018) urban sprawl and/or densification or the compact city approaches become inevitable.

The problems of urban sprawl have been recognised and discussed from the 1960s (Jacobs 1961) and the term compact city/densification dates to the 1970s (Dantzig and Saaty 1973; Breheny 1996) and has increasingly been debated since the 1990s (Newman 1992; De Roo 2000). Westerink et al. (2013) provided an overview of both advantages and disadvantages of urban sprawl and compact city development which are related to environmental, social, economic and resilience factors. Though there is evidence of loss of urban green space due to densification processes worldwide in Asian, Australian, some European and North America cities (Dong et al. 2022; Haaland and van den Bosch 2015), some studies are however showing reverse trends of increasing urban green space in China and most European cities because of strategic development policies and plans (Liu et al. 2022; Zhang et al. 2022; Zhao et al. 2013). Dong et al. (2022) revealed that approximately, 93.3% of some China cities showed significant decreasing trends of UGS coverage from $12.23 \pm 0.32\%$ in 2003 to $7.69 \pm 0.22\%$ in 2015. On the contrary, Zhao et al. (2013) found average green space coverage of some cities in China to increased steadily with urbanisation from 17% in 1989 to 37.3% in 2009. Sustainable urban development policies are key to managing the problems of sprawling and densification in our cities.

Study Area

Awutu Senya East Municipal Assembly (ASEMA) is in the Central Region of Ghana and is located on latitude 5°45′ south and 6°00′ north, and longitude 0°20′ west and 0°35′ east (Fig. 11.1) (GSS 2014). It is located about 31 km away from the national capital Accra with Kasoa as its capital (GSS 2014). It covers about 10 km^2 and is bordered by the Ga South Municipal Assembly, Awutu Senya and Gomoa East Districts at the east, north, west and south, respectively (Fig. 11.1).

The land area is made of isolated undulating highlands which range between 76 and 300 m above sea level. The soil is loamy with lowlands soils being clayey. The soil supports arable crops like pineapple, cassava, plantain, yam, maize, citrus and pawpaw. River Okrudu is the main river draining the landscape which overflows its banks and causes flooding in the rainy season (GSS 2014; Blay 2019). The municipality lies in the southwest plains of Ghana, characterised by high temperatures throughout the year. Temperatures range between 23 and 33 °C per annum. The average annual rainfall is about 750 mm. The municipality lies in the semi-deciduous forest zone. It is covered with short trees, shrub and grassland (Dickson and Benneh 1995). Trees cluster with height averaging 5 m and some short grasses that barely exceed 1 m. The population of the municipality was 108,422 as of 2010 and 94.1%

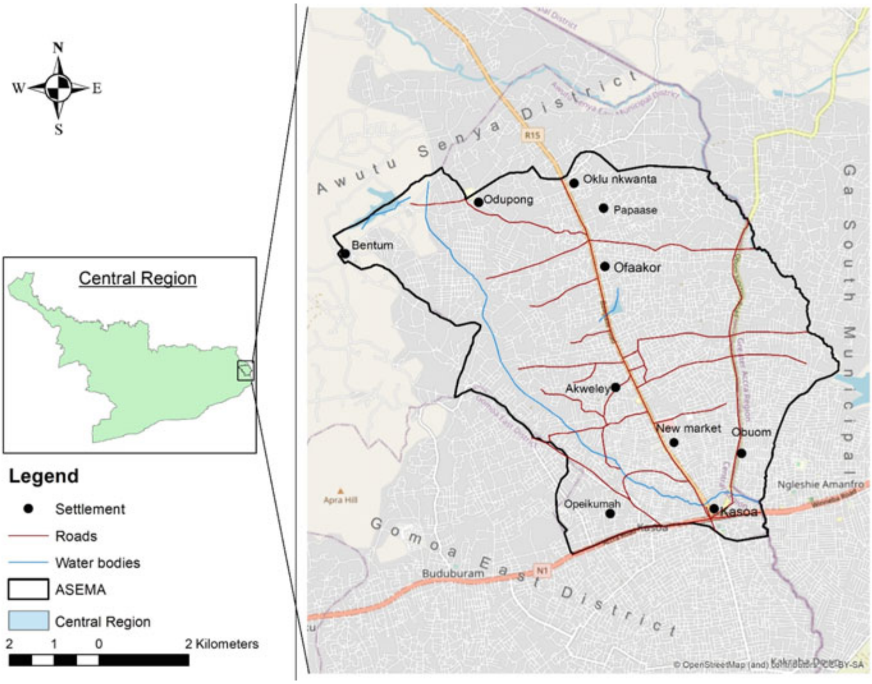


Fig. 11.1 Map of Awutu Senya East Municipal Assembly. *Source* Authors' construct

of the population live in urban areas as compared to 5.9% in the rural areas (GSS 2012). According to the Ghana Statistical Service (2012), a significant number of its population are migrants from most parts of the country. About 69.4% of the total population are economically active and engage in agriculture, service production, sales, craft and related trade works. There has been a very significant shift from farming to manufacturing and service production in the district owing to the taking over of agricultural land for residential and commercial activities (GSS 2012).

Materials and Methods

The study was carried out using an integrated method of remote sensing and social survey to assess the effects of increased urbanisation, urban sprawl on the vegetal cover and other elements of the earth system. The study used Landsat 4, Landsat 5 TM and Landsat 7 ETM+ images that were acquired in the years, 1986, 2002 and 2021 with attributes specified in Table 11.1. We chose 1986 as the base year for our analysis because there were no data (aerial photographs or satellite images) of the study area beyond this year. The study was conducted in 2021, hence the use of 2021 image. These images were acquired in the dry season, December, January and February, during which cloud cover is low hence the resultant images are good for LULC analysis. The selected images within the period had cloud cover of less than 10% thus, they were found to be suitable for the study. The Landsat 4 image of 1986 was a Landsat Multi-spectral Scanner (MSS) with spatial resolution of 60 m while the others were of 30 m. The images were downloaded from the United States Geological Survey (USGS) webpage. The path and row of the images are 193 and 056. Other data used included the district and regional shapefiles of Ghana that were made available on the rsgis.ug web portal for download.

The pre-processing, processing, classification and change detection processes of the data acquired were carried out in ENVI 5.3 software and ArcGIS 10.8 which are illustrated systematically in Fig. 11.2. The pre-processing of the images involved gap filling of 2002 and 2021 images to remove gaps of scan line off, subsetting of Awutu Senya East Municipal area using the district shapefile and layer stacking of bands. The images were calibrated to convert Landsat TM and ETM+ digital numbers to spectral reflectance above the atmosphere. The study combined bands 3, 4, 5 and the following false colours were assigned to them; 5 (red), 4 (green) and 3 (blue). The images were classified into four land cover classes using the supervised algorithm.

Table 11.1 Landsat MSS/ETM+/images and their attributes

Landsat product	Acquisition date	Path/row	Spatial resolution (m)	Source
Landsat TM 4	22 December 1986	193/056	60	USGS
Landsat 7 ETM+	3 February 2002	193/056	30	USGS
Landsat 8	12 January 2021	193/056	30	USGS

The classes included vegetation (shrubs, grasses, forest) represented by green colour, built-up (residential facilities, shops, offices, paved roads) denoted by yellow colour, bareland (burnt land, cleared surfaces and unpaved roads) represented by red colour and blue for water bodies such as rivers, dams and ponds. This was done using the spectral angle mapper based on the assumption that a single pixel selected represents a single ground cover material and can be uniquely assigned to only one feature class (Owusu 2018; Chu et al. 2018). Google Earth and training sites were used for the classification and the final validation of the classified images. Classified 1986 Landsat MSS image was resampled to 30 m using 2021 Landsat ETM+ image as the output reference image (Kusimi 2015). Change detection between 1986 and 2002, 2002 and 2021, and 1986 and 2021 were performed to find out the changes that had occurred over time using the change detection statistics algorithm in ENVI. This algorithm makes it possible to detect the changes that had occurred and the classes into which the changes occurred. The image processing techniques are shown in Fig. 11.2. Classified images and images of changes in LULC were presented as maps whereas statistics of the coverages of the various classes and the changes in LULC classes were presented as tables.

The study also used a social survey method to assess the perception of residents about the effects of depletion of the vegetal cover and the transformations in the environment. A questionnaire was administered to the public to seek their views and perception on the causes and impacts of the changing land use and land cover using Google form. The questionnaire was administered to residents who were enthused about the research and willing to answer questions concerning the research. Questions revolved around urbanisation, its impact on vegetation and the cascading environmental impacts. Respondents were guided when they were unable to fill the forms by themselves. Probing questions were asked when respondents provided additional information not stated on the questionnaire. The snowball method of sampling was used to select 250 respondents for the study. The municipality was divided into three

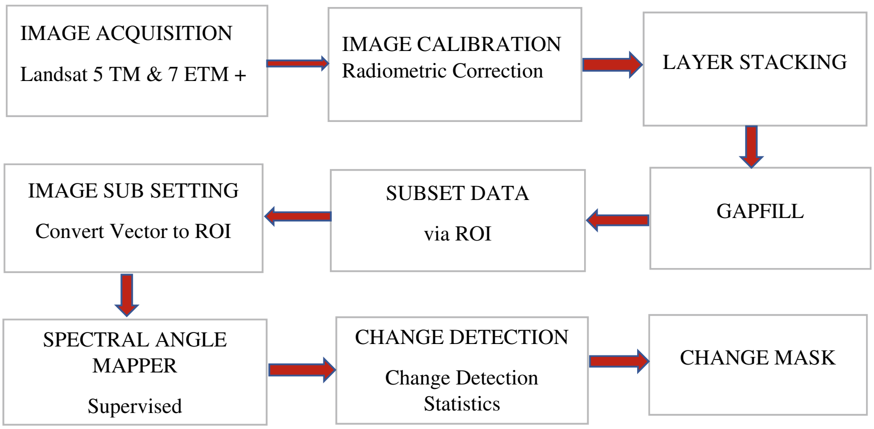


Fig. 11.2 Flowchart of data processing

main localities for the purpose of sampling. They are Kasoa in the southern locality, Ofaakor in the central zone, and Papaase and Oklu Nkwanta in the northern zone (Fig. 11.1). The selection of individuals to be interviewed begun with a 58-year-old resident who recommended respondents. The individuals that were selected mostly involved people that were of sound mind and have stayed in the municipality for at least 25 years and are aware of the transition in the district. Once the interview of respondents was done, they recommended suitable residents to be interviewed. Key informant interviews were held with the municipal planning officer and four (4) assemblymen. The questionnaires were analysed in Google into charts.

Results and Discussion

Land Use and Land Cover Types

Figures 11.3, 11.4 and 11.5 show the classified Landsat images of 1986, 2002 and 2021. Area coverage of the classes of the respective years is illustrated in Table 11.2, whereas the percentage coverage of each land mass for the respective years is shown in Fig. 11.6. In 1986, vegetation covered about 30.41 km^2 of the total land cover of the municipality, representing 53.5% land area. Vegetal cover was plentiful at the northern, north-western, south-western and some dotted portions across the rest of the municipality (Fig. 11.3). Bareland was the second most dominant feature covering 20.1 km^2 land area, forming 35.4% of the landscape. Bareland straddled southwest to northeast through the central part. Built-up covered 5.6 km^2 constituting 9.7% of the land mass. It is overriding at the south-eastern part with a westward trajectory. Water bodies covered only 0.8 km^2 of land area in the municipality forming less than one and a half (1.4%) of the surface area (Table 11.2 and Fig. 11.6).

In 2002, the area covered by bareland increased extensively to 35.1 km^2 representing 61.7% of land mass. Built-up also increased significantly to about 14.9 km^2 forming 26.1% of land area. Area occupied by vegetation and water bodies decreased to 6.6 km^2 and 0.3 km^2 representing 11.6% and 0.6%, respectively (Table 11.2 and Fig. 11.6). Bareland and built-up were now widespread across the locality with vegetation limited to the north-western tip of the municipality (Fig. 11.4). In 2021, the total land area covered by built-up increased to about 40.1 km^2 representing 70.6% of the study area (Table 11.2 and Fig. 11.6). Built-up had not only sprawled across the entire municipality but also intensified as the built environment pixels' density have increased across the landscape as shown in Fig. 11.5. Vegetation increased marginally by 2.1 km^2 from 6.6 km^2 (11.6%) in 2002 to 8.7 km^2 (15.3%) in 2021, and this is shown by the thinly covered greenish colour across the landscape (Fig. 11.5). Bareland decreased drastically to 7.8 km^2 forming 13.7% land mass. Water bodies also suffered a decline to 0.24 km^2 being 0.4% of the total land area (Table 11.2 and Fig. 11.6).

Fig. 11.3 Classified landsat MSS 1986 image

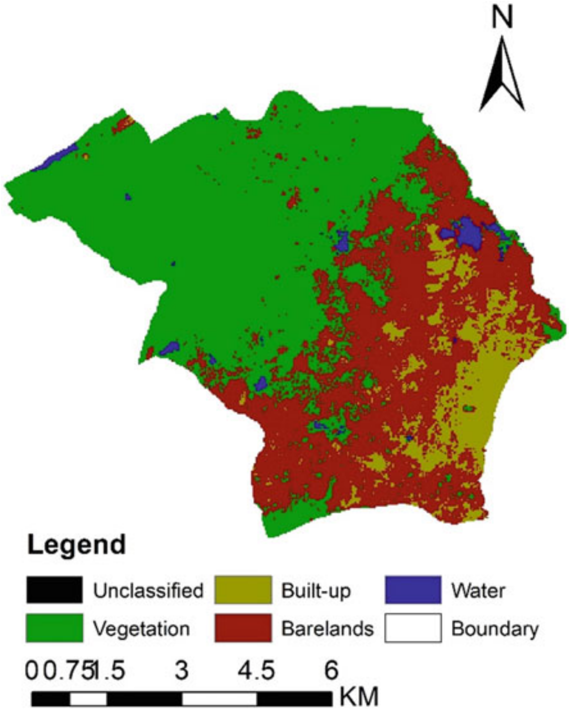
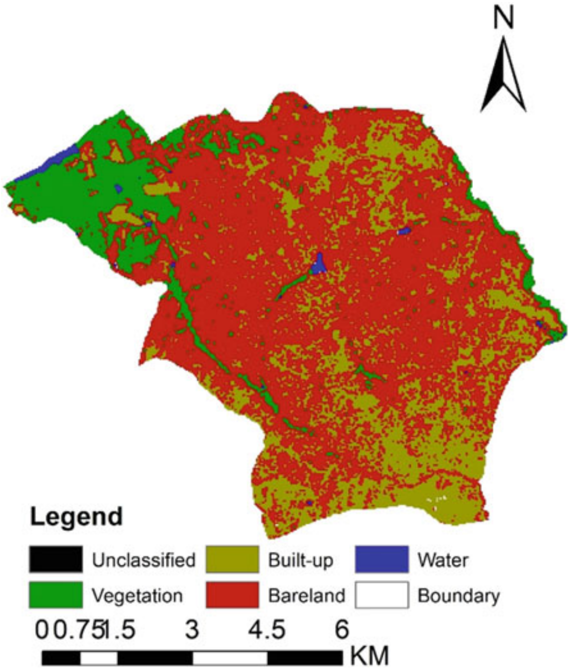


Fig. 11.4 Classified landsat ETM+ 2002 image



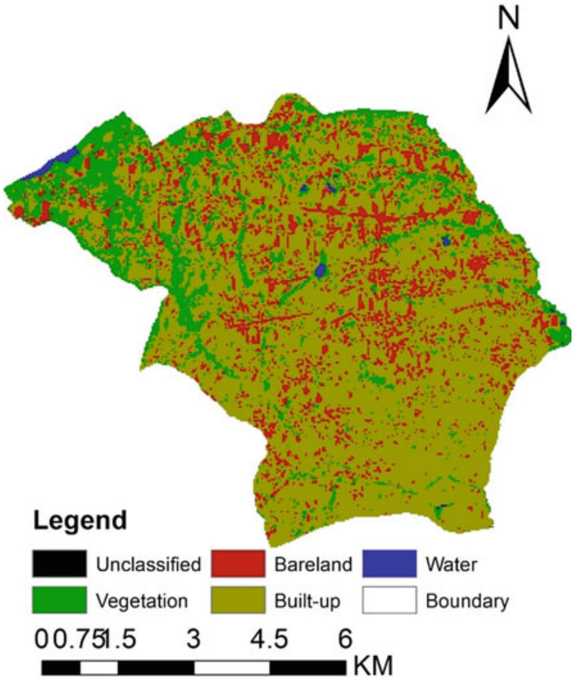


Fig. 11.5 Classified landsat ETM+ 2021 image

Table 11.2 Spatial coverage of land use and cover classes of 1986 and 2021 (km^2)

Land use and cover	1986	2002	2021
Vegetation	30.40	6.6	8.7
Built-up	5.55	14.9	40.1
Bareland	20.13	35.1	7.8
Waterbodies	0.8	0.3	0.24

Land Cover Change Detection

Change Detection 1986 and 2002

The changes in LULC between 1986 and 2002 of the Awutu Senya East Municipality were widespread. The changes are mapped in Fig. 11.7, and the percentage changes in the classes are shown in Fig. 11.6 while the change matrices of the classes are illustrated in Table 11.3. Whereas vegetation had declined in coverage from 53.5 to 11.6% (30.4–6.6 km^2), built-up coverage encountered over 100% growth from 9.7 to 26.1% (5.6–14.9 km^2) (Table 11.2 and Fig. 11.6). Vegetation and water bodies lost 23.8 km^2 and 0.5 km^2, respectively, of their coverage to other land classes while bareland and built-up gained 9.3 and 14.9 km^2, respectively, of the landscape of other LULC types (Table 11.3). The municipality lost about 78.3% (23.8 km^2) of its

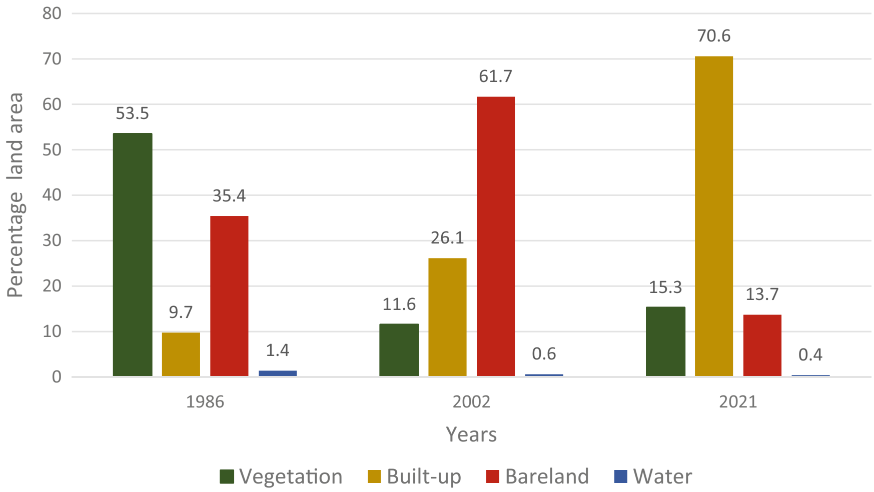


Fig. 11.6 Percentage coverage and changes of land use and land cover types 1986, 2002 and 2021. *Source* Extracts of classified images of 1986, 2002 and 2021

vegetative cover to other land classes; built-up gained 4.6 km^2, bareland 19.7 km^2, and water bodies 0.19 km^2. Only about 6.01 km^2 of vegetation, 2.83 km^2 of built-up, 12.18 km^2 of bareland and 0.13 km^2 of water bodies, respectively, remained unchanged during the period (Table 11.3). About 23.8 km^2 of vegetal cover depleted at annual rate of 1.49 km^2 whiles built-up growth rate was 0.58 km^2 per annum within the period. Figure 11.7 shows a visual representation of the land cover changes that occurred in the municipality between 1986 and 2002. The green, yellow, pink and blue areas represent the vegetation, built-up, bareland and water bodies, respectively, that existed in 1986. The red portion represents the areas that were converted to bareland. The larkspur blue and the quetzal green portions represent the expanded areas of built-up and vegetation, respectively.

Change Detection 2002 and 2021

Table 11.2 and Fig. 11.6 show that vegetation and built-up classes gained while bareland and water classes decreased between 2002 and 2021. Table 11.4 and Fig. 11.8 portray the changes in the indices of the classes and the resultant map between the years 2002 and 2021. Results of the image difference between 2002 and 2021 showed that the vegetal cover grew marginally by 2.1 km^2 (3.7%) but built-up expanded by 25.2 km^2 (44.5% increment) at annual growth rate of 1.32 km^2 per annum (Tables 11.2 and 11.4; Fig. 11.6). Bareland and water resources lost land masses of 27.3 and 0.1 km^2, respectively (Table 11.4). Despite the gains made by vegetal cover, its lost

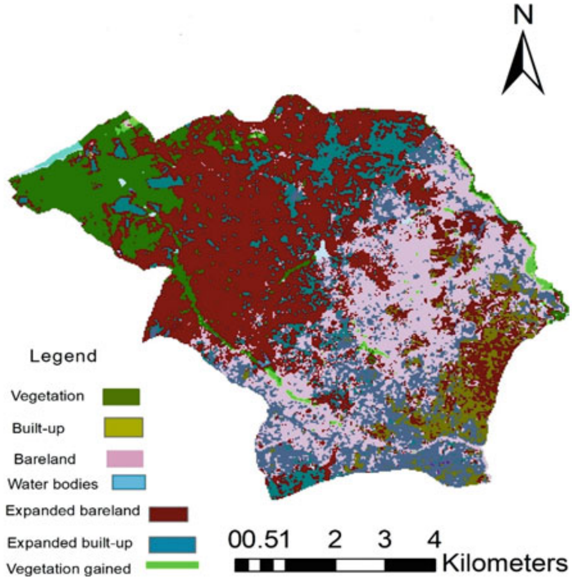


Fig. 11.7 Change detection between 1986 and 2002. *Source* Image differencing between 1986 and 2002 images

Table 11.3 Changes in LULC between 1986 and 2002

	Classes	1986 (km^2)			
		Vegetation	Bareland	Built-up	Water
2002 (km^2)	Vegetation	6.01	0.49	0.02	0.07
	Bareland	19.65	12.18	2.70	0.53
	Built-up	4.55	7.41	2.83	0.08
	Water	0.19	0.03	0.00	0.13
	Total changes	−23.82	9.32	14.93	−0.45

to built-up was still the greatest 2.6 km^2 as compared to 0.6 km^2 to bareland and 0.02 km^2 to water (Table 11.4).

Secondly, vegetative cover was the second dominant land cover (0.67 km^2) after bareland (2.25 km^2) that was transformed to built-up (Table 11.4). About 25.5 km^2 of

Table 11.4 Changes in LULC between 2002 and 2021

	Classes	2002 (km^2)			
		Vegetation	Bareland	Built-up	Water
2021 (km^2)	Vegetation	3.38	4.51	0.67	0.14
	Bareland	0.57	4.98	2.25	0.01
	Built-up	2.62	25.54	11.95	0.03
	Water	0.02	0.03	0.01	0.17
	Total changes	2.12	–27.26	25.28	–0.12

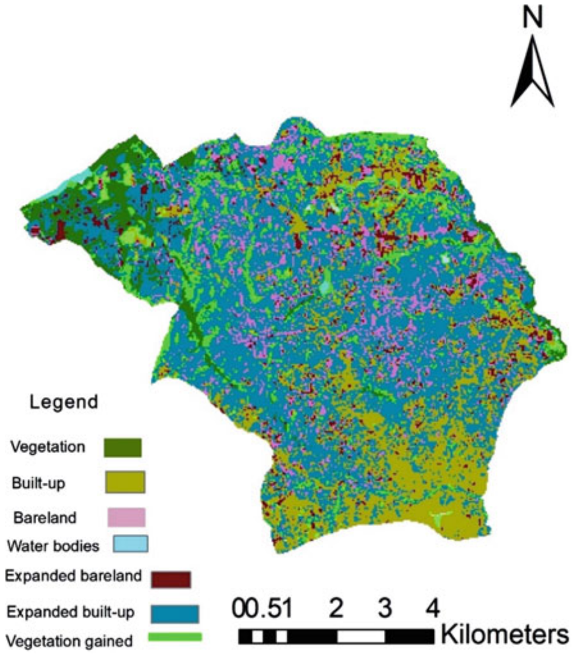


Fig. 11.8 Change detection between 2002 to 2021. *Source* Image differencing between 2002 and 2021

bareland was converted to built-up while 4.5 km^2 was to vegetal cover. These changes are represented visually on Fig. 11.7. About 3.38 km^2 of vegetation, 4.98 km^2 of bareland, 11.95 km^2 of built-up and 0.17 km^2 of water bodies remain unchanged between the period (Table 11.4). Bareland conversion was at 1.44 km^2 per annum during the period.

Change Detection 1986 and 2021

There were massive changes in LULC as displayed by Figs. 11.6 and 11.9 and change matrices in Table 11.5 between 1986 and 2021. Except built-up that increased in coverage throughout the period, other LULC classes diminished (Tables 11.2 and 11.5 and Fig. 11.6). Built-up increased by 34.6 km^2 signifying over 622% increment between the period. It derived a lot of conversions from vegetation 19 km^2 and bareland 16 km^2 classes (Table 11.5). Vegetative cover decreased dramatically by 21.7 km^2 within the 35 years span and almost 19 km^2 of the vegetal cover was changed into built-up and about 4.2 km^2 into bareland (Table 11.5). About 12.3 km^2 of bareland, as well as 0.6 km^2 of areas covered by water bodies were also changed to other LULC types particularly built-up. About 15.9 and 0.45 km^2 of bareland and water bodies were transformed to built-up (Table 11.5). The changes in LULC are depicted in Fig. 11.9. In all, 7.16 km^2 of vegetative cover, 2.9 km^2 of bareland, 4.82 km^2 of built-up and 0.12 km^2 of surface area of water bodies remained unconverted over the period (Table 11.5). The rate of transition of vegetal cover and bareland from 1986 to 2021 was 0.63 km^2 and 0.35 km^2 per annum, respectively, as against 0.99 km^2 growth in the built environment.

Fig. 11.9 Change detection between 1986 and 2021. *Source* Image differencing between 1986 and 2021

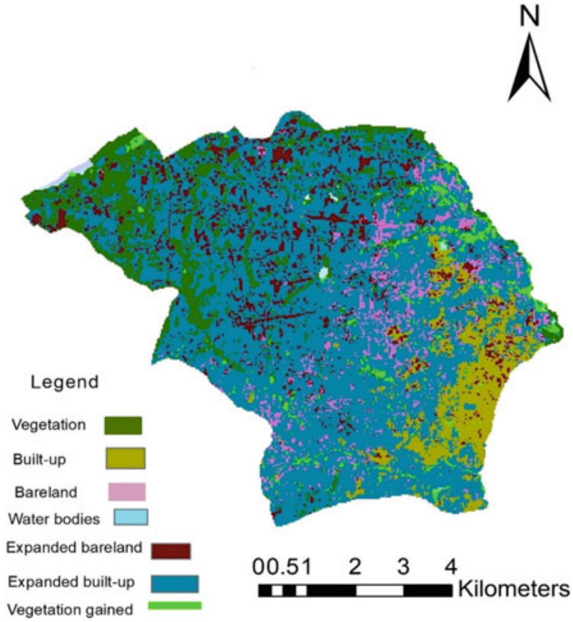


Table 11.5 Changes in LULC between 1986 and 2021

	Classes	1986 (km^2)			
		Vegetation	Bareland	Built-up	Water
2021 (km^2)	Vegetation	7.16	1.31	0.07	0.17
	Bareland	4.18	2.90	0.66	0.06
	Built-up	18.97	15.90	4.82	0.45
	Water	0.10	0.02	0.00	0.12
	Total changes	−21.7	−12.33	34.60	−0.57

Perception on the Causes and Effects of Landscape Transformation

Results of questionnaire analysis showed that more than 90% of the respondents affirmed that the municipality has gone through urban expansion and is mainly because of population increase due to in-migration. About 93% of the respondents stated that there has been a decrease in vegetative cover over the years. This is a comment on vegetal cover decline from a 57-year-old man who have stayed in the municipality for more than 30 years,

> Kasoa was not as we see it today. The area was occupied with abundant vegetation cover consisting of forest, shrubs, bushes and numerous farmlands with very few buildings that were dispersed within the various locality.

Results from the questionnaire analysis further revealed that the causes of devegetation included, human settlement development, construction of roads, parks and recreational facilities, animal grazing, increased demand for forest resources and the building of shops and offices for commercial purposes (Fig. 11.10). As demonstrated statistically by LULC classes and change matrices in Tables 11.2 and 11.5 and Fig. 11.6, the built environment expanded exponentially within the period which negatively impacted on the land cover of other classes. Trees were heavily logged to provide lumber for building and construction as well as farming leading to deforestation. Agricultural lands at the periphery and green spaces of gardens in the city centre have been converted to built-ups over the period. It was also reported that lots of herbs were harvested for herbal medicinal purposes. Livestock production in Ghana including cattle is pastured-based (Obese et al. 2013). This uncontrolled grazing system is associated with overgrazing which destroys vegetal cover and causes soil degradation. It was reported by some residents and confirmed by the municipal planning officer that cattle population and pastural activities have been on the increase over the years and this had also contributed to the degradation of the vegetative cover. Bushfires were also said to be another cause of the degradation of the vegetation. The bush is often set ablaze in the dry season to obtain fresh pasture or for game according to residents. A respondent in her account of the changes and causes of the vegetal and landscape transformation stated this:

> there was a pond around Opeikuma from which we used to fetch water, this has been reclaimed for the building of houses and shops.

All participants were of the view that the loss in vegetal cover have had an impact on their life and the environment. The impacts they enumerated included increase in urban heat, environmental degradation, decrease in farmlands, less amount of rainfall among others (Fig. 11.11). Most respondents (32.1%) perceived that there was increase in urban heat. A respondent shared this:

> We needed no fans in our rooms in the past but because of the heavy conversion of trees and other vegetative cover, there has been an increased in urban heat and one is compelled to use fans or air conditioner in the room now.

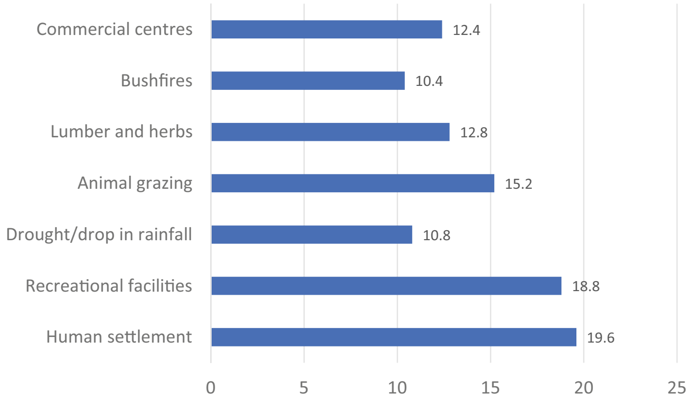


Fig. 11.10 Causes of depletion of vegetative cover

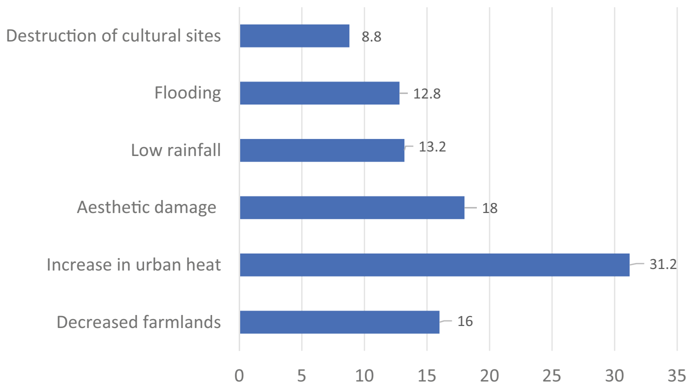


Fig. 11.11 Impacts of the decline in vegetative cover

Some respondents (18%) believed that the beauty and aesthetics that the vegetation provided to the municipality was no more owing to the disappearance of the vegetative cover (Fig. 11.11). Other respondents (13.2%) also complained that rainfall amounts have decreased and have become irregular over the years. These perceptions of respondents relate to the annual statistical data of rainfall and temperature of Accra between 1960 and 2011 from Ghana Metrological Agency. Though both the rainfall and temperature graphs in Fig. 11.12 depict fluctuating levels, the trendlines however show a rising pattern for temperature and a declining trend for rainfall. The trendline shows a drop in rainfall from about 900 mm in 1962 to below 800 mm in 2011 while temperatures have risen from 26 °C in 1960 to nearly 28 °C in 2011 (Fig. 11.12).

Flooding was another climatic impact of vegetal cover degradation noticed by about 13% of the respondents. It was explained during interviews that, though rainfall amounts are decreasing however, the development of properties close to the Okrudu

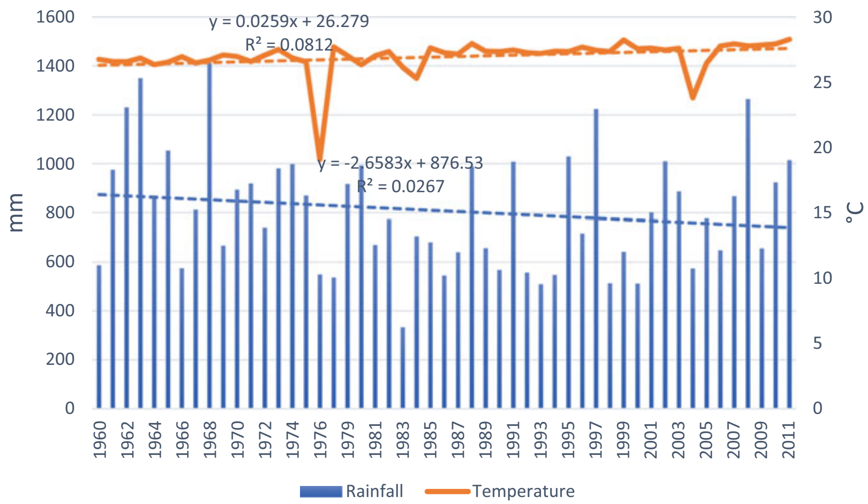


Fig. 11.12 Pattern of rainfall and temperature of Accra from 1960 to 2011

River, in water ways, floodable areas and poor waste management which causes solid waste to choke drains, have been causing floods in most localities of the municipality when it rains. This is backed by the report of Ghana Statistical Service survey which indicated that, the most widely used method of solid waste disposal in the municipality is burning and open disposal accounting for 43.4% (Ghana Statistical Service 2014). Some respondents constituting 8.8% stated that several sacred groves used as shrines have been transformed into built environments owing to urban sprawl, densification and compact building/infilling of physical developments (Fig. 11.11).

Discussion

Within 35 years, there have been significant transformations in the biophysical landscape of the locality. Built-up increased intensively and extensively at the expense of vegetation and bareland with water resources being the least affected. The rate of transformation of vegetal cover and bareland from 1986 to 2021 was 0.63 km^2 and 0.35 km^2 per annum, respectively, as against 0.99 km^2 growth in the built environment. This is because of the rapid increase in population of the Greater Accra Region resulting in a spillover effect on the municipality. Accra's population has increased from 491,817 in 1960 to 5.4 million in 2021 resulting in an increased in population density from 167 persons/km^2 in 1960 to 1678 persons/km^2 in 2021 (Ghana Statistical Service [GSS] 2013, 2021). This has caused a drift of people from Accra-Tema metropolitan areas to the Awutu Senya East Municipality and its environs for lands for housing among others. Consequently, the population of the municipality has also risen from 863 in 1970 to 131,721 in 2020 (GSS 2014; Yankson and Bertrand 2012).

According to GSS (2014), about 78% (84,579) of the population of the municipality are migrants from other parts of the country excluding Central Region and 28% (23,672) of them are from the Greater Accra Region alone. The resultant impact of the rising urbanisation and urban development is the grabbing of available lands for residential and commercial activities resulting in urban sprawl, depletion of vegetal cover and the conversion of other land cover types as portrayed by the 2002 and 2021 classified images. Similarly, a long-term observation by Hasan et al. (2022) suggested that urbanisation had propelled a decrease in green space and enhanced LST in an urbanised city in Bangladesh.

Though the forests were destroyed by other anthropogenic activities like logging and burning to clear land for agriculture or livestock grazing, these agricultural and grazing lands were later transitioned into urban space as revealed by the study. The four-year medium-term development plan of the municipality estimated the number of cattle being kept in the municipality between 2014 and 2017 to be about, 2,100 (Awutu Senya East Municipal Assembly 2017). The causes and nature of urban expansion that had led to the increase in urban sprawl and intensification/densification and the associated impact on vegetation and other components of the landscape in the Awutu Senya East Municipality is not very different from that of other peri-urban cities elsewhere in the world particularly in the developing countries as postulated by the urban densification/compact city concepts. Likewise, Siddique and Uddin (2022) found that area coverage such as forest cover, *agricultural land* and vegetation cover decreased from 68.34% in 1990 to 36.51% in 2020 in Chattogram city, Bangladesh. The decrease in the LULC was mainly due to the expansion of built-up areas which grew more than 600% over the period at the expense of other LULC types. There have also been some observations regarding the effects of urban sprawl and intensification (i.e. urban heat, loss of farmable lands, damage to urban aesthetics etc.) in literature. Some studies have shown that a reduction in urban green space have led to an increased in the land surface temperature (LST) and expansion in green spaces have resulted in minor decreases of LST of cities (Shin and Lee 2005; Hasan et al. 2022; Sun and Chen 2017; Yang et al. 2017). Also, according to Dong et al. (2022), significant decreasing trends of UGS coverage from 12.23 $\pm$ 0.32% in 2003 to 7.69 $\pm$ 0.22% in 2015 resulted in the decrease of the coverage of cooling spaces from 32.55 $\pm$ 0.76% in 2003 to 24.39 $\pm$ 0.60% in 2015.

However, urban green space is said to be increasing in coverage in some cities of China and Europe (Zhao et al. 2013). This is due to deliberate public policies on urban planning and development and urban greening constructions and development (Pauleit et al. 2005; Zhao et al. 2013) which is akin to the initiative of the municipality which saw an increase in vegetal cover from 6.6 to 8.7 km^2 between 2002 and 2021. According to the planning officer of the municipality, urban green policy under the auspices of the central government dabbed Green Ghana program which was adopted by the municipality and intensified in recent years has led to the greening of the municipality.

Limitations of the Study

From the social survey analysis, urban heat was one of the environmental concerns that emerged as the impacts of the declining cover of urban vegetative cover. It would have been prudent to do urban heat/land surface temperature analysis using remote sensing to validate the claims or perceptions of the respondents. However, this was impossible as there was not enough time to carry this analysis. This was an undergraduate dissertation which was time-bound, and amidst the COVID-19 pandemic, the academic calendar was restructured with a very shortened time framework for academic activities.

Conclusion and Recommendations

The study provides a quantitative assessment of urban sprawl and landscape transition of the locality using remote sensing analysis as well as a qualitative perspective on the socio-environmental impacts of these changes through a social survey technique. Increased in anthropogenic activities owing to rising population was found to relate to urban sprawl and intensification of the built environment causing a decrease in vegetal cover and bareland classes. Vegetation and bareland experienced greater transformations in their landscapes than water. Generally, vegetal cover dwindled between 1986 and 2021 from 53.5% of land mass coverage to 15.3% although it experienced a marginal regeneration of tree cover between 2002 and 2021. Bareland also experienced a fluctuating pattern with a net loss like vegetative cover. It increased from 35.4% in 1986 to 61.7% in 2002 and declined to 13.7% of total land mass in 2021. Built landscape however, assumed a rising trend throughout the period. It increased from 9.7% in 1986 to 26.1% in 2002 and to 70.6% in 2021. Water resources also declined throughout the period but the loss is negligible. Most conversions of vegetation in the municipality were into built-up and bareland. Built-up also gained lot of land conversions (16 km^2) from bareland. The transformation of vegetal and bareland covers into built-up has resulted in the massive urban sprawl of the locality between the period under study. Thus, the main driving force of the transformation of the vegetation and other LULC types in the area is urbanisation which caused an increase in the built-up environment. The perceived impacts of these changes by the people are destruction of urban aesthetics, increased in urban heat and flooding. The results of the study provide good information for urban planning in the Awutu Senya East Municipality which will be useful to policymakers, city authorities, the local people and other stakeholders in the municipality.

Urbanisation will continue within the peri-urban enclaves of Accra-Tema metropolitan areas for a while hence the need to adopt measures to curb the cascading impact of urban growth. Sustainable urban development polices on urban greening and the enforcement of land use plans need to be strictly adhered, to curb uncontrolled physical development/sprawling of the locality. Thus, besides National Green Ghana program, residents should be educated and encouraged to plant trees to increase the green space in the municipality to minimise urban heat and also increase the vegetative aesthetics of the locality. For instance, the central business area could be redeveloped into vertical structures to create space for parks and other green belt developments like city gardens. As observed by Pauleit et al. (2005) and Zhao et al. (2013), urban green space is said to be increasing in coverage in some cities of China and Europe due to deliberate public policies on urban planning and development and urban greening constructions and development. Such expansions in green spaces are likely to decrease LST of the locality as detected by Sun and Chen (2017). Lastly, it is recommended that similar studies in the locality should carry out land surface temperature analysis of the municipality to validate the perceptions on increasing urban heat/LST of the study area over the years.

Acknowledgements Our sincere gratitude goes to the people of the Awutu Senya East Municipality and the various stakeholders for providing the necessary data for the research.

References

Acheampong EP, Ampomah F, Doku TJ (2019) Using remote sensing to examine the rate of urbanization in Accra, Ghana: a case study of Ga East, West, Central and South Municipal. J Food Agri Environ 6(2)

Adarkwa KK (2012) The changing face of Ghanaian towns. AREF 4(1):1–29

Addae B, Oppelt N (2019) Land-use/land-cover change analysis and urban growth modelling in the greater Accra metropolitan area (GAMA), Ghana. Institute of Geodesy and Geoinformation, Technical University Berlin, Faculty VI, Straße des 17. Juni 135, 10623 Berlin, Germany, Department of Geography, Christian-Albrechts-Universität zu Kiel, Ludewig-Meyn-Straße 14, 24098 Kiel, Germany; oppelt@geographie.unikiel.de

Agyeman SA (2018) Impacts of urban sprawl on livelihoods and ecology in peri-urban fringe of the greater Accra metropolitan area. West Afr J Appl Ecol 28(SI):100–117

Anarfi K, Hill RA, Shiel C (2020) Highlighting the sustainability implications of urbanisation: a comparative analysis of two urban areas in Ghana. LND 9(9):300

Antrop M (2004) Landscape change and the urbanization process in Europe. Landsc Urban Plan 67(1–4):9–26

Awutu Senya East Municipal Assembly (2017) Four-year medium-term development. Retrieved from CR_Awutu+Senya+East_2014-2017+MMTDP.pdf—AWS. Accessed on 20 May 2022

Blay J (2019) Remote sensing and GIS analysis of urban growth and its impacts on surface temperature: a case study of Awutu Senya East Municipal Assembly. Doctoral dissertation, University of Ghana, Legon

Bodo T (2019) Rapid urbanization theories, causes, consequences, and coping strategies. Ann Geograph Stud 2(3):32–45

Breheny M (1996) Centrists, decentrists and compromisers. Views on the future of urban form. The compact city. A Sustain Urban Form 22:13–35

Cai Y, Chen Y, Tong C (2019) Spatiotemporal evolution of urban green space and its impact on the urban thermal environment based on remote sensing data. A case study of Fuzhou City China. Urban for Urban Green 41:333–343

Cao Y, Natuhara Y (2019) Effect of urbanization on vegetation in riparian area. Plant communities in artificial and semi-natural habitats. Sustain 12(1):204

Chu L, Sun T, Wang T, Li Z, Cai C (2018) Evolution and prediction of landscape pattern and habitat quality based on CA-Markov and Invest model in Hubei section of Three Gorges Reservoir Area (TGRA). Sustain 10(11):3854

Cobbinah PB, Amoako C (2012) Urban sprawl and the loss of peri-urban land in Kumasi Ghana. Int J Humanit Soc Sci 6(388):e397

Dallimer M, Tang Z, Bibby PR, Brindley P, Gaston KJ, Davies ZG (2011) Temporal changes in greenspace in a highly urbanized region. Biol Lett 7(5):763–766

Dantzi, GB, Saaty TL (1973) Compact city: a plan for a liveable urban environment; W.H. Freeman and Company: San Francisco, CA, USA

De Roo G (2000) Environmental conflicts in compact cities: complexity, decision making, and policy approaches. Environ Plann B Plann Des 27(1):151–162

Dickson KB, Benneh G (1995) A new geography of Ghana. Longman, UK

Dong Y, Ren Z, Fu Y, Hu N, Guo Y, Jia G, He X (2022) Decrease in the residents' accessibility of summer cooling services due to green space loss in Chinese cities. Environ Int 158:107002

Ghana Statistical Service [GSS] (2012) 2010 Population and housing census: summary report of results. Accra, Ghana, Ghana Statistical Service 2021. Accessed 25 Jan 2022 http://www.statsghana.gov.gh/docfiles/2010phc/2010_POPULATION_AND_HOUSING_CENSUS_FINAL_RESULTS.pdf

Ghana Statistical Service [GSS] (2014) 2010 Population and housing census. Report: district analytical report—Awutu Senya East Municipality—Accra. Ghana Statistical Service

Ghana Statistical Service [GSS] (2021) 2021 Population and housing census: press release on provisional results. Ghana Statistical Service—Accra. Retrieved 25 Jan 2021, from www.census2021.statsghana.gov.gh/dissemination

Ghana Statistical Service [GSS] (2013) 2010 Population and housing census: regional analytical report—greater Accra region. Ghana Statistical Service—Accra. Ghana Statistical Service

Glaeser EL (2014) A world of cities: the causes and consequences of urbanization in poorer countries. J Eur Econ Assoc 12(5):1154–1199

Haaland C, van Den Bosch CK (2015) Challenges and strategies for urban green-space planning in cities undergoing densification: A review. Urban For Urban greening 14(4):760–771

Habibi S, Asadi N (2011) Causes, results and methods of controlling urban sprawl. Procedia Eng 21:133–141

Han J (2020) Can urban sprawl be the cause of environmental deterioration? Based on the provincial panel data in China. Environ 189:109954

Hasan M, Hassan L, Al MA, Abualreesh MH, Idris MH, Kamal AH (2022) Urban green space mediates spatiotemporal variation in land surface temperature: a case study of an urbanized city, Bangladesh. Environ Sci Pollut Res 29(24):36376–36391

Jacobs J (1961) The death and life of great American cities. Book Unpublished resources, Randoms House, New York

Johnson MP (2001) Environmental impacts of urban sprawl: a survey of the literature and proposed research agenda. Environ Plan A 33(4):717–735

Kabisch N, Qureshi S, Haase D (2015) Human–environment interactions in urban green spaces—a systematic review of contemporary issues and prospects for future research. Environ Impact Assess Rev 50:25–34

Kusimi JM (2015) Characterizing land disturbance in Atewa range forest reserve and buffer zone. Land Use Policy 49:471–482

Liu Y, Fan P, Yue W, Song Y (2018) Impacts of land finance on urban sprawl in China: the case of Chongqing. Land Use Policy 72:420–432

Liu J, Zhang L, Zhang Q, Li C, Zhang G, Wang Y (2022) Spatiotemporal evolution differences of urban green space: A comparative case study of Shanghai and Xuchang in China. Land Use Policy 112:105824

Luan W, Li X (2021) Rapid urbanization and its driving mechanism in the Pan-Third Pole region. Sci Total Environ 750:141270

Newman P (1992) The compact city: an Australian perspective. Built Environ 18(4):285–300

Njoh AJ (2003) Urbanization and development in sub-Saharan Africa. Cities 20(3):167–174
Obese FY, Acheampong DA, Darfour-Oduro KA (2013) Growth and reproductive traits of Friesian x Sanga crossbred cattle in the Accra Plains of Ghana. African J Food, Agric Nutr Dev 18:13(2).
Owusu AB (2018) An assessment of urban vegetation abundance in Accra metropolitan area, Ghana A Geospatial Approach. J Environ Geogr 11(1–2):37–44
Park H, Fan P, John R, Chen J (2017) Urbanization on the Mongolian plateau after economic reform: changes and causes. Appl Geogr 86:118–127
Pauleit S, Ennos R, Golding Y (2005) Modeling the environmental impacts of urban land use and land cover change—a study in Merseyside. UK. Landsc Urban Plan 71(2–4):295–310
Saaty TL, De Paola P (2017) Rethinking design and urban planning for the cities of the future. Buildings 7(3):76
Shin DH, Lee KS (2005) Use of remote sensing and geographical information systems to estimate green space surface-temperature change as a result of urban expansion. Landsc Ecol Eng 1(2):169–176
Siddique S, Uddin M (2022) Green space dynamics in response to rapid urbanization: patterns, transformations, and topographic influence in Chattogram city Bangladesh. Land Use Policy 114:105974
Stow DA, Weeks JR, Shih HC, Coulter LL, Johnson H, Tsai YH, Kerr A, Benza M, Mensah F (2016) Inter-regional pattern of urbanization in southern Ghana in the first decade of the new millennium. Appl Geogr 71:32–43
Sun R, Chen L (2017) Effects of green space dynamics on urban heat islands: mitigation and diversification. Ecosyst Serv 23:38–46
Swenson JJ, Franklin J (2000) The effects of future urban development on habitat fragmentation in the Santa Monica mountains. Landsc Ecol 15(8):713–730
United Nations Department of Economic and Social Affairs [UNDESA] (2018) 2018 Revision of united nations (UN), 2013. Sustainable development changes. World economic and social survey 2013. Department of Economic and Social Affairs, UnitedNations Publication. http://www.un.org/en/development/desa/policy/wess/wesscurrent/wess2013/WESS2013.pdf_. (Accessed on 28 Apr 2022)
Westerink J, Haase D, Bauer A, Ravetz J, Jarrige F, Aalbers CB (2013) Dealing with sustainability trade-offs of the compact city in peri-urban planning across European city regions. Eur Plan Stud 21(4):473–497
Wolch JR, Byrne J, Newell JP (2014) Urban green space, public health, and environmental justice: The challenge of making cities 'just green enough.' Landsc Urban Plan 125:234–244
Xie Q, Liu J (2019) Combined nonlinear effects of economic growth and urbanization on CO_2 emissions in China: evidence from a panel data partially linear additive model. Energy 186
Yang J, Sun J, Ge Q, Li X (2017) Assessing the impacts of urbanization-associated green space on urban land surface temperature: a case study of Dalian, China. Urban for Urban Green 22:1
Yankson, PWY, Bertrand M (2012) Challenges of urbanization in Ghana, *CODESRIA:* Dakar
Zhang HL, Cubino JP, Nizamani MM, Harris AJ, Cheng XL, Da L, Sun Z, Wang HF (2022) Wealth and land use drive the distribution of urban green space in the tropical coastal city of Haikou China. Urban for Urban Green 71:127554
Zhao J, Chen S, Jiang B, Ren Y, Wang H, Vause J, Yu H (2013) Temporal trend of green space coverage in China and its relationship with urbanization over the last two decades. Sci Total Environ 442:455–465
Zhou D, Zhao S, Liu S, Zhang L (2014a) Spatiotemporal trends of terrestrial vegetation activity along the urban development intensity gradient in China's 32 major cities. Sci Total Environ 488:136–145
Zhou D, Zhao S, Liu S, Zhang L, Zhu C (2014b) Surface urban heat island in China's 32 major cities: spatial patterns and drivers. Remote Sens Environ 152:51–61

Chapter 12
Urbanisation and Economic Interdependency: An Econometric Analysis of Inter-State Change and Continuity in India, 1981–2011

Madhuri Sharma and Shweta Rani

Abstract This study examines the interdependency between economic and urban growth in the 35 states and union territories (UTs) of India during 1981–2011, using the framework of economic liberalisation of 1991. To examine the inter-state relationships in terms of sectoral composition and changing trends, seven variables representing the processes of urbanisation and urban growth rates along various dimensions of economic growth, including state level income and their sectoral contributions, are analysed for the entire study area for census years 1981–2011. Factor analysis, KMO test and Bartlett's test of sphericity evaluate the significant factors affecting urban and economic change in the states and UTs of India. We find wide regional disparities in growth and development, both spatially and temporally, with previously underdeveloped states and newly carved states growing at rates far better than anticipated. The emerging manufacturing-induced services have created the knowledge and skills to produce and process a wide range of industrial and consumer products, which have continued to drive the Indian economy. Simultaneously, the large-scale migration towards megacities and second-tier cities have created a *new spatial* order, with strategic face-lifting of specific parts and expanded informal settlements in others, marking an interesting dualism in Indian urban system in response to liberalisation.

Keywords Economic liberalisation · Factor analysis · India · KMO test · Migration · New spatial order

M. Sharma (✉)
Department of Geography and Sustainability, University of Tennessee, 416 Burchfiel Geography Building, 1000 Phillip Fulmer Way, Knoxville, TN 37996, USA
e-mail: msharma3@utk.edu

S. Rani
Department of Geography, Dyal Singh College, University of Delhi, New Delhi 110003, India
e-mail: shwetarani@dsc.du.ac.in

U. Chatterjee et al. (eds.), *Urban Commons, Future Smart Cities and Sustainability*, Springer Geography, https://doi.org/10.1007/978-3-031-24767-5_12

Introduction

In India, while the seeds of economic investment and infrastructure growth had already begun at its independence in 1947, the pace and competitive niche was still missing due to its protective policies. Modern India started emerging with the liberalisation of trade in 1990s and India's acceptance of the free market economy. The post-1990s era experienced rapid urban growth and expansion, creating its own set of economic opportunities, alongside unique types of urban poverty and regional inequalities (Dupont 2011; Goldman 2011; Mitra 2006; Nijman 2006; Obeng-Odom 2012; Sharma and Abhay 2022). In the initial years of liberalisation, the country faced very high inflation and a balance of payment crisis, which forced India's new (minority) government to introduce a comprehensive, orthodox, policy reform package—with currency devaluation, licence permit system and sharp reduction in tariff rates as its centrepiece. These long-awaited economic reforms were widely welcomed by critics of India's development strategy. These reforms meant getting rid of an internationally discredited statist development paradigm. Soon, India marked tremendous improvement in its total and sectoral gross domestic production (GDP). As of 2017, the Ministry of Statistics and Program Implementation suggests that the largest contributors to India's total GDP include services (61.7%), industry (23%) and agriculture (HTTP1 2021). Growth in productivity in India's service sector had remained a major contributor to the accelerated economic growth that occurred during the post-1980s (Goldar and Mitra 2008). They estimated that about 40% of increase in the growth rate of aggregate GDP in post-1980s was from increase in total productivity in the service sector. However, they also argued that while there was a major shift in the composition of GDP towards services contributing towards overall growth, it is the secondary sector which is, and will be, the lead sector in the long term. Thus, the *causality* happens from the secondary sector to other components of the tertiary sector. This relationship, however, can also be cyclic in that higher levels of urbanisation contribute towards higher GDP and vice versa such that the process of *urbanisation* starts getting recognised as a *causal factor* for growth and development rather than being *dependent* on industrialisation.

Economic growth occurs from both formal and informal economic sectors that are generally concentrated in cities and large metropolises (Dupont 2011; Goldar and Mitra 2008; Frick and Rodriguez-pose 2018; Sekkat 2017). It facilitates urbanisation that furthers the evolution of socio-economic structures, especially in developing countries (Naik and Rahman 2007). Capital investment is a prime necessity to trigger economic growth in developing economies wherein substantive investment, given the right conditions, can attract investment in infrastructure that would help promote manufacturing and other basic and non-basic activities, eventually attracting capitalists to partner-in for further cyclic investments till a level of maturity is achieved (Chandrashekhar 2013). This is the ultimate pathway towards attaining a stable industrialised/post-industrialised *economic-being,* which would eventually feed into the cyclic economic continuum (Coe et al. 2012; Narayana 2011).

The process of urbanisation and economic growth includes several urban components and economic indicators which are dynamic in nature—defined by space, spatiality, regionality, demography, human resources and skills, policy, politics, society and culture (Frick and Rodriguez-Pose 2018; Narayana 2011; Sekkat 2017; Yeung 2009). Urbanisation occurs as countries shift from rural-agricultural activity into a diverse set of urban industrial and tertiary activities (Davis and Henderson 2003; Dupont 2011; Kratke 2014; Obeng-Odom 2012). Collectively, then, these urban and economic components largely guide the patterns of growth and development in any region, and India is no exception to this. Thus, there is a need for greater attention to the revival, renewal and overhaul of the industrial sector such that sustained economic growth can be pursued in a country of 1.407 billion (HTTP2 2022). This study unravels these changing nature of relationships between urbanisation and urban economy across the 35 states and union territories (UTs) of India during 1981–2011, using the 1991 liberalisation as a comparative framework. In doing so, we also examine the changing nature of inter-dependencies among various components of urbanisation and economy as used by the Census of India to measure total growth and economic development. We are unable to expand this research to 2021 as the latest census results are unavailable due to COVID-19-induced delays.

Literature Review

Economic Liberalisation as a Framework

Since the adoption of liberal policies in India in 1991, there has been rapid growth in Foreign Direct Investment (FDI)—with considerable rise in the inflow of capital and exports, while also increasing the imports (Kratke 2014; Siddiqui 2017). These investments occurred along multiple dimensions such as the service sector, poverty eradication programs and other speculative activities (ibid.). In 1991, India experienced a balance of payment crisis—the same year when the Soviet Union had collapsed, and oil prices had risen due to Iraqi invasion of Kuwait. These crises created a situation wherein India had to enter into an emergency loan agreement with the International Monetary Fund (IMF)—marking a shift in Indian policy towards foreign capital (Kratke 2014; Nayyar 2017). Economic liberalisation was the eventual outcome that came with its own sets of terms and conditions–privatisation of public firms, enhanced role for market forces, relaxation of the licence-permit raj, openness towards foreign investment and financial deregulation (Joshi and Little 1994). These policies gradually opened doors to an emerging new economy, boosting India's manufacturing and service sectors, while also enhancing its overall face value by providing Indian commodities and human skills a global platform (Dupont 2011; Kratke 2014; Narayana 2011). In 2015–16, the Indian economy grew at 7% annually, better than the previous two years. By way of comparison, the GDP growth rate in developed countries during the same period was about 2%, compared to 4.4% in other developing countries (Patnaik 2015). Thus, India's growth rate was truly impressive at a global scale.

In his book *The Nature of Economic Growth*, Thirlwall (2002) analysed the trend in growth for select countries over longer periods of time, assuming that the manufacturing sector was an important engine of economic growth. He found that in many countries, there existed close association between their per capita income and level of industrialisation; at the same time there also existed strong relationship between the growth of GDP and growth of manufacturing which facilitated further expansion of the sector, with the most favourable growth characteristics. Thirlwall, while not in full agreement with neo-classical economists, suggested that demand-induced growth was the most critical pathway for economic growth of developing countries, as large demand in a commodity could eventually maximise the profits from fuller exploitation of the division of labour and economies of scale. In his unpacking of the mutually dependent complex relationships between TNCs and urban/regional development, Yeung (2009) critiqued the influential theories of urban and regional growth and provided relational views of TNCs in global production networks. He suggested that urban and regional development were inherently and increasingly a 'globalising' phenomenon. Artelasris (2021)'s analysis of Greece's economy in the post-1981 era of globalisation, economic integration and EU's increasing influence found that EU's policies had indeed helped advance their economy, with significant improvement in their income; and while there were brief phases of intra-regional inequality, the growth phases would return soon thereafter and would last much longer.

In many ways, India's situation mirrored Turkey's economic growth after the entry of IMF (Yeldan 2006). With the introduction of Structural Adjustment Program (SAP) in Turkey, financial investments were elevated over industry, with a promise of real economic upliftment. However, due to the fragile Turkish financial and fiscal systems, the IMF's programs instead put Turkey's economy at increased vulnerably (ibid.), which ended up by eventually having the foreign investors grab away the Turkish arbiters, drifting away with short-term capital flow which has also been characterised as 'Casino-Capitalism' (Siddiqui 2018). In India, the SAP came-in as a surprise, putting many economists and policy makers dumbfounded with the unforeseen and unpredictable ways in which IMF's loans had impacted various segments of the population, unduly benefiting the thin slice at the top whereas the low-to-middle class felt left behind. Similar findings were also noted in Obeng-Odom (2012)'s analysis of Ghana). Neoliberal economy does not work in vacuum, as illustrated in the production of splintered spaces of acute deprivation and affluence in developing economies (Nijman 2006; Shaban 2022; Obeng-Odom 2012). Much of the growth experienced by India during the post-liberalisation period was not experienced uniformly across the entire country due to uneven investments and distribution, divided along the rural-versus-urban. Regarding this, D'Monte (2002)'s analysis suggested that Mumbai, the financial capital of India, had suffered significant losses in manufacturing since the 1970s, particularly in the textile industries despite some gains in the service sectors, and yet, Mumbai was not a typical western-style post-industrial city since it retained a significantly large-scale manufacturing and human-intensive preindustrial characteristics, with low-income population and large-scale poverty (Nijman 2006). These changes facilitated fast urbanisation, drawing people from rural/smaller towns towards India's largest urban centres, while also creating urban villages with dilapidated housing and lower quality of life (Sharma and Abhay 2022)—exacerbating inequality and poverty (Dupont 2011; Nijman 2006; Obeng-Odom 2012).

Since primary activities like mining and agriculture are more spatially fixed than manufacturing, liberalisation-induced urban agglomerations and urbanisation economies can create deep spatial inequalities, exacerbating significant wage differentials (Shaban 2022). The economic liberalisation in the global south has facilitated free movement of labour and spatial fixing of agglomeration industries in advantageous locations (ibid.). Such policies by government planning and intervening institutions produce and exacerbate inequalities wherein favourable decision for some leads to relative deprivation of others (ibid.). This causes the rural–urban divide that adds to the uncontrolled migration of labour and slummisation of cities (Mitra and Murayama 2009; Shaban 2022; Sharma and Abhay 2022). Dupont (2011)'s examination of the consequences of economic liberalisation on Delhi's residents who did not perfectly fit into Delhi's vision of 'global city' found that although the restructuring was successful in creating a 'new' Indian middle class, this process also created polarisation and exclusion processes—*politics of forgetting*—towards marginalised groups. This extraordinary drive for global competitiveness had enormous negative consequences, and especially the poor slum dwellers as many informal settlements in Delhi and elsewhere had to be cleaned off, which subsequently exacerbated other types of urban and regional inequalities like homelessness, crime and poverty (Dupont 2011; Obeng-Odom 2012). These findings on Delhi (and Ghana) mirror Nijman (2006)'s take on Mumbai wherein liberalisation further marginalised the poor while also creating a new mysterious middle class, and new mafia side by side—socio-spatial manifestations of the neoliberal political economy.

In other parts of the global south, Obeng-Odom (2012)'s analysis of neoliberalism and urban economy in Ghana found that while the policies enabled strong entry of private sectors, eventually contributing towards growth in urban economy, jobs and capital accumulation, it simultaneously also exacerbated urban inequalities, given the nature of neoliberalism; thus, he contested the neoliberalism-induced changes and its impacts on people's quality of lives. Goldman (2011) critically highlighted how the rural communities in and around Bangalore were forcibly dispossessed of their lands in Karnataka government's self-proclaimed aspirations towards creating Asia's 'Silicon Valley'. Thus, the new art of 'speculative government' and the ways in which anxieties and dispossessions were experienced differentially across class, space/place and community, ended up redefining state relations as well as power of urban citizenship and rules of access. Likewise, other scholars found varied levels of differential treatments and inequalities experienced, especially by the low-income groups (see Chakraborty et al. 2022; Dupont 2011; Kratke 2014; Mitra 2006; Scott and Storper 2014; Sharma and Abhay 2022). Numerous scholars have indeed opined that socio-economic and spatial polarisation is an inherent characteristic of economic liberalisation in most developing countries (Dupont 2011; Goldman 2011; Kratke 2014; Nijman 2006; Obeng-Odom 2012; Yeldan 2006).

In pursuit of likening liberalisation and urban economic growth, scholars have used various theoretical frameworks to explain cities as spaces of dynamic agglomeration and polarisation on one hand, and the nexus of colonialism and location politics, land use and human interactions on the other hand, especially when one examines the *processes* by which spaces of uneven opportunities get created (Chakraborty et al. 2022; Goldman 2011; Nijman 2006; Scott and Storper 2014). Others have emphasised on different aspects of urbanisation (Goldman 2011; Naik and Rehman 2007; Nijman 2006), including historical perspectives of economic growth and urban growth (Short 1996), patterns of urban growth (Mohan and Dasgupta 2005) and dimensions of economic growth (WDI 2011). Almost everyone agreed that urbanisation and the consequential urban growth is inevitable and universal. Finally, while we agree that liberalisation, despite its economic benefit, did create inequalities of various types. However, we also acknowledge that creating an equitable society requires strategic planning and implementation in a developing economy of 1.407 billion people. Given the focus of this research paper, we limit ourselves to examining the interdependency between the economic growth and urban growth that occurred in India during 1981–2011.

Economic Restructuring, Urbanisation and Economic Growth

Technological change and innovation are essential to structural change, and in the context of developing economies, manufacturing can significantly accelerate their economy and overall growth and wellbeing of people, especially as higher growth in manufacturing positively increases labour productivity and expands the manufacturing sector, generating competitive economies including forward and backward linkages–all of which would eventually create competitive niche towards a circular and interdependent economy (Coe et al. 2012). Thus, when overall growth accelerates, manufacturing typically leads the way, growing faster than other sectors (Goldman 2011; Narayana 2011; Xu et al. 2021). For low-income countries, however, the contribution of manufacturing towards its total GDP stays low. When manufacturing increases its output share in response to changes in the domestic demand and in comparative advantage, faster sectoral growth noticeably raises the aggregate growth rates of output and labour productivity (Thirlwall 2002). This triggers growth in other basic and non-basic economic sectors, such as the IT-based quaternary and quinary activities (Narayan 2011). In India, with the lifting of restrictions on the imports of technology, the foreign firms found it attractive to set up collaborative enterprises, assuming a pathway for mutual growth and prosperity (Chandrashekhar 2013; Dupont 2011; Narayan 2011). It was expected to boost its domestic production along with foreign capital investments, sharing of innovative technology and management skills that would improve quality of life for all (Narayan 2011).

While economic restructuring can lead to a profound and phenomenal impact on economic growth, the types of economic growth can have consequential changes across the nation, given the diversity of uneven growth and development within and among Indian states/UTs. Fast urbanisation, especially in the developing countries, contributes to fast growth and expansion of giant urban agglomerates wherein a majority of people depend on urban jobs and urban services (Dupont 2011; Kratke 2014), accentuating further economic growth and social change, and eventually a more informed society (Naik and Rahman 2007). Indian urban scenario is transforming rapidly due to inherent biases towards urban-centric economy, and these have contributed to exponential levels of rural–urban and small-town-to-large-city mass scale migration (Mitra and Murayama 2009; Sekkat 2017; Sharma and Abhay 2022). Thus, while there is serial abandonment of rural areas and smaller towns crushed with high poverty and lack of opportunities, there also exists growth and opportunities in mid-to-large cities that somehow curtails poverty (Kratke 2014; Sekkat 2017).

There is a reciprocal relationship between urban development and economic development since economic growth and/or decline are intimately associated with urban expansion and/or contraction. A wide gamut of literature suggests that urbanisation is a *pre-requisite* for achieving rapid economic development; others concur urbanisation as the *engine* of economic growth and *agents* of change (Jacobs 1984; Kratke 2014; Mohan and Dasgupta 2005). Regarding the direct and indirect effects of economic liberalisation on urban and economic growth, numerous scholars have indicated significant growth in a country's economy, peoples' prosperity, rising new middle class and emergence of megacities and new global cities (Cieślik and Rokicki 2017; Dupont 2011; Goldman 2011; Kratke 2014; Narayana 2011; Xu et al. 2021). In evaluating the effectiveness of EU's funds on the spatial wage structure in Poland, Cieślik and Rokicki (2017) found statistically significant and positive relationship between the EU funds and individual wages at regional level, which improved the regional market potential as well as individual worker's and industry characteristics. In their detailed analysis of the effects of globalisation and governance on the economic growth of numerous Asian countries, Xu et al. (2021) found that globalisation not only improved overall economic growth, but it also helped these countries by introducing sound regulatory control and political stability; these steps eventually helped promote corruption-free and transparent economic policies across these nations, which cumulatively contributed towards sustainable development. Likewise, the speculative urbanism and strong drive towards the promotion of a new *global city* phenomena facilitated positive relationship between globalisation-induced IT firms and urban growth, sprawl and prosperity in Bangalore (Goldman 2011; Narayana 2011). However, Behera and Karthiyani (2021)'s evaluation of the effects of globalisation and economic shifts in India during 1976–2012 found that while economic globalisation reduced income inequality, social and political globalisation increased income inequality in the country. Their most interesting finding was that growth and investments in agriculture-related value addition industries actually helped reduce regional income inequalities; the authors, thus, concluded by drawing attention of the central government towards investing in agro-based industries that can indeed narrow the rural–urban divide by creating livelihoods for rural population (ibid.).

Measurement Indicators for Economic Growth and Urbanisation

A wide range of factors and indicators are critical towards understanding the complex relationships between urbanisation and economy. Economic growth reflecting the process of urbanisation and urban growth includes indicators such as city size, urban growth rates and components of economic growth. Davis (1955) suggests the need to consider various sectors of economy that have changed and transitioned over time due to technological innovations–from primary to tertiary and quaternary; others emphasise on the shifting work force due to the process of urbanisation. Kaldor (1996), however, argues that it is impossible to understand the growth and development process without taking a sectoral approach, largely focused on the growth of manufacturing output, service sector and the growth of GDP. New industrial investments and expansion of the service industry in new locations have been a major factor affecting growth and sprawl of existing urban areas in India, and hence, it is important to include these when examining the reciprocal relationships between urbanisation and economic growth (Narayana 2011; Sivaramakrishnan and Singh 2003). Also, despite the growth in major economic sectors, India still retains its agrarian characteristics, and even though urban areas display a concentration of large number of urban and economic indicators, its rural counterparts lack developmental traits, creating huge disparity in development indicators across the rural–urban divide. As such, numerous scholars have treated rural–urban imbalance in development as an explanation for the unprecedented growth of urban centres.

Finally, given the nexus between urban growth and economic growth, it is important to understand the basic definitions, scales and components of urbanisation and economic growth in the context of India. The definition of town assumes that urbanisation is the consequence of industrialisation and hence, urban areas must have an overwhelming share of those engaged in non-agricultural activities (Bhagat 2002). Based on this definition, India's cities have continued to grow, and the world's largest democracy with a Census 2011 population of 1.24 billion (1.407 billion on 9/19/2022, HTTP2 2022) has attained a slow but steady economic growth, with its GDP growing at an average annual rate of 8.4% (CSO 2011). Thus, this research will (i) analyse the changing nature of relationships between urbanisation (urban components) and economy (economic indicators); (ii) identify and discuss the most significant and dominant factors for growth and development in India; and (3) examine the patterns of subregional development across the states/UTs in India.

Research Design

Study Area and Scale of Analysis

India with its 27 states and 8 UTs (Census 2011 definition) occupies a strategic position in the South Asian subcontinent (Fig. 12.1). We chose India for this study due to its economic and demographic significance at the global scale, and its enormous human resource potentials from 1.407 billion population (HTTP2 2022), with a fast-growing, educationally savvy middle-class consumerist genre—an integral part of India's booming urban economy.

As the world's largest democracy, India is also one of the fastest urbanising economies in the world, with its urban population having increased by five times during six decades (1951–2011)–from 62 million (17.3%, Census 1951) to 377 million (31.2%, Census 2011) (Fig. 12.2). As of June 19, 2022, World Bank estimated India's urbanisation at a record high of 483 million, accounting towards 35.01% of its total population (HTTP3 2022). At such a rapid growth, it is predicted that within a generation, India will be transformed from a rural/agrarian society to an urban economy (Sud 2009). At the same time, even though India's economic growth has been driven by the service sector, accounting towards 61.7% of its total GDP in 2017 (HTTP1 2021), a significant part of this service sector is dominated by informal economy wherein informal labour and informalisation of economic activities even within the formal sectors have taken over in the era of economic liberalisation (Nijman 2006). This paper will examine some of these changes in manufacturing versus services during the transitioning decades of 1981–2011, using the 1991 liberalisation as a comparative framework, using states/UTs as the scale of analysis.

Data Source and Methods

We use economic data from the Census of India for 1981, 1991, 2001 and 2011, tabled under the Primary Census Abstract, Central Statistical Organisation (for data on Net State Domestic Product). The Census of India, incepted in 1872, is the richest and the most accurate source of data for a variety of urban components. After extracting the required data for every state/UT for all the four decades, we collect the data for the estimates of state income from the National Accounts Statistics (NAS)–a division of Central Statistical Organisation.

Net State Domestic Product (NSDP) is calculated based on the System of National Accounts (SNA) of the United Nations and World Bank with different base years. State income (Net State Domestic Product/NSDP) reflects the status of economic growth at the state level and is defined as the income generated by the production of goods and services within the geographical boundaries of a state. This is derived by netting the gross state/district domestic product estimates (GSDP/GDDP) by the consumption of fixed capital (CFC)—the most important single economic indicator that can measure the growth and pattern of economic development of a state. The

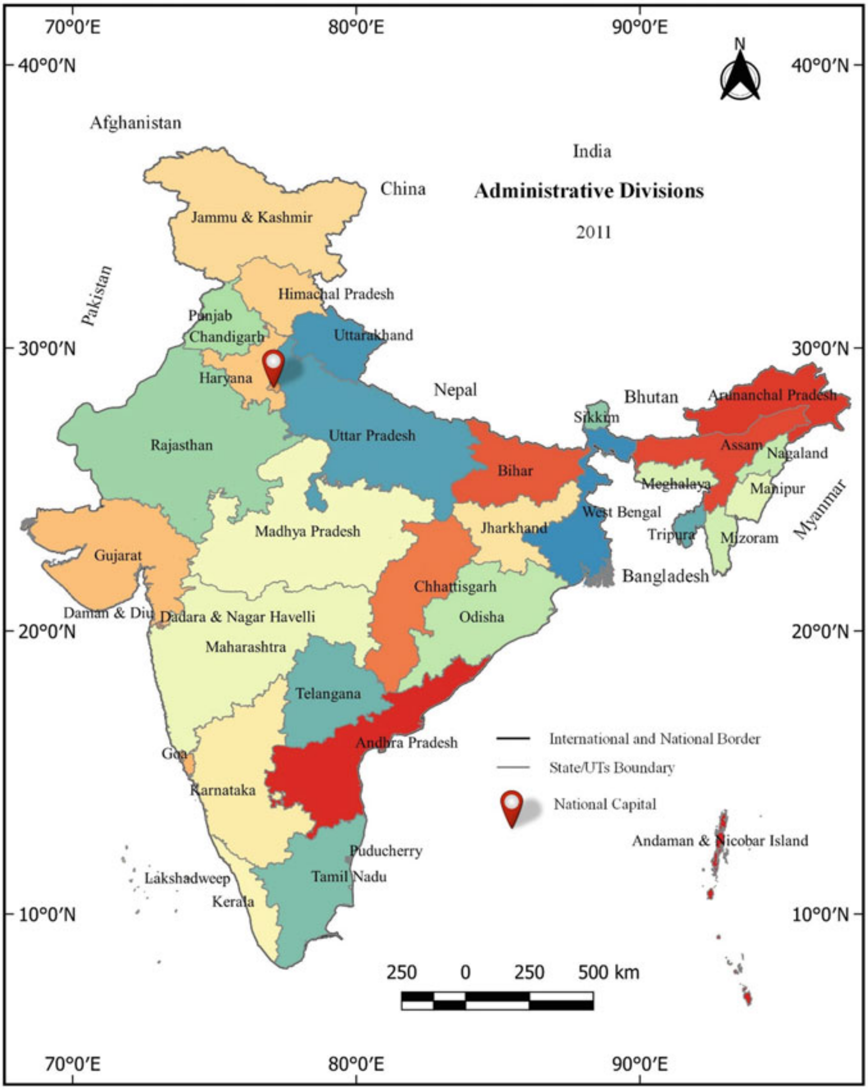
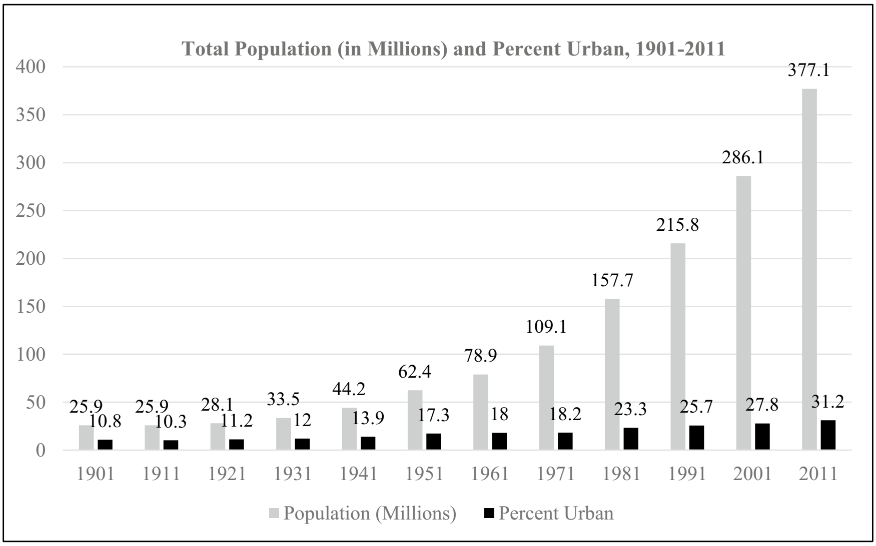


Fig. 12.1 Study area

estimate of state's income is prepared at a base year price termed as 'at constant price'. which over the years gives the measure of real growth. In this study, we use 1980–1981 and 1993–1994 as the base years (for the states and UTs where data is missing for 1980–1981 series). Data is also available for other new series at constant price of 1993–1994, 1999–2000 and 2004–2005 base years, which have been readjusted to the base year of 1980–1981 (CSO 1988, 1989a), using the price inflation statistics.



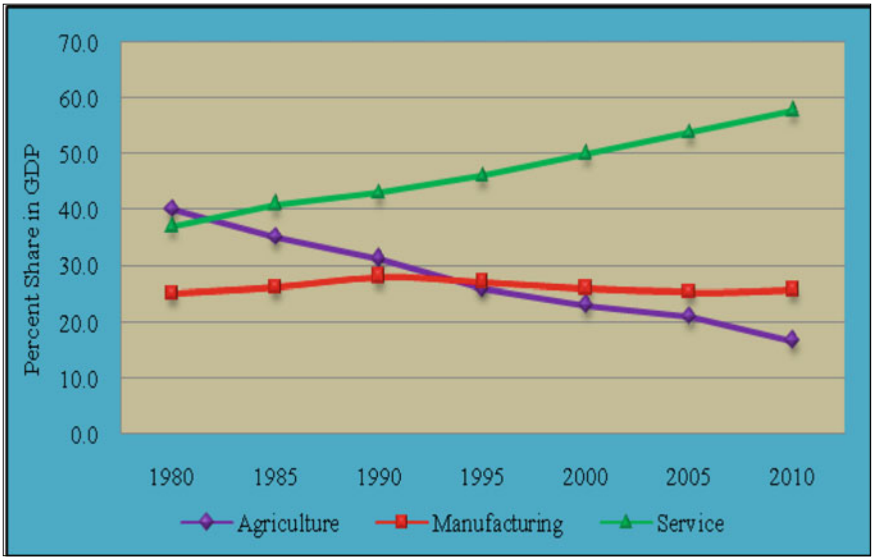


Fig. 12.2 Total population growth and percent urbanisation in India, 1901–2011 (top) and sectoral share of GDP in India, 1981–2011 (bottom). *Source* Census of India, 1901 to 2011 (top) and World Bank Central Database, May 2011 and CSO, August 2011 (bottom)

Principal Component Analysis (PCA) and Visual Insights into Growth and Development

We use seven urban and economic indicators to measure the levels of growth and development across the 35 states/UTs in India. These include percent urban population (X1), average annual urban growth rate (X2), average annual per capita NSDP

(X3), average annual NSDP growth rate (X4), average annual per capita NSDP growth rate (X5), percent share of manufacturing (X6) and service sector in Net State Domestic Product (X7). The PCA culls out the most significant factors that help explain the patterns of growth and development in India. We employ the Kaiser–Meyer–Olkin (KMO) test and Bartlett's test of Sphericity for testing the adequacy and significance of the results (Glen 2016; Kaiser and Rice 1974). The value of KMO test varies between 0-to-1, with a higher value indicating the suitability of factor analysis for the dataset, and the fact that the results are not merely a chance factor and vice versa. The equation for the **Kaiser–Meyer–Olkin (KMO_j) test is:**

$$\mathrm{KMO} = \frac{\sum\sum_{j \neq k} r_{jk}^2}{\sum\sum_{j \neq k} r_{jk}^2 + \sum\sum_{j \neq k} p_{jk}^2} \tag{12.1}$$

where r_{ij} is the simple correlation coefficient between variables j and k, and p_{jk} is the partial correlation coefficient between variables j and k, and Σ is the summation.

In Bartlett's test, the significance level < 0.05 supports the validity of factor analysis as a useful tool for the data being analysed (Hair et al. 2010). The formulae for Bartlett's test is:

$$X^2 = -((n-1)-(2p-5)/6)\log(det(R)) \tag{12.2}$$

where $n =$ number of observations, $p =$ number of variables, and R is the correlation matrix of the variables.

After creating the factor scores, we examine the extractions and the factor loadings to gain insights into the sectoral shifts over the decades. Choropleth maps of important scores help understand their spatial patterns and potential reasons for such distribution over the years. Later, we also compute composite scores for each principal components for all 35 states/UTs and categorised them into three groups based on their level of growth and development for the census years 1981 and 2011. This helped gain insights into the pre- and post-liberalisation impacts across the states/UTs, using the 1991-liberalisation as a comparative framework.

Results and Discussion

Spatial Patterns of Inter-State Urbanisation and Urban Growth Rates

Urbanisation has grown exponentially from 17.3% (1951) to 31.2% (2011), with significantly uneven spatial distribution across the states and UTs. The National Capital Territory of Delhi (NCT-Delhi) and the UT-Chandigarh with 97.50% and

97.25% urban population are the most urbanised in India (Sharma and Abhay 2022); in contrast, Bihar (11.30% urban) is the least (Census 2011). In terms of regional distribution of urban population, Tamil Nadu (48.45%), Maharashtra (45.23%), Gujarat (42.58%) and Karnataka (38.57%) are the most urbanised and the most developed states in the country (Census 2011). Together with Punjab and West Bengal, these six states account for half of India's total urban population. Economic liberalisation has greatly affected the nature and pattern of urban growth rates in the country, with some regions experiencing rapid economic growth while others lagging far behind, imparting a unique character to Indian urban system. The average annual urban growth rate is significantly different from the levels of urbanisation across Indian states/UTs, with the most developed Indian states with large urban population marking moderate-to-low growth in urban population due to their saturation; in contrast, the underdeveloped and developing states with pre-dominance of rural characteristics registered far greater average annual rates of urban growth. These include Bihar, Sikkim, Arunachal Pradesh, Nagaland, Haryana and Goa.

The State of Indian Economy and Growth Sectors

Table 12.1a shows the changing structure of Indian economy in the broad sectors for select time points. Regarding value-added share, service sector emerges as a leading contributor since the 1990s (India KLEMS database). In this regard, even Behera and Karthiayani (2021) and Narayana (2011)'s analysis found that agro-based value-added sectors and manufacturing-induced service sectors, both of which classified as service economy, had grown tremendously since the liberalisation, and these were critically needed to reduce regional inequalities (Behera and Karthiayani 2021).

The integration of India into the global economy also contributed to urban propulsion, and while not everyone was employed in well-paid good quality jobs, they had some opportunities in informal economy that provided food for their families (Mitra 2006; Sharma 2017). The urban-centric economic focus cyclically propelled urbanisation, reducing their dependency on primary sectors of economy. Our analysis found that the combined contribution of industry and service sectors towards total GDP was significantly higher than that of agriculture. Also noted in CSO (2011) and World Bank (2011), in 1950–1951, the share of urban economic sectors towards India's GDP was only 29%, which increased to 47% in 1980–1981, and 61% in 2010–2011, and is likely to reach 75% by 2021 (Census data still awaited). The sectoral shares of GDP at the national level since 1980s to 2010 suggest that the service sector superseded the other two, with a value reaching 50.0% by 2000–2001, and as high as 57.7% by 2010–2011.

Table 12.1 Total variance explained (**a**) and rotated component matrix (**b**) for urban components and economic indicators in India, 1980–81

Indicators	A-Initial eigen values				B-Components		
	Eigen ≥ 1; Extraction	Total	Variance (%)	Cumulative (%)	1	2	3
Percent Urban population	0.919	2.515	35.931	35.931	**0.938**	0.023	–0.197
Average annual Urban growth rate (1980–1985)	0.660	1.957	27.955	63.885	0.020	0.190	**0.790**
Average annual per capita net state Domestic product (NSDP)	0.800	1.059	15.124	79.009	**0.894**	–0.006	0.009
Average annual NSDP growth rate (1980–1985)	0.953	0.898	12.834	91.843	0.074	**0.972**	0.049
Average annual per capita NSDP Growth Rate (1980–1985)	0.924	0.376	5.368	97.211	–0.048	**0.956**	0.088
Percent share of manufacturing sector in NSDP	0.745	0.131	1.873	99.084	**0.512**	–0.067	0.448
Percent share of service sector in NSDP	0.529	0.064	0.0916	100.000	**0.735**	0.234	–0.461
Variance (%)					35.574	27.924	15.512
Cumulative (%)					35.574	63.498	79.009

Note Extraction method: Principal component analysis

Performance and Pattern of Per Capita Net State Domestic Product in India

Net State Domestic Product (NSDP) is the most important indicator representing a state's economic growth. In terms of average annual per capita NSDP, there exists significant inter-state variations, with exceptionally high average annual per capita NSDP in Chandigarh (Rs. 99,487 lakhs), Delhi (Rs. 95,943 lakhs) and Goa (Rs. 98,807 lakhs) compared to other states/UTs (DES 2011). For readers familiarity, 1 lakh INR (Indian National Rupee) = INR 100,000 (1USD ~ INR78/00, on 6/14/2022; all the figures reported here were calculated at constant price of 2004–05). Goa, the smallest states endowed with mesmerising scenic landscape and natural beaches, attracts the bulk of tourist dollars from around the world, contributing significantly towards its revenue. With the special circumstances of these top three, Haryana (Rs. 59,188 lakhs) and Maharashtra (Rs. 62,729 lakhs) are the richest states. The proximity of Haryana to NCT-Delhi and Greater Mumbai (the most populated and India's financial capital) in Maharashtra play crucial economic roles as well. In contrast, Madhya Pradesh, Uttar Pradesh and Bihar, accounting towards 31.1% of India's total population, are the poorest, with their per capita income far below the national average of Rs. 35,917 lakhs.

Major Factors of Urban Economic Growth

The KMO test yielded a result of 0.586, validating the usefulness of factor analysis in this research. Using a cut-off eigen value $\geq$ 1, the factor analysis for 1980–81 showed communalities and weights for all seven variables (Table 12.1a). Extraction results show that except X_7, the factor loadings of all other variables are $\geq$ 0.6. Using the cut-off level of $\pm$ 0.6 to evaluate the factor loadings, we find that the highest variances are extracted for X4, X5 and X1, with values of $r = 0.953$, $r = 0.924$ and $r = 0.919$, respectively. The three components (I, II and III) cumulatively explain 79.009 of total variance; Table 12.1b shows the values of the actual factor loadings for the three components.

The *first factor* exhibits dimensions pertaining to the size of economy and the economic sectors including manufacturing and service. It yields higher factor loadings for variables percent urban population ($r = 0.938$), per capita NSDP ($r = 0.894$), manufacturing ($r = 0.735$) and service sector share to NSDP ($r = 0.512$). About 36% of the total variation is attributed to the variables captured by component 1–which we name as ***manufacturing-induced economic urbanisation***. The second component essentially represents economic growth and is highly correlated ($r = 0.972$) with NSDP growth rate and average annual per capita NSDP growth rate ($r = 0.952$)–we name it ***economy-induced urbanisation***. The third factor yields higher factor loadings ($r = 0.790$) with average annual urban growth rate. When we look at the loadings of each of these components, using $\pm$ 0.44 as the cut-off level, even the component III represents an interesting characteristic of urban economy of the 1980s, which was far more propelled by manufacturing (+0.444) rather than the service sector (–0.461)—marking an interesting era in Indian's urban economic growth and transition period when the service sector had not yet caught up, and manufacturing was still the de facto attraction—a suction force that pulled the bulk of migrants, accentuating rapid urbanisation—we call it ***migration-induced urbanisation***.

New Economic Reforms and Indian Economy

The next two consecutive quinquennial years, i.e. 1985–85 and 1990–91, yield similar results as the preceding one with minor variations in second and third factor. Hence, the composite scores are not mapped. However, significant changes

Table 12.2 Eigen values, variances and rotated component matrix of urban and economic indicators in India (1995–96)

Factor loadings of variables	1995–96		
	1	2	3
Eigen values	2.859	1.891	1.126
Variance (%)	40.843	27.015	16.091
Percent Urban population	0.381	0.830	0.033
Average annual Urban growth rate (1995–2000)	−0.561	0.461	0.029
Average annual per capita net state domestic product (NSDP)	−0.102	0.903	0.278
Average annual NSDP growth rate (1995–2000)	0.905	0.239	−0.097
Average annual per capita NSDP growth rate (1995–2000)	0.956	0.130	−0.001
Percent share of manufacturing sector in NSDP	0.025	0.232	0.938
Percent share of service sector in NSDP	0.380	0.626	−0.569

were observed during post-reform period, marking significant departure from earlier decades. During 1995–96, the extracted three factors explained 83.95% of the total variations (Table 12.2). In fact, three noticeable changes emerged when compared with results of pre-reform period. Manufacturing sector share to NSDP extracted maximum value among all variables. Factor 1 shows high interrelation with the dimensions of economy and economic growth. It is to be noted that economic growth represented by GDP growth rate and per capita GDP growth rate formed part of the second component in 1980, whereas factor 2 represents a combination of urban attributes, size of economy and service sector.

The beginning of the 1990s was marked by the conceptualisation, formulation and implementation of the 'New Economic Reforms'–the neoliberal economic revolution in India, wherein the IMF had already entered the scene with SAP and the concomitant enforcement of terms and conditions. Economic sectors got tremendous boost, and India became the ultimate choice of multi-national and foreign direct investors, especially those motivated by the IT and increased demands of low-end maquiladora industries and outsourcing giants (Dupont 2011; Narayana 2011). In this regard, we found several supporting scholarships that have discussed the transformations in the 1990s. The economic liberalisation accelerated rural to urban migration, often forcing rural folks into dispossessing their lands in the process of transitioning Indian cities as the 'global cities' of twenty-first century (Goldman 2011; Shaban 2022). This also occurred primarily based on the assumption that there would be massive inflow of capital, both from within and outside the country, resulting in rapid development of infrastructure and industrial growth (Kratke 2014). This was likely to give impetus to the process of urbanisation in the country since much of the industrial growth and consequential growth in employment would be within or around the existing urban centres (Kundu 1997). Very true to the expectation, the nation recorded a significant growth in urbanites, which thenceforth became part of second factor in 1995–96.

Emergence of Economic Sectors in the New Millennium (2010–11)

Year 2000–01 and 2005–06 yielded similar results in line with earlier observations and are not discussed here. However, for 2010–11, only two principal components were extracted (unlike three in all other cases), accounting for much of the information captured by seven variables, cumulatively explaining 74% of total variance (Table 12.3a). The KMO test score (0.629) reaffirmed the validity of factor analysis.

The first component is the most highly correlated with percent urban population, percent share of service sector in NSDP, and average annual NSDP growth rate, with higher factor loadings of $r = 0.875$, $r = 0.853$ and $r = 0.770$, respectively. In fact, annual average urban growth rate presents an exceptional case of high interrelationship with factor 2 ($r = 0.798$). It is important to recognise that the share of service sector to NSDP witnessed a sharp boom with significant value addition to the

Table 12.3 Total variance explained (A) and rotated component matrix (B) for urban components and economic indicators in India, 2010–11

Indicators	A-Initial eigen values				B-Components	
	Eigen ≥ 1; Extraction	Total	Variance (%)	Cumulative (%)	1	2
Percent Urban population	0.927	2.733	39.039	39.039	**0.875**	−0.020
Average annual Urban growth rate (1980–1985)	0.657	1.468	20.971	60.010	0.202	0.798
Average annual per capita net state Domestic product (NSDP)	0.807	0.901	12.872	72.882	0.631	0.203
Average annual NSDP growth rate (1980–1985)	0.689	0.748	10.690	83.572	**0.770**	−0.310
Average annual per capita NSDP Growth Rate (1980–1985)	0.686	0.640	9.140	92.712	0.220	−0.799
Percent share of manufacturing sector in NSDP	0.270	0.360	5.145	97.856	0.363	0.771
Percent share of service sector in NSDP	0.765	0.150	2.144	100.000	**0.853**	0.259
Variance (%)					44.623	29.387
Cumulative (%)					44.623	74.01

Note Extraction method: Principal component analysis economy. Consequently, service sector showed high interrelationship with first and second sector for 2000–01, 2005–05 and 2010–11, respectively. In this connection, it is worthwhile to be reminded that majority of Indian states had a significantly higher share of service sector contribution to NSDP. States and UTs like NCT-Delhi, Chandigarh, Mizoram, Kerala, Maharashtra, Tamil Nadu and Puducherry are noteworthy with more than 50% of their contribution towards NSDP coming from the service sector (Census of India 2011). This was also the time when significant growth in the service sector was occurring across the urban areas throughout the country, and simultaneously large, mid- or small towns, all experienced significant growth in urban population that provided the needed labour in the service sectors of various types.

The Composite Scores and Levels of Development

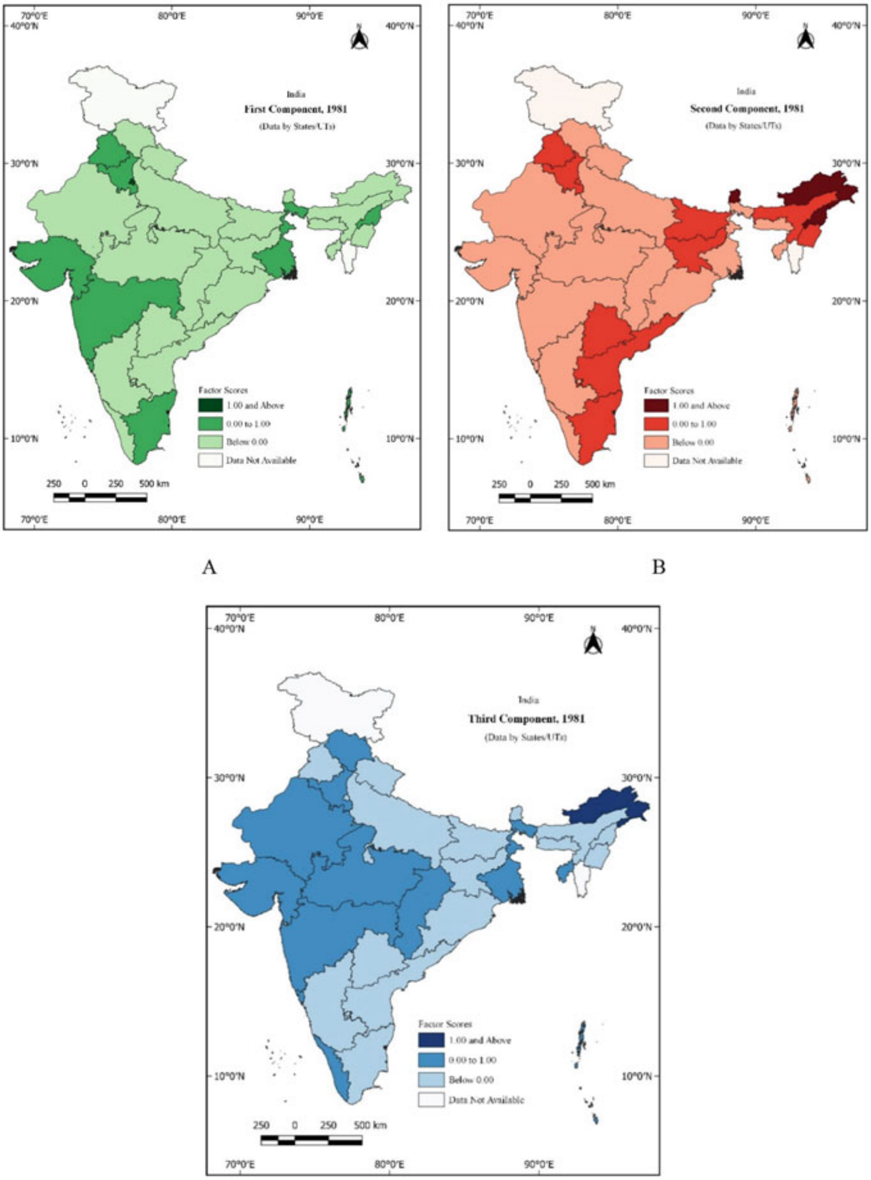
Based on the scores of factor analysis (FA), composite scores were computed for each principal components for all states/UTs. These are the weighted sum of the standardised scores for the given set of indicators. These scores are useful in studying the nature and pattern of states/UTs in the study area pertaining to various scores obtained with respect to growth and development of the nation. A value of 1 and above indicates better performance of the factor and are termed as highly developed. Based on these results, the states/UTs are categorised into three mutually exclusive groups–high, moderate and less developed region–reflecting their levels of growth and development for the census years 1980–81 and 2010–11, respectively (Table 12.4).

The obtained composite scores are mapped to visually analyse their spatial dimensions. In 1980–81, NCT-Delhi and Puducherry performed better with an index of ≥ 1 for the first factor. However, for second and third factors, three states from the north-east–Arunachal Pradesh, Sikkim and Nagaland yielded high positive scores. An overall analysis of these three factors reveals that the states that were both industrially and economically developed had a low positive score. On the other hand, the underdeveloped and relatively poorer states of Bihar, Odisha, Uttar Pradesh, Madhya Pradesh and other north-eastern states recorded a low negative score. The spatial distribution of states based on the scores obtained is shown in Fig. 12.3a–c. In a span of a decade and a half, there were noted interchange of variables' characteristics for the first and second components. Goa and Maharashtra had obtained high scores in 1995. As part of the third factor, showing high interrelation with manufacturing sector share to NSDP, the states/UTs of Tamil Nadu, Gujarat and Puducherry benefitted the most. The developing states of Himachal Pradesh and West Bengal too witnessed a lift in their industrial sector, yielding a high score ≥ 1. Bihar, Rajasthan, Madhya Pradesh and Arunachal Pradesh closely followed them.

In 2011, factor 1 represented a combination of majority of the variables; 3 out of 7 variables showed high interrelation with first factor. NCT-Delhi, Puducherry, Goa and Maharashtra performed better when all the variables were taken together with a

Table 12.4 Level of growth and development in India (1980–81 and 2010–11)

Factor scores	≥ 1.00	> 0.00 and < 1.00	≤ 0.00
Level	Highly developed	Moderately developed	Less developed
Components (1981)-I	Delhi (NCT), Puducherry	Goa, Maharashtra, Tamil Nadu, Punjab, Gujarat, Nagaland, West Bengal, Andaman and Nicobar and Haryana	Arunachal Pradesh, Manipur, Karnataka, Sikkim, Kerala, Andhra Pradesh, Meghalaya, Rajasthan, Assam, Uttar Pradesh, Himachal Pradesh, Madhya Pradesh, Odisha, Bihar and Tripura
II	Arunachal Pradesh, Sikkim, Nagaland	Haryana, Assam, Punjab, Bihar, Tamil Nadu, Andhra Pradesh, Delhi (NCT) and Manipur	Rajasthan, Gujarat, Odisha, Uttar Pradesh, Maharashtra, Karnataka, West Bengal, Andaman and Nicobar, Meghalaya, Madhya Pradesh, Himachal Pradesh, Puducherry, Tripura, Kerala and Goa
III	Arunachal Pradesh, Puducherry	Kerala, Tripura, Goa, Andaman and Nicobar, Madhya Pradesh, Maharashtra, West Bengal, Rajasthan, Himachal Pradesh, Haryana and Gujarat	Odisha, Uttar Pradesh, Karnataka, Andhra Pradesh, Bihar, Punjab, Tamil Nadu, Nagaland, Meghalaya, Assam, Manipur, Delhi (NCT) and Sikkim
Components (2011)-I	Delhi, Puducherry, Goa, Maharashtra	Sikkim, Tamil Nadu, Gujarat, Haryana, Tripura, Andaman and Nicobar, Arunachal Pradesh and Karnataka	Kerala, Andhra Pradesh, Meghalaya, Punjab, West Bengal, Jammu and Kashmir, Himachal Pradesh, Odisha, Uttar Pradesh, Madhya Pradesh, Bihar, Assam and Rajasthan
II	Bihar, Maharashtra, Arunachal Pradesh	Puducherry, Tamil Nadu, Odisha, Madhya Pradesh, Delhi (NCT), Andaman and Nicobar, Gujarat, Rajasthan, Haryana, Andhra Pradesh and Punjab	Karnataka, Jammu and Kashmir, Uttar Pradesh, Himachal Pradesh, Assam, Kerala, Goa, Meghalaya, West Bengal, Sikkim and Tripura

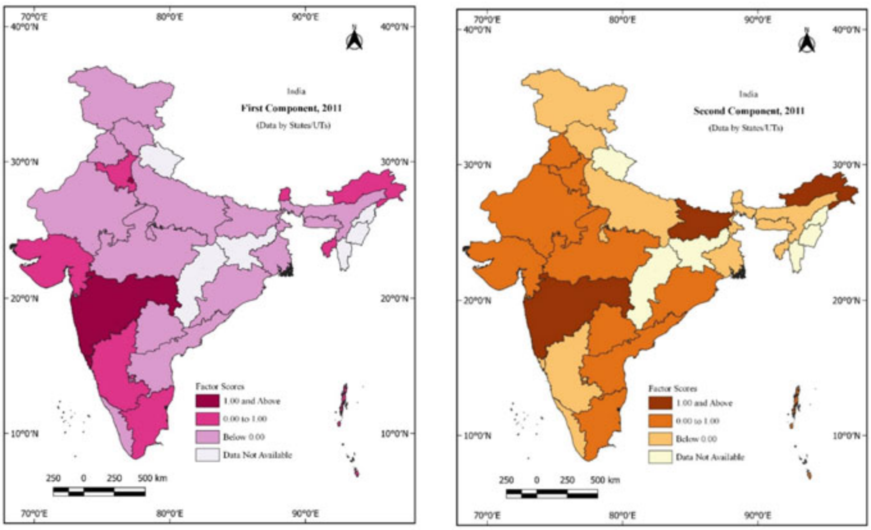


A B

C

Fig. 12.3 Spatial distribution of factor scores for principal components in India, 1980–81 factor score ≥ 1. This indicates better utilisation of the variables pertaining to each component. Percent urban population along with size of economy and economic sectors yielded high factor scores mostly for developed sates/UTs as illustrated in Fig. 12.4a. Among others, per capita NSDP showed higher factor loading (r = 0.875). It is in this context that Panagariya (2010) had indicated that India clocked a steady annual average growth of 8.5% for six years, beginning 2003–2004 and ending in 2008–2009, characterised with phenomenal growth experienced by the poorest states in recent years. Rajasthan and Odisha grew at 9.4% each, and Bihar at 8.4%. Likewise, the three newest states–Uttarakhand, Chhattisgarh and Jharkhand, which were carved out of poorer mother states of Madhya Pradesh, Uttar Pradesh and Bihar respectively, also grew at rates exceeding 9%. In fact, these three newly developed states performed much better than their mother states since their inception on the yardstick of per capita NSDP. By 1999–2000, Uttarakhand had a per capita income that was 1.4 times that of Uttar Pradesh, which had doubled by 2006–2007, and grew by 2.6 times that of the mother state by 2010–2011. The per capita income growth rate of Chhattisgarh was nine-tenths that of Madhya Pradesh and had steadily bridged the gap to achieve an impressive 30% lead over the latter by 2007–2008. Though Jharkhand began with a per capita income twice that of Bihar, it lost its ground compared to its inception.

The second factor represents urban attributes including annual average urban growth rate and percent share of manufacturing in NSDP. Figure 12.4b shows the scores for factor 2. Bihar, Maharashtra and Odisha are the three states that recorded high factor scores (≥ 1.00). Based on the discussion of principal components and the



A B

Fig. 12.4 Spatial distribution of factor scores for principal components in India, 2010–11 factor scores, it is obvious that among the combination of seven urban components and economic indicators, only two prominent variables maintained consistent and strong interrelationship with factor 1. These include *percent urban population* and *average annual per capita,* representing urban attributes and size of economy. In addition, sectoral composition to NSDP also received added impetus during and post-1990s. At disaggregate level, based on the scores obtained from factor analysis, Gujarat emerged as one of the most promising states, exhibiting phenomenal growth in terms of average annual per capita NSDP, average annual urban growth rates and the growth-enhancing manufacturing sector.

Conclusions

This paper examined the role of urban processes and urbanisation in the economic growth in India during 1981–2011, using the 1991 economic liberalisation as a framework. We explored the changing nature of relationships between urbanisation and the transitioning economic sectors that were the socio-economic and spatial manifestations of the liberalisation. Without doubt, India experienced rapid economic growth and development in every state and UT, albeit at varying levels. While the developed states/UTs including NCT-Delhi, Maharashtra, Gujarat, Goa, Puducherry and Tamil Nadu achieved significant growth, the developing states benefitted the most in terms of pace and growth rates regarding their urban components and economic indicators. Bihar, Arunachal Pradesh, Madhya Pradesh and Odisha were the classic examples of these phenomena. Interestingly, the newly carved out states like Uttarakhand and Chhattisgarh performed far better than their mother states, with the exception of Jharkhand where progress slowed down later on. We also found an interesting dualism in Indian urban system wherein the states with larger shares of industrial and service sectors attracted job seekers from rural areas and smaller towns, given the demand-induced labour needs in response to liberalisation's expansive industrial base and infrastructure.

Starting with 1980s, India witnessed accelerated economic growth, partly due to commendable growth in productivity in the service sector, which significantly contributed towards the aggregate value-added growth during 1981–2011, and eventual increase in urban population. This period represented diversification of economic structure that led to openness of external trade and investment and an ability to withstand external and internal shocks. Moreover, liberalisation of domestic economy and the increasing integration of India with the global economy helped the nation maintain the tempo of growth and development. Among principal factors, percent urban population and average annual per capita NSDP emerged as the two dominant variables maintaining a significant and strong positive correlation with high factor loadings. For most of the years, the trio were part of Factor 1. However, variables pertaining to manufacturing and service sectors' share to NSDP received additional thrust during the post reform era. The revitalisation of industries along with the growth of service sector led to significant growth in economy. Hence, along with urban attributes and size of the economy, the economic sector dimension including service sector's share to NSDP became representative of First Factor in 2001 and thereafter. The development of services such as banking, transport and communication, real-estate and IT is now regarded as one of the preconditions of economic growth, especially in context of developing economy like India. A significantly rising part of the value-added by manufacturers now consists of services, catering largely to tertiary and quaternary sectors. India today has the knowledge and 1.407 billion educated human resource, with a capacity to produce and process a wide variety of industrial and consumer products, along with providing quality services that can continue to drive the Indian economy.

Regarding the regional and global scale impacts of liberalisation in India, without doubt, the economic growth and prosperity were felt by the larger urban communities, ging rise to the *new middle class,* especially in the megacities of India in pursuit of making them the new *global cities* (Dupont 2011; Goldman 2011; Nijman 2006). This accelerated large-scale migration towards the megacities and second-tier cities, creating a *new spatial* order within and among the cities of India that involved strategic *face-lifting* of specific parts, as also the formation of informal settlements and urban villages in other parts of these new *global cities* (Dupont 2011; Mitra 2006; Mitra and Murayama 2009; Sharma 2017; Sharma and Abhay 2022). Narayana (2011)'s admirable illustrations of Bangalore's dramatic transitioning into the 'Silicon Valley' of Asia and the global south, is a testimony of the multi-faceted ways in which the economic liberalisation did its job. It propelled numerous service sectors by opening doors to international investors as well as domestic-international partnerships by creating a competitive playground for all. These produced cumulative cycles of basic and non-basic activities, putting India on a global map as a major competitor. These changes offered the much-needed face-lifting to numerous mid- and small-sized cities that became hot spots for a variety of human resource training destinations (IMF 2017; Mehta et al. 2012) that served well as the outsourcing centres and the newly skilled labour pool for the restructured industries. These processes continued to fuel rural–urban migration. The fruits of these changes, despite benefitting the newly emerging middle class, served well to provide at least food to the otherwise hungry and destitute poorer segments.

Also, while the socio-economic and spatial polarisation also increased in the country, the dreams of achieving the new middle-class status and aspirations of living a better quality of life, nevertheless, were already sown. As indicated by Behera and Karthiayani (2021), while the urban economy helped improve the status of urban dwellers, it also created large-scale regional inequalities. However, it was agro-based value-added industries that helped narrow down the economic inequalities. Our analysis and published scholarships provide pathways for a comprehensive development planning for all. This include attracting investments domestically and internationally, both such that balanced growth and development can be achieved for all. India has now become a choice location for IT and allied industries. However, with an abundance of educated, savvy and young human resource, India should push itself beyond the maquiladora status promoted largely by the first world countries (IMF 2017; Mehta et al. 2012). There exists enormous potential in India's talented and vast human resource, and the only way to bring real prosperity and holistic growth for all is by implementing equitably balanced investments in urban and rural economies alike.

References

Artelaris P (2021) Regional economic growth and inequality in Greece. Reg Sci Policy Pract 13:141–158

Behera DK, Karthiayani VP (2021) Do globalization progress and sectoral growth shifts affect income inequality? An exploratory analysis from India. Reg Sci Pol Pract 352–376. https://doi.org/10.1111/rsp3.12499

Bhagat RB (2002) Challenges of rural-Urban classification for decentralized governance. Econ Pol Wkly 37(25):2413–2416

Census of India (1981) Series I, India, paper 1 of 1982, final population tables; part II, special report and tables, primary census abstract; general population, 1983.

Census of India (1991) Series I, India, paper 2 of 1992, final population tables; brief analysis of primary census abstract

Census of India (2001) Series I, India, paper 1 of 2002, final population tables; part II, special report and tables, primary census abstract; general population, 2002

Census of India (2011) Series I, India, paper 2 of 2012, final population tables; brief analysis of primary census abstract

Central Statistical Organisation (CSO) (1988) New series on national accounts with 1980–81 as Base year, 1980–81 to 1985–86, Government of India, New Delhi

Central Statistical Organisation (CSO) (1989) National accounts statistics (1980–81 to 1986–87), Government of India, New Delhi

Chakraborty A, Sharma M, Abhay RK (2022) Colonial imprints in contemporary urban livability: an inter-ward analysis of Kolkata. GeoJournal: Special Issue Focus: Urbanism, Smart Cities and Modelling. Published online 10 March 2022. https://doi.org/10.1007/s10708-022-10606-7

Chandrashekhar CP (2013) Fragile foundation: foreign capital and growth after liberalisation. Soc Sci 41(1/2):17–33

Cieślik A, Rokicki B (2017) EU structural interventions and individual wages in Poland: empirical evidence for 2004–2006 financial framework. Reg Sci Pol Pract 9(3):201–217

Coe N, Kelly M, Philip F, Henry YWC (2012) Economic geography: a contemporary introduction. Neil MC, Philip FK, Henry WCY (eds)

Davis JC, Henderson JV (2003) Evidence on the political economy of the urbanization process. Brown University, Providence, Department of Economics

Davis K (1955) The origin and growth of urbanization in the world. Am J Soc 60(5):429–437

D'Monte D (2002) Ripping the fabric: the decline of Mumbai and its mills. Oxford University Press, New Delhi

DES (2011) Directorate of economics statistics of respective state governments, and for all India-CSO, 1st November 2011

Dupont VDN (2011) The dream of Delhi as a global city. Int J Urban Reg Res 35(3):533–554. https://doi.org/10.1111/j.1468-2427.2010.01027.x

Frick SA, Rodriguez-Pose A (2018) Big or small cities? On city size and economic growth. Growth and Change 49(1):4–332. https://doi.org/10.1111/grow.12232

Glen S (2016) Kaiser-Meyer-Olkin (KMO) test for Sampling adequacy. From StatisticsHowTo.com: Elementary Statistics for the rest of us! https://www.statisticshowto.com/kaiser-meyer-olkin/

Goldar B, Mitra A (2008) Productivity increase and changing sectoral composition: contribution to economic growth in India. IEG working paper E/291/2008, Institute of Economic Growth, Delhi

Goldman M (2011) Speculative urbanism and the making of the next world city. Int J Urban Reg Res 35(3):555–581. https://doi.org/10.1111/j.1468-2427.2010.01001.x

Hair JF, Black WC, Babin BJ, Anderson RE (2010) Multivariate data analysis. Pearson University Press, New Jersey, pp 280–285

Henderson JV (2003) The urbanization process and economic growth: the so-what question. J Econ Growth 8(1):47–71

HTTP1 (2021) Sector-wise GDP of India. Ministry of statistics and programme implementation, Published on 6.17.2021

HTTP2 (2022) Worldometer estimates. Last accessed on 19 June 2022 at https://www.worldometers.info/world-population/india-population/

HTTP3 (2022) World bank estimates. Last accessed on 19 June 2022 at https://tradingeconomics.com/india/urban-population-wb-data.html

IMF Report (2017) South asia regional update, May 2017 South Asia: continued robust growth

Jacob J (1984) Cities and the wealth of nations: principles of economic life. Vintage, New York

Joshi V, Little IMD (1994) India: marcoeconomics and political economy, 1964–1991. Oxford University Press, Washington, DC

Kaiser HF, Rice J, Little J, Mark I (1974) Edu Psychol Measur 34:111–117. https://doi.org/10.1177/001316447403400115

Kaldor N (1996) Causes of growth and stagnation in the world economy (The raffaele mattioli lectures). Cambridge University Press, Cambridge

Kratke K (2014) Cities in contemporary capitalism. Int J Urban Reg Res 38(5):1660–77. https://doi.org/10.1111/1468-2427.12165

Kundu A (1997) Trends and structure of employment in the 1990s: implications for Urban growth. Econ Pol Wkly 32(24):1399–1405

Mehta D, Bhatnagar A, Agarwal B (2012) Globalization and time arbitrage in India's outsourcing industries. Int J Soc Sci Interdisc Res 1(8):139–153. ISSN: 2277-3630

Mitra A (2006) Labour market mobility of low-income households, Econom Polit Wkly 2123–2130

Mitra A, Murayama M (2009) Rural to urban migration: a district-level analysis for India. Int J Migr Health Soc Care 5(2):35–52

Mohan R, Dasgupta S (2005) The 21st century: Asia becomes urban. Econom Polit Wkly 213–223

Naik NTK, Rahman SM (2007) Urbanization of India. Serial Publications, New Delhi

Narayana MR (2011) Globalization and urban economic growth: evidence for Bangalore India. Int J Urban Reg Res 35(6):1284–1301. https://doi.org/10.1111/j.1468-2427.2011.01016.x

Nayyar D (2017) Economic liberalisation in India: then and now. Econom Polit Wkly LII(2):41–48

Nijman J (2006) Mumbai's mysterious middle class. Int J Urban Reg Res 30(4):758–775. https://doi.org/10.1111/j.1468-2427.2006.00694.x

Obeng-Odom F (2012) Neoliberalism and the Urban economy in Ghana: urban employment, inequality, and poverty. Growth Chang 43(1):85–109

Panagariya A (2010) India on the growth turnpike: no state left behind

Patnaik P (2015) The Nehru-Mahalanobis strategy. Soc Sci 43(3/4):3–10

Shaban A (2022) Spatial development and inequalities in the Global South. Reg Sci Policy Pract 14:211–214. https://doi.org/10.1111/rsp3.12531

Sharma M (2017) Quality of life of labour engaged in the informal economy in the national capital territory of Delhi, India. Khoj: Int Peer Rev J Geogr 4(1):14. https://doi.org/10.5958/2455-6963.2017.00002.9

Sharma M, Abhay RK (2022) Urban growth and quality of life: inter-district and intra district analysis of housing in NCT-Delhi, 2001–2011–2020. GeoJournal: Special issue focus: Urbanism, smart cities and modelling. Published online, 1.7.2022. https://rdcu.be/cEzyJ; https://doi.org/10.1007/s10708-021-10570-8

Scott A, Storper M (2014) The nature of cities: the scope and limits of urban theory. Int J Urban Reg Res 1–15. https://doi.org/10.1111/1468-2427.12134

Sekkat K (2017) Urban concentration and poverty in developing countries global economy. Growth Chang 48(3):435–458. https://doi.org/10.1111/grow.12166

Short RJ (1996) The urban order: an introduction to cities, culture and power. Blackwell Publisher, USA

Siddiqui K (2017) Capital liberalization and economic instability. J Econom Polit Wkly 4(1):659–677

Siddiqui K (2018) The political economy of India's postplanning economic reform: a critical review. World Rev Polit Econom 9(2):235–264. https://www.jstor.org/stable/10.13169/worlrevipoliecon.9.2.0235. https://doi.org/10.13169/worlrevipoliecon.9.2.0235

Sivaramakrishnan KC, Singh BN (2003) "*Urbanization*" study report for research projects on India-2025 conducted by centre for policy research, New Delhi

Sud I (2009) Governance for a modern society: combining smarter government decentralization and accountability to people. India 2039 Policy Paper 6. Centennial Group, Washington D.C.

Thirlwall AP (2002) The nature of economic growth: an alternative framework for understanding the performance of nations. Edward Elgar Publishing Ltd., London

WDI (2011) World development indicators (2011). The World Bank

Xu X, Abbas HSM, Sun C, Gillani S, Ullah A, Raza MAA (2021) Impact of globalization and governance determinants on economic growth: an empirical analysis of Asian economies. Growth Chang 52:1137–1154. https://doi.org/10.1111/grow.12475

Yeung HW (2009) Transnational corporations, global production networks, and urban and regional development: a geographer's perspective on multinational enterprises and the global economy. Growth Chang 40(2):197–226

Yeldan Y (2006) Neoliberal global remedies: from speculative-led growth to IMF-led crisis in Turkey. Rev Rad Polit Econom 38(2):193–213

Chapter 13
Comprehending the Land Use Dynamics in Urban Regions by Conducting an Ex-post Master Plan Evaluation

Sushmita Choudhary and Subrata Chattopadhyay

Abstract Comprehensive plans, known as 'master plan' or 'blueprint', are statutory tools to guide cities' current and future land utilisation and zoning for 20–25 years. Urban master planning and land use plans are criticised for being costly, having rigid bylaws, and failing to control the development in a planned manner. Therefore, the research conducted an ex-post plan evaluation of urban land use plans prepared under master plans to determine if the proposed land uses conformed to subsequent existing land uses. Considering the rigidity of the planning process in India, the research adopted a conformance-based evaluation methodology and quantitative analysis for the case of five cities, viz. Indore, Ghaziabad, Lucknow, Jaipur and Surat to comprehend the urban land use dynamics. The results showed that the master plans of almost all the cities were considerably non-conforming. The non-conformance was evident in all land use categories and most significantly in commercial, recreational, circulation and overall developed/urbanised area. The research concludes that, given the lack of accountability for value-added outcomes and ex-post urban plan evaluation, proposed urban plans remain unevaluated, resulting in areas of non-conformance. The research recommends incorporating sustainable urban management strategies along with monitoring and ex-post plan evaluation to adhere to the planning proposals in order to use the land judiciously and provide a better quality of life.

Keywords Master/development plans · Urban planning · Land use · Ex-post plan evaluation · Conformance-based evaluation

S. Choudhary (✉) · S. Chattopadhyay
Department of Architecture and Regional Planning, Indian Institute of Technology, Kharagpur, West Bengal 721302, India
e-mail: sush2annie@iitkgp.ac.in

S. Chattopadhyay
e-mail: schat@arp.iitkgp.ac.in

U. Chatterjee et al. (eds.), *Urban Commons, Future Smart Cities and Sustainability*, Springer Geography, https://doi.org/10.1007/978-3-031-24767-5_13

Introduction

Land as an essential natural resource is positioned at the basal ground in the composite structure of 'population-resource-environment-development' (Zhang et al. 2005). As a result, comprehensive and urban land use plans are essential for sustainable urban development and spatial planning (Bulti and Sori 2017). Even though its demise has been continually predicted, comprehensive plans remain operational and assist decision-makers in managing urbanisation and building community consensus on land use concerns (Kaiser and Godschalk 1995). The planning process is constantly criticised because governments spend a lot of time and resources making plans that, most of the time, 'sit on the shelf' for years without implementation (Berke et al. 2006; Norton 2005). Additionally, land use plans and planning are attacked for having excessively rigid bylaws and still failing to control the development in a planned manner. Hence, the demand for confirmatory value-added outcomes is increasing in the planning process (Kaiser and Godschalk 1995; Laurian et al. 2010; Newcomer 1997). Although five-year reviews of these plans are compulsory, the realities of planning practice reveal that monitoring and evaluation are frequently overlooked stages in the planning process (Seasons 2002). Without any attempt to determine the extent of goal implementation in a previous plan, planning agencies experience a 'new plan syndrome', where they produce an updated, revised or modified plan despite knowing that the actual developed urban land use substantially differs from the plan recommendations (Calkins 1979).

Plan evaluation is a rigorous but crucial exercise because it monitors the progress of planning proposals and supports efficient planning dynamics. Evaluation practices provide a valuable opportunity to suggest revisions or adjustments to planning products and procedures. Furthermore, it empowers the building of a planning system based on an ongoing learning practice and gives planning legitimacy in the eyes of the public (Oliveira and Pinho 2010a, b; Seasons 2002). Evaluation of a plan refers to examining the outputs and effects of current and previous actions and deciding whether these are consistent with the plan objectives (Minnery et al. 1993). There are three phases of plan evaluation in the planning process, which include ex-ante, ongoing and ex-post evaluations. Ex-ante evaluation takes place at the onset of the planning process, ongoing evaluation occurs during the plan implementation, and ex-post evaluation, concerned with the impacts of the plan, takes place after it has been implemented. The literature suggests that compared to ex-ante evaluations, the latter phases are studied to a lesser extent (Hoch 2002; Oliveira and Pinho 2010b). Moreover, rarely is the ex-post outcome evaluation of land use plans conducted, even though it is the final measure of the effectiveness of development management (Bulti and Sori 2017; Carmona and Sieh 2008). This crucial aspect of the urban plan implementation and evaluation gap has been criticised by academics in the United Kingdom (Gilg and Kelly 1997), the United States (Berke et al. 2006; Ryan and Gao 2019), New Zealand (Laurian et al. 2010; Laurian et al. 2004a, b), Israel (Rachelle and Morris 1978), Ethiopia (Bulti and Sori 2017), Australia (Minnery et al. 1993) and China (Hao et al. 2009; Shen et al. 2019; Tian and Shen 2011; Zhong et al. 2014).

To fill this gap for ex-post plan implementation evaluation, scholars generally follow two distinct approaches to ascertain whether and to what extent the goals and outcomes of the plans have been accomplished: conformance-based and performance-based (Oliveira and Pinho 2010b). The conformance-based approach, primarily concerned with the goal and outcome alignment of the plans, views the role of urban plans as a blueprint (Alfasi et al. 2012; Brody and Highfield 2005; Laurian et al. 2004a, b; Rachelle and Morris 1978; Talen 1997). This method uses one or both standards to determine whether a planning exercise was successful or not. The first criterion is to what extent the ground realities conform to the plans or adhere to planning policy guidelines. Another one is if the instruments intended to implement a plan/policy, such as ordinances, detailed programs or projects, budgetary allowances, actually help accomplish its stated goals. Examples of conformance-based approaches include a comparison between proposed land use of comprehensive plans with consequent development efforts in Florida (Brody and Highfield 2005), comprehensive plans in Pueblo, Colorado (Talen 1996a), and local storm-water management and development permits in New Zealand (Laurian et al. 2004a, b). However, these analyses do not determine whether the observed outcomes result from planning activities or external influences (Laurian et al. 2010). The performance-based approach, conversely, views the plan as a guide and investigates how it affects the associated decision-making processes (Berke et al. 2006; Dalton 1989; Laurian et al. 2004a, b; Oliveira and Pinho 2009). A pioneering example of this approach is the Dutch school of planning evaluation (Alexander 2009; Driessen 1997; Mastop and Faludi 1997). Instead of focusing on how well a plan can lead to a particular goal, performance-based approaches analyse how the plan affects local discourse and the ongoing policy formulation and implementation process (Alexander and Faludi 1989; Driessen 1997; Ryan and Gao 2019).

Most scholars usually adopt either of the approaches to conduct an ex-post plan evaluation as both are considered valid yet potentially conflicting (Laurian et al. 2004a, b; Loh 2011; Rachelle and Morris 1978). Moreover, some scholars have attempted to integrate both approaches (Altes 2006; Berke et al. 2006). However, decisions regarding the adopted methodology get influenced by aspects like the nature of the plan, time and resource constraints, the decision regarding breadth versus depth of the research scope and the requirements of the identified research questions (Faludi 1989; Seasons 2002). Additionally, it is impractical and often unattainable to have an ideal plan monitoring and evaluation paradigm; hence, it is suggested that the notion and practice of plan evaluation must be progressively introduced in the planning process cycle and improved upon with time (Seasons 2002).

In the Indian context, for instance, a study attempted to delve into land use planning for a ward in Mumbai empirically by comparing existing land use to the envisioned use of the study area (Pethe et al. 2014). However, the author does not explore the study from the monitoring or ex-post plan implementation evaluation perspective. Instead, it presents it as a case of master plan failure and looks for new approaches towards urban planning in the global south cities. In India, master plans

(MPs) or development plans (DPs)[1] are considered a failure and have been criticised for decades (Bapat 1983; Bhan 2013; Meshram 2006; Nallathiga 2006; Pethe et al. 2014). Surprisingly, without even conducting a formal ex-post plan evaluation to conclude the success or failure of these plans.

India is rapidly urbanising, and the MPs are still the statutory tools to guide, control cities' growth and critically manage spatial sustainability (Raparthi 2015). The MP's scope is to provide broad proposals and specify land use allocation for primary land uses like residential, commercial, industrial, public and semi-public, recreational and circulation systems in Indian cities for a 20-year time horizon (Meshram 2006; Raparthi 2015). The urban maladies in Indian cities arise because of the disjunction between plan preparation and implementation, which creates a dichotomy between MP proposals and the existing ground realities (Meshram 2006).

Additionally, issues like urban sprawl, piecemeal constructions and interventions, environmental degradation, pollution and traffic congestion become the characteristics of a city in the absence or failure of MPs (Aayog 2021). But then the question arises: In the purview of lack of ex-post plan evaluation, how do we comprehend that an MP has failed to get implemented? These plans may successfully implement some land uses but may fail to do so in others. Theorists and urban planners may thus assume or hypothesise the success or failure of an MP. Therefore, the continuous process of plan implementation evaluations can help identify critical issues in different cities and specific land uses that need more attention.

As land use plans are the most common subject of monitoring and evaluation (Seasons 2002), the research has thus attempted an ex-post evaluation of land use plans proposed under the MPs. The research analyses the primary land uses in Indian cities at an aggregate MP level. Therefore, the research aims to assess the effectiveness of the proposed MPs in Indian cities by conducting an ex-post plan evaluation with the following research objectives (ROs).

1. RO1: To identify if the proposed MPs in the selected Indian cities were implemented, i.e. whether or not the proposed land use (PLU) under an MP conforms to the existing land use (ELU).
2. RO2: To identify in the selected Indian cities the land use categories which show conformance between the PLUs in MPs and the ELUs.
3. RO3: To determine the conformance variation shown by the individual land use categories in each MP of the selected Indian cities.

The research is focused primarily on conducting an ex-post plan evaluation, thereby establishing its need in the Indian planning scenario. However, it does not intend to identify the causal linkages or answer 'why' the MPs or land uses were not implemented. This research is instead centred around 'where', 'which' and 'how much' in the plan implementation evaluation, considering the Indian planning context and data availability. Following this introductory section, the second section of the

[1] As mentioned in URDPFI guidelines, master plan (MP) and development plan (DP) are identical terms and vary across the states in terminology only (MoUD 2014).

chapter is materials and methods, which presents the empirical evaluations complementary to the three research objectives. The third section presents the findings of the three analyses and discusses which MPs and land use categories were implemented and to what extent. The fourth section discusses the challenges/limitations of the study, and finally, the fifth section of the chapter ends with the conclusions.

Materials and Methods

Most former studies have dealt with plan implementation evaluation by considering individual case studies. On the contrary, this research followed a systematic and quantitative cross-sectional study of ex-post plan evaluation. Furthermore, quantitative analysis is relatively scarce for conducting plan implementation evaluation (Talen 1996a, b, 1997). This diverse dataset allows for the systematic ex-post plan evaluation, thereby bridging this knowledge gap in the planning literature. The research adopted the conformance-based ex-post evaluation methodology (Fig. 13.1), considering the blueprint nature of MPs and the rigidity of the planning process in India. The primary aim of the analysis was to comprehend the level of conformance between ELU and PLU as envisioned in the MP. This section of the chapter initially discusses the case study selection and the details of the land use data collected for the analysis. Next, the section moves forward with the conformance-based evaluation methods adopted to answer the three research objectives. The RO1 was first addressed by undertaking a master plan-wise analysis, followed by an urban land use category-wise analysis to address the RO2. Furthermore, RO1 and RO2 were answered using the statistical hypothesis testing technique, and finally, to address RO3, a conformance evaluation was carried out.

Case Study Selection

India is developing rapidly with high population, economic and urbanisation growth rates (Sudhira and Gururaja 2012). The level of urbanisation in the country is such that approximately 377 million inhabitants live in 7935 towns/cities, accounting for around 31.16% of the total population (Census of India 2011; Das 2013). Moreover, urbanisation is more prominent in the million-plus cities of India, which are the vital urban hubs accommodating 42.6% of the urban population (Chendrayudu and Chandrasekarayya 2020; Das 2013; Raparthi 2015; Sudhira and Gururaja 2012). In 1951, only five cities had a population above one million (m) in India. The same figure in 1981 increased to 12, whereas in 1991 this number rose to 23, and in 2001 the figure augmented to 35. The number of inhabitants of million-plus cities has rapidly increased in recent decades (Chendrayudu and Chandrasekarayya 2020). According to the Census of India (2011), 53 urban agglomerations (UAs) have a million or

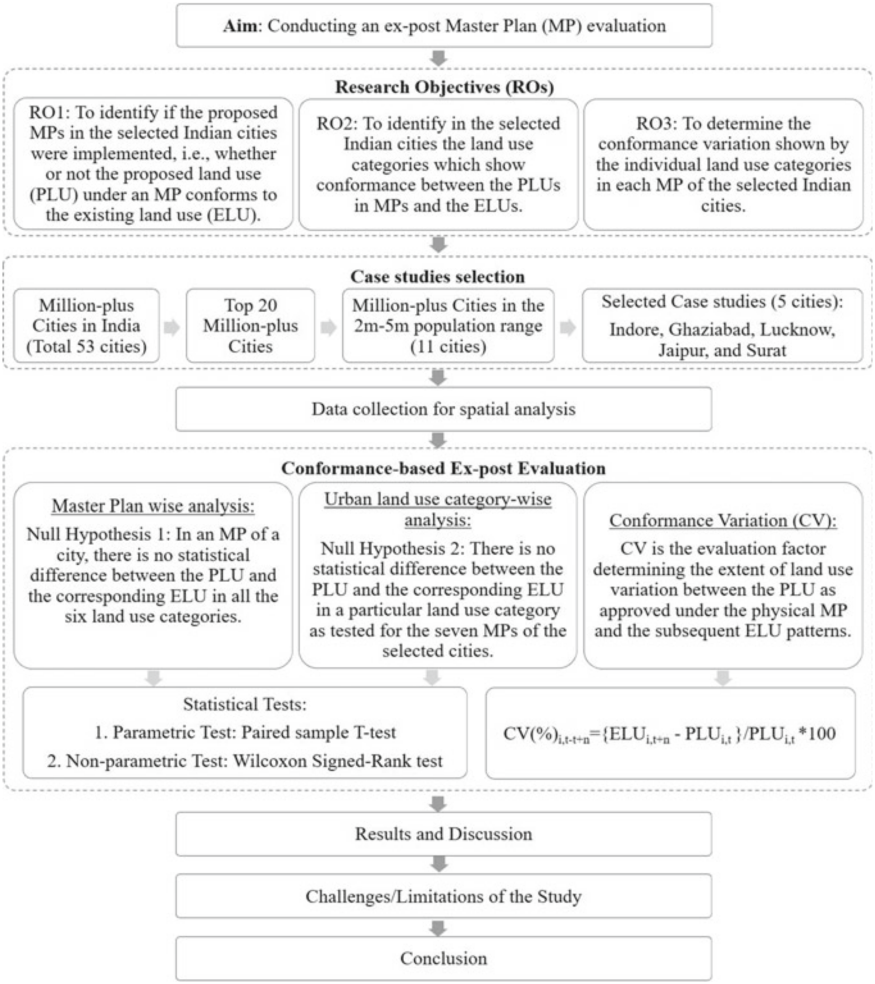


Fig. 13.1 Research methodology

above population (Ministry of Home Affairs, n.d.). Since the last census, 18 new UAs have been added to this list (Das 2013).

These statistics suggest that the million-plus cities are vital for the research to comprehend the urban land use dynamics. Additionally, these cities encounter issues like congestion, pollution, and social polarisation, and the urban growth in these cities impacts the overall regional development of the country (Chendrayudu and Chandrasekarayya 2020). Approximately 31% of the urban population resides in the top-20 most populated million-plus cities, according to the Census of India (2011) (Sudhira and Gururaja 2012).

This research selected the case studies from this list of the top-20 million-plus cities (Table 13.1). However, the cities with a population above five million were not chosen as their size was huge to comprehend the complex urban land use dynamics by undertaking only the conformance-based ex-post plan evaluation. Therefore, the research selected the case studies from the 2–5 m population range from the list of the top-20 million-plus cities to understand the ex-post plan evaluation scenario. An additional criterion for selecting these cities was that these UAs had a history of MPs preparation since independence. In this population range, there were 11 million-plus cities, and the collection of land use data of MPs from these 11 UAs was attempted for the research. However, land use data of seven MPs from five cities, namely Indore, Ghaziabad, Lucknow, Jaipur and Surat (Fig. 13.2), could be successfully obtained from various authorities. The following is a brief description of the selected case studies:

1. Indore in Madhya Pradesh has a population of 2.17 m. The city is an ancient settlement that dates back to the end of the fifteenth century. Patrick Geddes, a well-known architect and town planner, was invited to promote Indore's proper

Table 13.1 Top-20 most populated cities in India

S. No.	City/urban agglomeration	State/territory	Population (in million)
1.	Greater Mumbai	Maharashtra	18.41
2.	Delhi	Delhi	16.31
3.	Kolkata	West Bengal	14.11
4.	Chennai	Tamil Nadu	8.70
5.	Bangalore	Karnataka	8.50
6.	Hyderabad	Telangana	7.75
7.	Ahmedabad	Gujarat	6.35
8.	Pune	Maharashtra	5.05
9.	Surat	Gujarat	4.59
10.	Jaipur (M Corp.)	Rajasthan	3.07
11.	Kanpur	Uttar Pradesh	2.92
12.	Lucknow	Uttar Pradesh	2.90
13.	Nagpur	Maharashtra	2.50
14.	Ghaziabad	Uttar Pradesh	2.36
15.	Indore	Madhya Pradesh	2.17
16.	Coimbatore	Tamil Nadu	2.15
17.	Kochi	Kerala	2.12
18.	Patna	Bihar	2.05
19.	Kozhikode	Kerala	2.03
20.	Bhopal	Madhya Pradesh	1.88

Source Census of India (2011)

Fig. 13.2 Location of selected case studies

development in 1918. The Indore DP 1974–1991, adopted under the Town & Country Planning Organization Act, 1973, was the first post-independence planning intervention. The second DP was prepared for Indore in 2008 with the horizon year of 2021 (Indore Municipal Corporation 2018).

2. Ghaziabad in Uttar Pradesh, having a population of 2.36 m, started its planned development in 1958. On March 9, 1977, the Ghaziabad Development Authority (GDA) was constituted under the Urban Planning and Development Act, 1973. The primary objective of the GDA was to prepare MP for planned urban development. The city has had three MPs prepared since independence, namely MP1961–1981, MP1981–2001 and MP 2001–2021 (Nagar Nigam Ghaziabad, n.d.).
3. Lucknow, the capital of Uttar Pradesh, has a population of 2.90 m. Under the Uttar Pradesh Urban Planning and Development Act, 1975, Lucknow Development Authority (LDA) was established, which prepared the first MP for Lucknow

for 1970–2001. The second MP for Lucknow was formulated in 2001 with a perspective of 2021, and the current MP is for the horizon year 2031 (TCPO India 2020).
4. Jaipur, the capital of Rajasthan, also known as Pink City, has a population of 3.07 m. Jaipur was planned on a grid-iron pattern as a walled city in 1727. In 1976, the first MP for the horizon year 1991 was approved under Urban Improvement Trust (UIT) Act. In 1982, Jaipur Development Authority (JDA) was constituted to prepare the MP 1998–2011 and the current MP 2009–2025 (Bedi et al. 2019).
5. Surat, Gujarat, has a population of 4.59 m. In 1986, Surat Urban Development Authority (SUDA) was formed under the Gujarat Town Planning and Urban Development Act, 1976. SUDA is the concerned authority in preparing the Development Plans in Surat. The city has had three DPs since independence, namely DP 1986–2001, DP 2004–2011 and the current DP 2014–2035 (SUDA, n.d.).

Data Collection for Spatial Analysis

To conduct the conformance-based ex-post evaluation, the PLU data envisioned in the MP and the consequent ELU data pairs for the MPs of selected cities were collected. This data from secondary sources was mainly gathered from various government organisations, including development authorities and town planning departments (Table 13.2).

Master Plan-Wise Analysis

This section of the chapter addresses the RO1, which discusses the master plan-wise analysis. The null hypothesis shaped to answer the RO1 was:

Null Hypothesis 1: In an MP of a city, there is no statistical difference between the PLU and the corresponding ELU in all the six land use categories.

This analysis was carried out for seven MPs in five selected cities. The six land use categories considered under the MPs were residential, commercial, industrial, govt./public and semi-public, recreational and circulation. The null hypothesis was tested with a 95% confidence interval using parametric and nonparametric statistical tests on IBM SPSS Statistics 20 software. The analysis aimed to identify whether the MPs showed conformance between the PLU and ELU at an aggregate level.

Urban Land Use Category-Wise Analysis

This section focuses on the RO2, encompassing the urban land use category-wise analysis. The corresponding null hypothesis formed to answer the RO2 was:

Table 13.2 Details of the data collection process

Location on map	UAs/cities	Population in million (m)	Master plan (MP)/development plan (DP)	Source	Data collection
A	Indore	2.17	DP 1974–1991[a] DP 2008–2021	DP, Directorate of Town and Country Planning, Madhya Pradesh	September 2021 to October 2021
B	Ghaziabad	2.36	MP1961–1981 MP1981–2001[a] MP 2001–2021	MP section, GDA, Ghaziabad	
C	Lucknow	2.90	MP1970–2001[a] MP 2001–2021 MP 2031	(TCPO India 2020)	
D	Jaipur	3.07	MP 1971–1991[a] MP 1998–2011[a] MP 2009–2025	MP section, (JDA), Jaipur	April 2020 to May 2020
E	Surat	4.59	DP 1986–2001[a] DP 2004–2011[a] DP 2014–2035	DP section, SUDA, Surat	

[a]Data was collected for these master plans for the research

Null Hypothesis 2: There is no statistical difference between the PLU and the corresponding ELU in a particular land use category as tested for the seven MPs of the selected cities.

Each land use category in the seven MPs of the five selected cities was examined for the research. For this analysis, seven urban land use categories were evaluated. The first six land use categories were residential, commercial, industrial, govt./public and semi-public, recreational and circulation. The sum of the aforementioned land use categories formed the last category, overall developed/urbanised area. The null hypothesis was tested on IBM SPSS Statistics 20 software with a 95% confidence interval using parametric and nonparametric statistical tests. The analysis aimed to identify whether the PLU categories conformed to the ELU at an aggregate level.

Conformance Variation (CV)

This section of the chapter focuses on quantifying the CV between the PLU and its corresponding ELU to comprehend to what extent the proposed plan was implemented. Conformance-based approaches generally use GIS-based spatial overlay analysis to identify the CV (Bulti and Sori 2017; Hao et al. 2009; Ryan and Gao

Table 13.3 Land use data of selected cities

Land use category (area in hectares)		Indore DP 1974–1991	Ghaziabad MP 1981–2001	Lucknow MP 1970–2001	Jaipur MP 1971–1991	Jaipur MP 1998–2011	Surat DP 1986–2001	Surat DP 2004–2011
Residential	PLU	5060	4287.51	15,924	6960	13,825	9806.18	20,400
	ELU	4660	4670	8945	6426.4	17,445	6189	10,249
Commercial	PLU	648	359.29	983	647.49	2064	415.72	765
	ELU	570	274	360	384.45	825	256	466
Industrial	PLU	1498	1987.62	731	1804.89	1862	3023.4	4394
	ELU	843	1710	990	1007.66	1888	2784	3889
Govt./public and semi-public	PLU	1417	557.56	379	1222.14	3843	579.82	6421
	ELU	1096	425.65	560	1015.75	1830	735	1360
Recreational	PLU	1417	1561.13	1869	404.68	3461	106.61	1236
	ELU	290	399.5	435	214.48	529	58	234
Circulation	PLU	2105	1133.59	2260	2436.2	4741	1561.41	4073
	ELU	1370	752.85	1240	1177.63	3142	1661	3531
Overall developed/urbanised area	PLU	12,145	10,039.2	23,682	13,557	30,830	17,043	37,289
	ELU	8829	8485	16,270	10,226.4	26,415	13,234	19,729

MP Master Plan; *DP* Development Plan; *PLU* Proposed Land Use; and *ELU* Existing Land Use

2019; Zhang et al. 2005). Moreover, most of these studies focus on a single city as a case study. This research, on the contrary, deals with multiple cities and their MPs. For this reason, it would be arduous to use spatial overlay analysis. Additionally, no standard method is prescribed in the literature to quantify the CV. Therefore, the research has adopted the basic formula to capture the percentage change and determine the mathematical expression for CV.

In the context of ex-post land use plan evaluation, CV is the evaluation factor determining the extent of land use variation between the PLU as approved under the physical MP and the subsequent ELU patterns (Omollo 2019). The mathematical expression for CV(%) is given by:

$$\mathrm{CV}(\%)_{i,t-t+n} = \{\mathrm{ELU}_{i,t+n} - \mathrm{PLU}_{i,t}\}/\mathrm{PLU}_{i,t} * 100 \tag{13.1}$$

where $\mathrm{PLU}_{i,t}$ = PLU for land use category 'i' at a time 't',

$\mathrm{ELU}_{i,t+n}$ = ELU for land use category 'i' at the time '$t + n$',

n = MP/DP period,

i = land use categories, namely residential, commercial, industrial, govt./public and semi-public, recreational, circulation and overall developed/urbanised area,

$\mathrm{CV}(\%)_{i,t-t+n}$ = CV in the land use category 'i' at the time '$t + n$' from time 't'.

Results and Discussion

The results of the three analyses mentioned earlier will be discussed sequentially in this section.

Master Plan-Wise Analysis

For the seven MPs, land use data was collected in pairs for the PLU and the consequent ELU. The difference between the collected pairs of land use data in most of the MPs was continuous, normally distributed and random. However, the difference between the collected pairs of land use data was not normal for the MP of Surat and Lucknow. Additionally, the outliers were present in the difference between the collected pairs of land use data of Surat DP 1986–2001, Jaipur MP 1998–2011, Lucknow MP 1970–2001 and Ghaziabad MP 1981–2001. Therefore, the analysis undertook both parametric and nonparametric tests to address non-normality and the presence of outliers. A paired sample t-test was conducted for the parametric test, and a Wilcoxon signed-rank test was used for the nonparametric test. The Wilcoxon signed-rank test is the nonparametric equivalent of the parametric paired sample t-test.

Table 13.4 Master plan-wise results of paired sample t-test

MP/DP	Pairs	Paired differences			t	df	Significance (p) value (two-tailed)
		mean	Std. deviation	Std. error mean			
Indore DP 1974–1991	ELU-PLU	−552.67	367.66	150.09	−3.68	5	0.01
Ghaziabad MP 1981–2001	ELU-PLU	−275.78	507.16	207.05	−1.33	5	0.24
Lucknow MP 1970–2001	ELU-PLU	−1602.67	2715.88	1108.75	−1.45	5	0.21
Jaipur MP 1971–1991	ELU-PLU	−541.50	422.59	172.52	−3.14	5	0.03
Jaipur MP 1998–2011	ELU-PLU	−689.50	2323.50	948.57	−0.73	5	0.50
Surat DP 1986–2001	ELU-PLU	−635.02	1468.58	599.55	−1.06	5	0.34
Surat DP 2004–2011	ELU-PLU	−2926.67	3972.57	1621.79	−1.81	5	0.13

MP Master Plan; *DP* Development Plan; *PLU* Proposed Land Use; and *ELU* Existing Land Use

Parametric Test: Paired Sample t-test

The parametric test was conducted using paired sample t-test to determine if the arithmetic means of the two pairs of observations were equal for the MP of selected cities. The two pairs tested were the arithmetic mean of six PLU areas (in hectares) against their consequent arithmetic mean of six ELU areas (in hectares). The test was conducted for seven MPs from five cities.

The test results found (Table 13.4) a statistically significant difference between the PLU in Indore DP 1974–1991 and the consequent ELU, as the significance (p) value is 0.01. Similarly, the test found a statistically significant difference between the PLU in Jaipur MP 1971–1991 and the consequent ELU, as the p-value is 0.03. Therefore, the null hypothesis was rejected with a 95% confidence level. The analysis indicates that, on average, plan conformance in Jaipur MP 1971–1991 and Indore DP 1974–1991 decreased by −541.51 and −552.67, respectively. The analysis suggests with 95% confidence that the PLUs and consequent ELUs in these two MPs were significantly non-conforming as the associated significance value was less than 0.05. However, for the rest of the five MPs, the results showed the conformance between PLUs and ELUs as the associated p-value was more than 0.05.

Nonparametric Test: Wilcoxon Signed-Rank Test

The nonparametric test was conducted using the Wilcoxon signed-rank test to determine if the median of the two pairs of observations was equal for an MP of selected

Table 13.5 Master plan-wise results of Wilcoxon signed-rank test

MP	Pairs	Z	Significance (*p*) value (two-tailed)
Indore DP 1974–1991	ELU-PLU	−2.20	0.03
Ghaziabad MP 1981–2001	ELU-PLU	−1.15	0.25
Lucknow MP 1970–2001	ELU-PLU	−1.57	0.12
Jaipur MP 1971–1991	ELU-PLU	−2.20	0.03
Jaipur MP 1998–2011	ELU-PLU	−0.73	0.46
Surat DP 1986–2001	ELU-PLU	−1.15	0.25
Surat DP 2004–2011	ELU-PLU	−2.20	0.03

PLU Proposed Land Use; *ELU* Existing Land Use; *MP* Master Plan; *DP* Development Plan
Note Based on negative ranks.

cities. The two pairs tested were the median of six PLU areas (in hectares) of an MP against their consequent median of six ELU areas (in hectares). The test was conducted for seven MPs from five cities.

Similar to the paired sample t-test results, Wilcoxon signed-rank test also found a significant difference between the PLU and the corresponding ELU in the Indore DP 1974–1991 and Jaipur MP 1971–1991, $n = 6$, $Z = -2.20$, $p < 0.03$ (Table 13.5). Furthermore, the test found a significant difference between the PLU and the corresponding ELU of Surat DP 2004–2011, $n = 6$, $Z = -2.20$, $p < 0.03$. The analysis suggests with 95% confidence that the PLUs and consequent ELUs in these three MPs were significantly non-conforming as the associated significance value was less than 0.05.

However, the rest of the four MPs showed conformance between PLUs and ELUs as the associated p-value was more than 0.05 (Table 13.5).

Urban Land Use Category-Wise Analysis

For this analysis, seven urban land use categories were tested to identify whether the PLU categories got implemented on the ground at an aggregate level, considering the seven MPs. The primary land use categories analysed were residential, commercial, industrial, govt./public and semi-public, recreational, circulation and overall developed/urbanised area. For the seven land use categories of MPs, land use data was analysed in pairs of the PLU and the consequent ELU.

The difference between the collected pairs of land use data in each land use category was continuous, normally distributed and random. However, the difference between the paired land use data was not normally distributed in the commercial, govt./public and semi-public and overall developed/urbanised area land use categories. Additionally, the outliers were present in the difference between the paired land use data for the commercial land use, govt./public and semi-public land use, recreational land use and overall developed/urbanised area. To address non-normality and the presence of outliers, the research performed both parametric and nonparametric statistical tests.

Parametric Test: Paired Sample t-test

The parametric test was conducted using paired sample t-test to determine if the arithmetic means of the two pairs of observations were equal for the land use categories under consideration. The two pairs tested were the arithmetic mean of the PLU areas (in hectares) against their consequent arithmetic mean of ELU areas (in hectares) in each land use category of seven MPs.

The test results found (Table 13.6) a statistically significant difference between the PLU and the consequent ELU in the commercial ($p = 0.04$), recreational ($p = 0.02$), circulation ($p = 0.01$) and overall developed/urbanised area ($p = 0.03$) land use categories. Therefore, the null hypothesis was rejected with a 95% confidence level for these four land use categories as the associated significance value was less than 0.05, indicating non-conformance between PLU and ELU. However, the results showed the conformance between PLUs and ELUs for the rest of the three land use categories, namely residential, industrial and govt./public and semi-public as the associated significance (p) value was more than 0.05.

Table 13.6 Urban land use category-wise results of paired sample t-test

Land use pairs	Paired differences			t	df	Significance (p) value (two-tailed)
	mean	Std. deviation	Std. error mean			
Residential ELU-PLU	−2525.47	4723.74	1785.40	−1.42	6	0.21
Commercial ELU-PLU	−392.43	416.86	157.56	−2.49	6	0.04
Industrial ELU-PLU	−312.75	373.51	141.17	−2.22	6	0.07
Govt./public and semi-public ELU-PLU	−1056.73	1917.85	724.88	−1.46	6	0.20
Recreational ELU-PLU	−1127.92	949.52	358.88	−3.14	6	0.02
Circulation ELU-PLU	−776.53	569.95	215.42	−3.61	6	0.01
Overall developed/urbanised area ELU-PLU	−5913.82	5431.12	2052.77	−2.88	6	0.03

PLU Proposed Land Use; *ELU* Existing Land Use

Nonparametric Test: Wilcoxon Signed-Rank Test

For the land use categories under consideration, the Wilcoxon signed-rank test was applied to identify whether the median of the two pairs of observations was equal. The two pairs tested were the median of the PLU areas (in hectares) versus their respective median of ELU areas (in hectares) in each land use category of seven MPs.

Wilcoxon signed-rank test found a significant difference between the PLU and the corresponding ELU in the commercial, recreational and overall developed/urbanised area land use categories, $n = 7$, $Z = -2.36$, $p < 0.02$ (Table 13.7). Moreover, the test found a significant difference between the PLU and the corresponding ELU in circulation land use, $n = 7$, $Z = -2.19$, $p < 0.03$. Therefore, the null hypothesis was rejected with a 95% confidence level for the commercial, recreational, circulation and overall developed/urbanised area land use categories.

On the other hand, the results showed the conformance between proposed and ELUs for the rest of the three land use categories, namely residential, industrial and govt./public and semi-public (Table 13.7). The associated significance (p) value for these land use categories was more than 0.05, suggesting that the null hypothesis failed to be rejected. Additionally, the parametric and nonparametric tests yielded similar results for the urban land use category-wise analysis.

Conformance Variation (CV)

To determine the extent of MP implementation, expression (13.1) was used to calculate the land use CV(%) in the seven land use categories of the seven MPs. A positive CV(%) indicates that ELU coverage for a given land use category surpassed the PLU, indicating higher land consumption. On the other hand, a negative CV(%) suggests that the ELU was less than the PLU under the MP. Likewise, if the CV(%) is zero, it would imply that the MP was implemented as the ELU matched the PLU.

Table 13.7 Urban land use category-wise results of Wilcoxon signed-rank test

Land use pairs	Z	Significance (two-tailed)
Residential ELU-PLU	−1.35	0.18
Commercial ELU-PLU	−2.37	0.02
Industrial ELU-PLU	−1.69	0.09
Govt./public and semi-public ELU-PLU	−1.52	0.13
Recreational ELU-PLU	−2.37	0.02
Circulation ELU-PLU	−2.20	0.03
Overall developed/urbanised area ELU-PLU	−2.37	0.02

PLU Proposed Land Use; *ELU* Existing Land Use.
Note Based on negative ranks.

The CV(%) analysis results suggest that all the MPs and all the land use categories considered in the seven MPs showed non-conformance (Table 13.8). Most MPs and land use categories had a negative CV(%), indicating that the ELU was less than the PLU and that the land use was not implemented as proposed in the MP. Alternatively, it could imply that the PLU was projected much higher than the actual requirement for the city. This section of the chapter further discusses the CV(%) results along the MPs and land use categories.

CV(%) Along the MPs

The CV(%) results along the MPs indicate a significant non-conformance in the overall developed/urbanised area in all the MPs (Table 13.8). The higher the CV(%) in the overall developed/urbanised area, the higher the non-conformance between ELU and the PLU, indicating that MPs were not implemented as proposed. In the case of Indore DP 1974–1991, there was a significant CV(%) of −27.30% in the overall developed/urbanised area. The highest CV(%) in Indore was observed in the recreational (−79.53%) and industrial (−43.72%) land use categories, whereas residential land use showed the lowest CV(%) of −7.91%. Ghaziabad MP 1981–2001 showed a CV(%) of −15.48% in the overall developed/urbanised area. The most deviated land use category in Ghaziabad is also recreational land use (−74.41%), followed by circulation land use (−33.59%). Lucknow MP 1970–2001 also showed a significant CV(%) of −31.30% in the overall developed/urbanised area. Additionally, all the land use categories showed a considerable CV(%) of more than ± 35%, which contrasts with the master plan-wise analysis results, which suggested that the PLUs in Lucknow MP 1970–2001 conformed with the consequent ELUs.

In the case of Jaipur city, Jaipur MP 1971–1991 showed a significant CV(%) of −24.57% in the overall developed/urbanised area. Circulation land use had the highest CV(%) of −51.66% in this MP, followed by recreational (−47.00%), industrial (−44.17%) and commercial (−40.60%). Residential land use showed the lowest CV(%) of −7.67%. In the Jaipur MP 1998–2011, however, the CV(%) in the overall developed/urbanised area was lowest (−14.32%) compared to other MPs. Interestingly, recreational land use deviated significantly with a CV(%) of −84.71%, whereas industrial land use showed the lowest CV(%) of 1.40%. These are the maximum and minimum CV(%) observed in all the MPs and all land use categories. The remaining land use categories in the Jaipur MP 1998–2011 also showed a considerable CV(%) including commercial (−60.02%), govt./public and semi-public (−52.38%), circulation (−33.72%) and residential (26.18%).

As observed in Surat city, Surat DP 1986–2001 showed a CV(%) of −22.35% in the overall developed/urbanised area. A significant CV(%) was observed in land use categories like recreational (−45.60%), commercial (−38.42%), residential (−36.89%) and govt./public and semi-public (26.76%). However, the industrial (−7.92%) and circulation (6.38%) land use categories showed the lowest CV(%)in the Surat DP 1986–2001. In the Surat DP 2004–2011, however, the CV(%) in the overall developed/urbanised area was highest (−47.10%) compared to other MPs.

Table 13.8 Land use CV(%) in master plans

MP/DP	Indore DP 1974–1991	Ghaziabad MP 1981–2001	Lucknow MP 1970–2001	Jaipur MP 1971–1991	Jaipur MP 1998–2011	Surat DP 1986–2001	Surat DP 2004–2011	Average land use CV(%)
Residential	−7.91	8.92	−43.83	−7.67	26.18	−36.89	−49.75	−15.85
Commercial	−12.04	−23.74	−63.38	−40.60	−60.02	−38.42	−39.08	−39.62
Industrial	−43.72	−13.97	35.43	−44.17	1.40	−7.92	−11.50	−12.06
Govt./public and semi-public	−22.65	−23.66	47.76	−16.88	−52.38	26.76	−78.82	−17.12
Recreational	−79.53	−74.41	−76.73	−47.00	−84.71	−45.60	−81.06	−69.86
Circulation	−34.92	−33.59	−45.13	−51.66	−33.72	6.38	−13.30	−29.42
Overall developed/urbanised area	−27.30	−15.48	−31.30	−24.57	−14.32	−22.35	−47.10	−26.06

The highest CV(%) in Surat DP 2004–2011 was observed in recreational (−81.06%) and govt./public and semi-public (−78.82%), followed by residential (−49.75%) and commercial (−39.08%) land use categories. Circulation (−13.30%) and industrial (−11.50%) land use categories showed less CV(%) as compared to other land use categories in this MP.

CV(%) Along the Land Use Categories

According to the CV(%) analysis results (Table 13.8), Surat DP 2004–2011 (−49.75%) and Lucknow MP 1970–2001 (−43.83%) showed maximum CV(%) in residential land use. However, in the same category, Jaipur MP 1998–2011 had a significant positive CV(%) of 26.18%, indicating higher land consumption than the proposed amount. In the commercial land use category, Jaipur MP 1998–2011 and Lucknow MP 1970–2001 observed a high CV(%) of up to −60%. The average CV(%) in commercial land use was as high as −40%, while Indore (−12%) comparatively showed a lower CV(%). In the case of industrial land use, Indore and Lucknow showed a CV(%) of −43.72% and 35.43%, respectively. Considering the case of Jaipur city, the CV(%) was as low as 1.40% for the Jaipur MP 1998–2011, whereas the highest CV(%) was −44.17% for the Jaipur MP 1971–1991. Surat (−11.50%) and Ghaziabad (−13.97%), on the other hand, showed a lower percentage of industrial land use CV(%). In the govt./public and semi-public land use findings, a high CV(%) of −78.82% was observed in the Surat DP 2004–2011, and the Surat DP 1986–2001 showed a CV(%) of 26.76%. In the same land use category, Jaipur city MP 1998–2011 showed more than −50% CV(%), followed by Lucknow (47.76%).

In the recreational land use, all the cities showed a significant amount of CV(%) of more than −45% and an average CV(%) of −69.86%, indicating that this particular land use had the highest non-conformance. In the recreational land use, Jaipur city showed the highest CV(%) of up to −84.71% in Jaipur MP 1998–2011, followed by Surat DP 2004–2011 (−81%), and cities like Indore, Lucknow and Ghaziabad had a CV(%) of more than 70%. In the circulation land use category, the highest CV(%) of −51.66% was observed in Jaipur MP 1971–1991, followed by Lucknow (−45.13%), Indore (−34.92%) and Ghaziabad (−33.59%). Surat city DPs (less than ± 14%) among the five cities show the lowest CV(%) in circulation land use. The findings suggest that the MPs have failed to get implemented in all the cities as the overall developed/urbanised area showed an average CV(%) of −26%, which is most remarkable in Surat, Jaipur, Lucknow and Indore. Among the five cities, Surat had the highest CV(%) of −47.10% in the Surat DP 2004–2011 and −22.35% in Surat DP 1986–2011. Lucknow city also showed a non-conformance of −31.30%, followed by Indore having a CV(%) of 27.30%. Jaipur city MP 1971–1991 showed a −24.57% CV(%). However, Jaipur MP 1998–2011 had the lowest CV(%) of −14.32%.

Discussion

The findings of the three analyses broadly align with each other. The master plan-wise analysis indicated with 95% confidence that the Jaipur MP 1971–1991, the Indore DP 1974–1991 and the Surat DP 2004–2011 showed non-conformance on the ground. Similar results were obtained from the CV(%) evaluation also. In the overall developed/urbanised area of the Jaipur MP 1971–1991, Indore DP 1974–1991 and Surat DP 2004–2011, a CV(%) of −24.57%, −27.30% and −47.10%, respectively, was observed. Additionally, Lucknow MP 1970–2001 (−31.30%), Surat DP 1986–2001 (−22.35%), Ghaziabad MP 1981–2001 (−15.48%) and Jaipur MP 1998–2011 (−14.32%) showed a significant CV(%) in the overall developed/urbanised area, which was not captured in the statistical analyses.

Simultaneously, urban land use category-wise analysis suggested with a 95% confidence that the commercial, recreational, circulation and overall developed/urbanised area land use categories were not implemented as proposed. Likewise, it was observed that the recreational, commercial, circulation and overall developed/urbanised area land use categories showed an average CV(%) of up to −69.86%, −39.62%, −29.42% and −26.06%, respectively (Fig. 13.3). However, the statistical analyses showed conformity in the rest of the land uses. Nevertheless, the CV(%) results suggested that a significant amount of non-conformity was present in almost all land use categories.

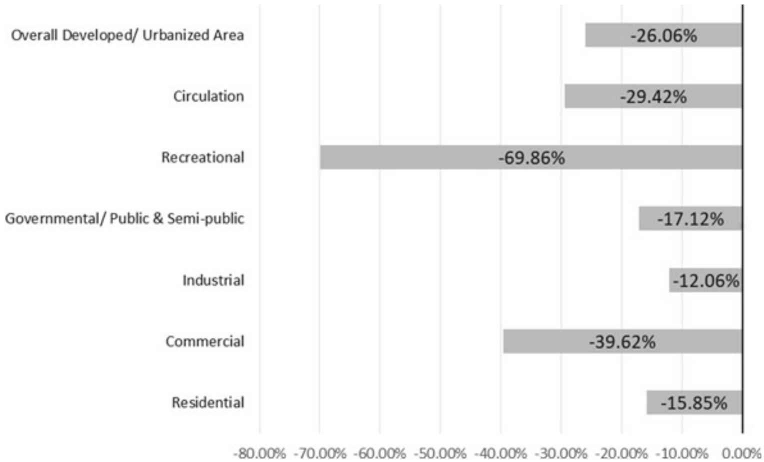


Fig. 13.3 Average CV(%) in the land use categories

Challenges/Limitations of the Study

Land use data from only five of the 11 cities in the 2–5 m population range could be collected due to the data non-availability and restrictions to provide the data from the concerned development authorities and other related departments. The willingness to make available the land use data across the cities also varied. For instance, in Indore, the land use data was simply available on the development authority website. On the contrary, in other million-plus cities, authorities were unwilling to share the data even after visiting the concerned departments. Additionally, acquiring the data for previous MPs was challenging due to the lack of ex-post plan evaluation practice. Also, it was difficult to collect data by personally visiting these departments in different cities considering the pandemic situation. However, this data limitation was handled by evaluating a sample of seven MPs from the selected five cities. Moreover, the same methodology can be applied in future with larger sample size, and statistical analysis can be performed using a paired sample t-test or z-test, depending on the sample size.

The analysis was conducted using a conformance-based evaluation, which has the limitation of not addressing attribution and causal linkages. To address this limitation, further research can be undertaken by combining performance-based and conformance-based evaluations to carry out a detailed ex-post plan evaluation.

Conclusion

The ex-post urban plan evaluation seems remarkably needful considering the amount of non-conformance identified in the land use plans. Surprisingly, MPs have been continuously prepared over the decades to guide cities' urban development and land use management without accountability for value-added outcomes. Furthermore, how do we know what happened to the plans after the exhaustive exercise of the master planning process? The research attempted to look into the answers by understanding the urban land use dynamics after the plan implementation. Land use data from seven MPs for cities with populations ranging from 2 to 5 m was collected to test the research hypothesis. The research aimed to comprehend whether or not the proposed MPs were conforming with the ground realities, which land use categories showed conformance or otherwise, and to what extent.

The findings of the research analysis were intriguing because all the MPs showed significant non-conformance, remarkably in Indore, Lucknow, Jaipur and Surat. According to the land use category-wise analysis results, the highest non-conformance was observed in recreational, commercial, circulation and overall developed/urbanised area land use categories with an average CV(%) of −69.86%, −39.62%, −29.42% and −26.06%, respectively.

Furthermore, the research findings indicate that recreational land use is poorly implemented in all cities and, as a result, requires special attention to understand the underlying issues with implementation. Considering the increasing urbanisation, land as a limited resource must be used wisely and sustainably. Thus, by incorporating sustainable urban management strategies, we can help to provide a better quality of life and green spaces. The research findings highlight the need for ex-post urban plan evaluation and establish the presence of non-conformance between the planning proposals and the consequent ELUs. The results indicate that even with detailed land use guidelines and planning experience, concerned authorities/departments fail to implement the MPs, and the final step of the planning process, i.e. plan evaluation, remains untouched.

Overall, the results of CV(%) showed a range of (−84.71%, 47.76%), which are significant, but how substantial is a CV(%) of, say, ± 15%. So, how do we determine whether the amount of CV(%) indicates that the plan was successfully implemented or not? As there is no established definition of a successful plan, the extent of CV(%) is an important aspect that should be investigated further. The research provides a methodology to evaluate MPs by bridging a gap by introducing a statistical approach and simultaneously witnessing a noticeable amount of CV(%). Further research can be conducted on ex-post plan evaluation using multiple methods, including conformance and performance-based approaches. Moreover, the performance-based techniques would help to identify the causal linkages. To ensure that planning proposals are implemented, the role of urban planners can be expanded to monitor the development persistently and conduct ex-post plan evaluations to identify CVs(%) at various scales. The severity of non-conformance, for example, may differ at the city and local area planning levels. This will further help the urban planners to understand the areas where the development control needs to be strengthened, and the plans can be updated effectively, thereby completing the planning process cycle.

References

Aayog N (2021) Reforms in urban planning capacity in India (Issue September). https://www.niti.gov.in/sites/default/files/2021-09/UrbanPlanningCapacity-in-India-16092021.pdf

Alexander E (2009) Dilemmas in evaluating planning, or back to basics: what is planning for? Plan Theo Pract 10(2):233–244. https://doi.org/10.1080/14649350902884177

Alexander E, Faludi A (1989) Planning and plan implementation: notes on evaluation criteria. Environ Plann B Plann Des 16(2):127–140. https://doi.org/10.1068/b160127

Alfasi N, Almagor J, Benenson I (2012) The actual impact of comprehensive land-use plans: insights from high resolution observations. Land Use Pol 29(4):862–877. https://doi.org/10.1016/j.landusepol.2012.01.003

Altes WKK (2006) Stagnation in housing production: Another success in the Dutch "planner's paradise"? Environ Plann B Plann Des 33(1):97–114. https://doi.org/10.1068/b31192

Bapat M (1983) Hutments and city. Econom Polit Wkly 18(11):399–401. https://www.jstor.org/stable/4371956

Bedi P, Tripathi NG, Singh HB (2019) Smart tourism innovations for smart region, case of Jaipur metropolitan region, India. In: Advances in 21st century human settlements. Springer Singapore. https://doi.org/10.1007/978-981-10-8588-8_9

Berke P, Backhurst M, Day M, Ericksen N, Laurian L, Crawford J, Dixon J (2006) What makes plan implementation successful? An evaluation of local plans and implementation practices in New Zealand. Environ Plann B Plann Des 33(4):581–600. https://doi.org/10.1068/b31166

Bhan G (2013) Planned illegalities: housing and the "failure" of planning in Delhi: 1947–2010. Econ Pol Wkly 48(24):58–70

Brody SD, Highfield WE (2005) Does planning work?: testing the implementation of local environmental planning in Florida. J Am Plann Assoc 71(2):159–175. https://doi.org/10.1080/01944360508976690

Bulti DT, Sori ND (2017) Evaluating land-use plan using conformance-based approach in Adama city, Ethiopia. Spat Inf Res 25(4):605–613. https://doi.org/10.1007/s41324-017-0125-3

Calkins HW (1979) The planning monitor: an accountability theory of plan evaluation. Environ Plan A 11(7):745–758. https://doi.org/10.1068/a110745

Carmona M, Sieh L (2008) Performance measurement in planning—towards a holistic view. Eviron Plann C Gov Policy 26(2):428–454. https://doi.org/10.1068/c62m

Census of India (2011) Visualisations | Government of India. Census India. https://censusindia.gov.in/census.website/data/data-visualizations/PopulationSearch_PCA_Indicators

Chendrayudu N, Chandrasekarayya T (2020) Trend and growth pattern of population in million plus cities of India-an Overview. Geo Eye 9(1):8–15. https://doi.org/10.53989/bu.ge.v9i1.3

Dalton LC (1989) The limits of regulation evidence from localplan implementation in California. J Am Plann Assoc 55(2):151–168. https://doi.org/10.1080/01944368908976015

Das KC (2013) The growing number and size of towns/cities in India: emerging issues from 2011 census data. Int Union Sci Study Population, 13. https://iussp.org/sites/default/files/event_call_for_papers/UrbantransitionIndia_IUSSP2013.pdf

Driessen P (1997) Performance and implementing institutions in rural land development. Environ Plann B Plann Des 24(6):859–869. https://doi.org/10.1068/b240859

Faludi A (1989) Conformance vs. performance: implications for evaluation. Impact Ass 7(2–3):135–151. https://doi.org/10.1080/07349165.1989.9726017

Gilg AW, Kelly MP (1997) The delivery of planning policy in Great Britain: explaining the implementation gap. New evidence from a case study in rural England. Environ Plann C: Gov Pol 15(1):19–36. https://doi.org/10.1068/c150019

Hao P, Sliuzas R, Zhan Q, Geertman S (2009) Land use deviations from the plan: a GIS based analysis of urban development in Shenzhen. In: The 11th international conference on computers in urban planning and urban management, pp 1–17. https://www.researchgate.net/publication/262314226_Land_use_deviations_from_the_plan_a_GIS_based_analysis_of_urban_development_in_Shenzhen

Hoch CJ (2002) Evaluating plans pragmatically. Plan Theory 1(1):53–75. https://doi.org/10.1177/147309520200100104

Indore Municipal Corporation (2018) Indore smart city abd master plan (Final). https://www.smartcityindore.org/proposed-master-plan/

Kaiser EJ, Godschalk DR (1995) Twentieth century land use planning a stalwart family tree. J Am Plann Assoc 61(3):365–385. https://doi.org/10.1080/01944369508975648

Laurian L, Crawford J, Day M, Kouwenhoven P, Mason G, Ericksen N, Beattie L (2010) Evaluating the outcomes of plans: theory, practice, and methodology. Environ Plann B Plann Des 37(4):740–757. https://doi.org/10.1068/b35051

Laurian L, Day M, Backhurst M, Berke P, Ericksen N, Crawford J, Dixon J, Chapman S (2004a) What drives plan implementation? Plans, planning agencies and developers. J Environ Plann Manage 47(4):555–577. https://doi.org/10.1080/0964056042000243230

Laurian L, Day M, Berke P, Ericksen N, Backhurst M, Crawford J, Dixon J (2004b) Evaluating plan implementation: a conformance-based methodology. J Am Plann Assoc 70(4):471–480. https://doi.org/10.1080/01944360408976395

Loh CG (2011) Assessing and interpreting non-conformance in land-use planning implementation. Plan Pract Res 26(3):271–287. https://doi.org/10.1080/02697459.2011.580111

Mastop H, Faludi A (1997) Evaluation of strategic plans: the performance principle. Environ Plann B Plann Des 24(6):815–832. https://doi.org/10.1068/b240815
Meshram DS (2006) Interface between city development plans and master plans. Itpi J 2:1–9
Ministry of Home Affairs (nd) Home | Government of India. MHA. Retrieved 13 July 2022, from https://censusindia.gov.in/census.website/
Minnery J, Cameron C, Brown J, Newman P (1993) Evaluation in urban planning. Aust Planner 31(1):8–13. https://doi.org/10.1080/07293682.1993.9657595
MoUD (2014) URDPFI guidelines, 2014. In: Ministry of urban development: vol 1
Nagar Nigam Ghaziabad (nd) Nagar Nigam Ghaziabad official website. Retrieved 2 Mar 2022, from https://ghaziabadnagarnigam.in/index.html
Nallathiga R (2006) Development planning or development control—the changing focus of master plan of Mumbai. ITPI J 4(3):28–35
Newcomer KE (1997) Using performance measurement to improve programs. N Dir Eval 1997(75):5–14. https://doi.org/10.1002/ev.1076
Norton RK (2005) More and better local planning: state-mandated local planning in coastal north carolina. J Am Plann Assoc 71(1):55–71. https://doi.org/10.1080/01944360508976405
Oliveira V, Pinho P (2009) Evaluating plans, processes and results. Plan Theor Pract 10(1):35–63. https://doi.org/10.1080/14649350802661741
Oliveira V, Pinho P (2010a) Measuring success in planning: developing and testing a methodology for planning evaluation. Town Plann Rev 81(3):307–332. https://doi.org/10.3828/tpr.2010.7
Oliveira V, Pinho P (2010b) Evaluation in urban planning: advances and prospects. J Plan Lit 24(4):343–361. https://doi.org/10.1177/0885412210364589
Omollo WO (2019) Conformity assessment to development plan implementation as a tool for development control in Kisii Town Kenya. South Afri J Geomatics 7(3):331. https://doi.org/10.4314/sajg.v7i3.10
Pethe A, Nallathiga R, Gandhi S, Tandel V (2014) Re-thinking urban planning in India: learning from the wedge between the de jure and de facto development in Mumbai. Cities 39:120–132. https://doi.org/10.1016/j.cities.2014.02.006
Rachelle A, Morris H (1978) Implementation of urban land use plans. J Am Plann Assoc 44(3):274–285. https://doi.org/10.1080/01944367808976905
Raparthi K (2015) Assessing smart-growth strategies in Indian cities: grounded theory approach to planning practice. J Urban Plann Dev 141(4):05014031. https://doi.org/10.1061/(asce)up.1943-5444.0000267
Ryan BD, Gao S (2019) Plan Implementation Challenges in a Shrinking City: a conformance evaluation of Youngstown's (OH) comprehensive plan with a subsequent zoning code. J Am Plann Assoc 85(4):424–444. https://doi.org/10.1080/01944363.2019.1637769
Seasons M (2002) Evaluation and municipal urban planning: practice and prospects. Can J Program Eval 17(1):43–71
Shen X, Wang X, Zhang Z, Lu Z, Lv T (2019) Evaluating the effectiveness of land use plans in containing urban expansion: an integrated view. Land Use Pol 80(October 2018):205–213. https://doi.org/10.1016/j.landusepol.2018.10.001
SUDA S (nd) Surat urban development authority—SUDA. Retrieved 13 July 2022, from https://www.sudaonline.org/
Sudhira HS, Gururaja KV (2012) Population crunch in India: is it urban or still rural? Curr Sci 103(1):37–40
Talen E (1996a) After the plans: methods to evaluate the implementation success of plans. J Plan Educ Res 16(2):79–91. https://doi.org/10.1177/0739456X9601600201
Talen E (1996b) Do plans get implemented? A review of evaluation in planning. J Plan Lit 10(3):248–259. https://doi.org/10.1177/088541229601000302
Talen E (1997) Success, failure, and conformance: an alternative approach to planning evaluation. Environ Plann B Plann Des 24(4):573–587. https://doi.org/10.1068/b240573

TCPO India (2020) Dynamics of PUA: prospects and challenges of sustainable development—a case study of Lucknow. http://tcpo.gov.in/sites/default/files/TCPO/RP/Final-report-of-Lucknow.pdf

Tian L, Shen T (2011) Evaluation of plan implementation in the transitional China: a case of Guangzhou city master plan. Cities 28(1):11–27. https://doi.org/10.1016/j.cities.2010.07.002

Zhang X, Pan Q, Zhao Y, Huang Q (2005) Research on spatial deviation analysis model of land-use change. MIPPR 2005: Image Anal Tech 6044(November 2005):60440C. https://doi.org/10.1117/12.652320

Zhong T, Mitchell B, Huang X (2014) Success or failure: evaluating the implementation of China's national general land use plan (1997–2010). Habitat Int 44:93–101. https://doi.org/10.1016/j.habitatint.2014.05.003

Chapter 14
Rethinking Urban Sprawl: Moving Towards Sustainable Urban Planning Practice in Zambia

Roy Alexander Chileshe, Idah Ethel Zulu, Gillie Cheelo, Ephraim Kabunda Munshifwa, Niraj Jain, and Anthony Mushinge

Abstract Zambia's urban population, estimated at almost 45%, is growing rapidly resulting in uncontrolled development, especially in peri-urban areas. This chapter explores sustainability of urban planning practice in developing country situations. In particular, the study examines first, the background of urban development in the country and its spatial distribution and association with population and economic growth. Secondly, the chapter examines post-independence urban development with its concomitant rural–urban migration of population, relatively high urban growth rates and urban sprawl. The chapter is cognizant that developments in most of the rapidly growing cities in Zambia have typically been informal and uncoordinated in low-density areas and swallowing up surrounding rural land. The chapter also examines the integrated development planning (IDP) approach currently promulgated as a solution to most planning ills. Thus, the chapter explores sustainability of current urban planning approaches, with respect to satisfying social, economic and environmental development needs of people and in countering urban sprawl. The chapter uses geospatial analysis of past, present and future trends of urban sprawl in Kitwe the largest city in the Copperbelt Province, to contextualise the understanding of urban sprawl and sustainable urban development policies in Zambia.

Keywords Urban development · Urban sprawl · Sustainable urban planning · Integrated development planning · Zambia

R. A. Chileshe (✉) · I. E. Zulu · G. Cheelo
Department of Urban and Regional Planning, Copperbelt University, Kitwe, Zambia
e-mail: chilesher@yahoo.co.uk

E. K. Munshifwa · N. Jain · A. Mushinge
Department of Real Estate Studies, Copperbelt University, Kitwe, Zambia
e-mail: ephraim.munshifwa@cbu.ac.zm

U. Chatterjee et al. (eds.), *Urban Commons, Future Smart Cities and Sustainability*, Springer Geography, https://doi.org/10.1007/978-3-031-24767-5_14

Introduction

The World Bank has estimated that currently about 55% (4.2 billion people) in the world live in cities which trend will continue (Saghir and Santoro 2018; Yiran et al. 2020). By the year 2050, the urban population will double in developing countries. Sub-Saharan Africa has the fastest-growing population growth in Africa estimated to about four percent (4%). This rapid population growth rate has consequences for the achievement of Sustainable Development Goals related to people's living conditions in the cities and towns. Rapid population growth in urban areas of sub-Saharan African is mostly attributed to rural–urban migration (UN-Habitat 2009; Saghir and Santoro 2018; Yiran et al. 2020). It is responsible for increased demand for city and town infrastructure and leads to the infill of undeveloped parts of the urban built environment and growth of cities and towns beyond their boundaries into nearby rural areas.

The relatively high growth rate of African towns and cities overwhelms the capacity of several local authorities, to plan for and provide satisfactory and affordable housing-related services. In order to cope with this challenging housing and services gap, several sub-Saharan African governments have since adopted policies that accommodate private sector participation and consequently resulting in rapid expansion of towns and cities beyond their boundaries (Fuseini and Kemp 2016; Fuseini et al. 2017; Yiran et al. 2020) caused a phenomenon called urban sprawl. Urban sprawl in the development context refers to uncontrolled and uncoordinated expansion of a city or town has its genesis from rapid development of a city and in turn fast urban sprawl results in encroachment and compromise of rural land use (Johnson 2001; Liu et al. 2011).

Urban sprawl negatively affects the three pillars of sustainable development that is social, economic and environment and consequently results in sustainability challenges for cities. For this reason, OECD (2018) study has proposed policy actions aimed at addressing unsustainable urban sprawl in European cities. However, studies from developed countries informed OECD report and its proposals. Yiran et al. (2020) rightly point out that generally research on urban sprawl in sub-Saharan Africa is extremely limited despite the relatively high urban population growth (UNECA 2017; Yiran et al. 2020). The outcomes of urban sustainability practices point to promotion of quality urban ecosystems, more green open spaces, protection of ecological sensitive areas, and less pollution and thereby contributing to prosperity in cities (Mersal 2016). Thus, this chapter explores urban sprawl and sustainability of urban planning practice and approaches in Zambia with regard to meeting socio-economic and environmental development needs of people and countering urban sprawl.

Materials and Methods

The City of Kitwe, located in the Copperbelt Province of Zambia is the case study, deliberately selected for its large size and relatively high population. Collection and analysis of data are characterised as mostly qualitative using secondary data from journals, books, government-documents, historical and current planning laws. Specifically, the Town and Country Planning Act (Republic of Zambia 1962); The Housing (Statutory and Improvement Areas) Act (Republic of Zambia 1975); Urban and Regional Planners Act (Republic of Zambia 2011); and The Urban and Regional Planning Act (Republic of Zambia 2015) were reviewed. Purposively selected people were interviewed in-depth. Further, LANDSAT Satellite imagery of the City of Kitwe was analysed using GIS to understand sprawl, informality and developments in ecological sensitive areas.

For data processing, image classification, and change analysis, Cloud-free Landsat (4 and 5, 8) satellite imagery were downloaded for Google Earth Engine via SEPAL Cloud-based application already preprocessed (corrected surface reflectance, georeferencing) and clipped to the study area (Kitwe District boundary). Landsat imagery used was of 30 m spatial resolution and approximately 27–30 days temporal resolution specifically using the blue, green, red, nir, swir1 and swir2 bands. Landsat imagery classification into built-up/settlement, agriculture/grassland, water and forestland cover classes used Random tree classification in ArcGIS 10.8. To understand spatial trend of the urban sprawl (built-up areas) for the study areas for the period 1990–2001, 2001–2009 and 2009–2020, using the semi-automatic classification plugin (SCP) in QGIS Desktop application to quantify and visualise of urban sprawl over the period being studied, post-classification change detection was applied. To calculate the detailed urban sprawl the built-up/settlement land cover is masked. This is in readiness for Shannon entropy and FRACTUAL landscape metrics analysis. Reference data sets included roads, rivers, streams, power-line residential neighbourhood boundary shapefiles.

Quantification of urban sprawl at district level for the years 1990, 2001, 2009 and 2020 was done. Nature of urban sprawl (linear growth, clusters and leaf frog) were determined based on visual image interpretation, 1 km buffering to the main roads and dividing the study area boundary into four grids. Firstly, Shannon Entropy was used to determine the degree of urban sprawl as whether being dispersed (growth on the edges) or compact (Moghadam and Mofrad 2018). Secondly, FRACTUAL landscape metrics of each timestamp were calculated to determine the main characteristics of the urban sprawl in more detailed, the specifically characteristics measured are absolute size, complexity and isolation (Magidi and Ahmed 2019).

Results

Background of Urban Development in Zambia

In Zambia, the colonial urban development process started from the 1890s to 1960s. Before this period local indigenous people used to live in scattered and sparsely population villages across the country. The British came with new policies and imposed them on indigenous people (Makasa 2019). British brought colonial policies of overseas expansion directed by ideologies of crown control, capitalism and modernism. Crown control ensured administrative control of the colony in question by agents of the British government in particular the British South African Company. The Company accumulated wealth from trade, extraction and production, but costs for municipal planning and administration were minimum. This meant '*There was to be industrialisation without urbanism*' (Home 1997; Makasa 2019: 66). During the period 1891–1924 and 1924–1964, the colonial territory Northern Rhodesia (today Zambia) was extensively and desperately surveyed for minerals (Mvunga 1980, 1982; Makasa 2019). After discovery of minerals several mines established, BS Co rule ended in 1924 after which the territory became a British Protectorate, and later in 1935, the more centrally located Lusaka became the capital of Northern Rhodesia (Makasa 2019).

European settlement, indigenous people displacement and genesis of informality

The colonisation of Zambia was followed-up by a grandiose Cecil Rhodes idea, 'Cape (South Africa) to Cairo (Egypt) railway line' corridor, to later link Africa with Europe for purposes of trade, and commerce (Hall 1972; Makasa 2019). The corridor of land 50 km astride the planned railway and road infrastructure declared Crown Land, under the Crown Lands and Native Reserves Order-in-Council of 1928 to make way for white settler farmers (Hall 1972; Mutale 2004) resulted in removal by force a large number of indigenous Africans (Hall 1972; Mvunga 1980, 1982; Makasa 2019).

Indigenous people living along this strip of land lost their customary right to land and increased dependency on wage employment (Tait 1997). The colonial government designated Crown Land for European settlement and development. Indigenous Africans were restricted to live in Trust Lands and Native Reserves (Mvunga 1980, 1982) today categorised by law as customary land. In this way, the separate development policy of the colonial government was enforced and it is clear that the genesis of informal settlements partly lies in the colonial foundations of the land tenure system of the country. Copper mineral deposits were discovered in the Copperbelt Province of Zambia leading to opening of mines and establishment of towns some of which have developed into Cities. The towns linked by the railway line as follows: Ndola to Luanshya in 1929; Ndola to Kitwe in 1930; Kitwe to Chambishi junction in 1931; Chambishi Junction to Chililabombwe, and Mufulira to Mokambo 1929 to 1932 and Kitwe to Chingola through to Chililabombwe in 1932 (Makasa 2019).

Colonial urban development policies and rural–urban migration

Several colonial policies including hut and poll tax; industrialisation without urbanisation of Africans; rural–urban migration; labour migration and employment-tied housing; townships and urban segregation; and the pass system drove colonial urban policy. Thus, the colonial government driven by capitalism created a need for cash among African people by requiring able-bodied men living in villages to offer their labour (Makasa 2019).

The poll-tax requirement together with the denial of a market for African produce and indeed the African men's attraction of exotic material possession and lifestyle compelled them to sell their labour for cash on the market. Rural–urban migrations coerced by the colonial policy started slowly and increased with time. Later there was a failure to match industrial activities with urban and housing development, which consequently resulted in poorly planned urban areas, urban racial settlement and a shortage of housing with squatters on the periphery of planned area settlements (Hall 1972; Tipple 1981; Tait 1997; Roberts 1996; Mutale 2004). Colonial urban housing types comprised high-cost low-density housing for Europeans, medium-cost, medium-density housing for non-Europeans and low-cost high-density housing for Africans.

Post-independence Urban Development and Planning

After Independence in 1964, the new government was sensitive of its colonial past where Africans suffered the injustice of planned housing segregation. Thus, the priority of government was to deal with the housing needs of the majority Africans. In reaction to colonial urban development policies, the new government abolished the hut and poll tax; ignored rural–urban migration; built more housing to address industrialisation without urbanisation of the Africans. Further, the government banned migratory labour and people had the freedom to live in places of choice. Consequently, the country experienced a high rural–urban migration of population directed to the towns on the railway line where employment opportunities and reasonable incomes were relatively available (Jayarajan 1979). At this stage, it is important to remember that town planning during the colonial period was for the benefit of the European people who chose to build detached houses on large suburban parcels of land. Given the small population of Europeans, the result was low-density sprawl, few widely spread community services and wide use of motor vehicles. In the initial days of independence, many whites left the country and formal housing areas experienced a class transition (Knauder 1982). Consequently, an urban-elite emerged and occupied the housing position of the colonial rulers (Tipple 1981; Rakodi 1986).

Zambia has since independence experienced a rapid population growth (Changula 2015). The UN estimates the population at **19,357,914 with an approximate growth rate of about 3%**. Its urban growth rates have been high and worrisome and about 45% of the total population of the country now lives in urban areas (UN-Worldometer

2022). Lusaka the capital city is the largest and fast-growing city, which has more than tripled its population since independence. Mainly, the historical urbanisation drivers have been discovery of minerals at the turn of the twentieth century and natural population growth (Changula 2015) (Table 14.1).

The formation and growth of the major towns and cities up-to the time of Independence in 1964 were almost completely dependent on the copper export sector of the economy. Since Independence, effort by government increased the scope of manufacturing and commercial activities in the country. The informal sector has tremendously grown and the 'formal' employment opportunities in urban and rural areas have not caught up with the increase output of school leavers and women labour force. Although the informal sector has been absorbing the increasing number of unemployed, it is unsustainable and thus unlikely to continue in the future.

After Independence, the government's focus has been to improve housing situation in urban areas, particularly to meet the housing needs of the low wage earners by the provision of low-cost housing and site and service schemes (Republic of Zambia

Table 14.1 Historic and future urban growth in Zambia

Historic urban growth 1990–2010				Future urban growth 2025–2035	
Main urban centres of Zambia	Population 1990	Population 2000	Population 2010	Population 2025	Population 2035
Lusaka	769,353	1,084,703	1,747,152	3,285,329	4,560,560
Kitwe	–	363,734	501,360	871,560	1,190,534
Ndola	329,228	374,757	451,246	646,417	777,276
Kabwe	154,318	176,758	202,360	253,429	286,418
Chingola	142,383	147,448	185,246	331,747	417,590
Mufulira	123,936	122,336	151,309	208,330	238,112
Living stone	76,875	97,488	134,349	214,579	280,508
Luanshya	18,143	115,579	130,076	163,775	182,773
Chipata	52,213	73,110	116,627	224,086	331,642
Kasama	47,653	74,243	101,845	162,640	216,620
Solwezi	23,435	38,121	90,856	238,623	354,546
Mansa	37,882	41,059	78,153	176,538	272,307
Chililabombwe	48,055	54,504	77,818	140,927	196,673
Kafue	43,801	45,890	72,166	131,490	178,793
Mazabuka	24,596	47,148	71,700	125,801	166,493
Mongu	29,302	44,310	52,324	66,044	78,081
Kalulushi	31,474	–	51,863	137,811	191,006
Choma	30,143	40,405	51,842	75,276	92,465
Kapiri Mposhi	13,540	27,219	44,783	94,749	150,129

Source Republic of Zambia (1990, 2001, 2014a, b), Changula (2015)

1996; Makasa 1996). Government efforts have however been overwhelmed by the number of rural migrants coming to towns. The small informal settlements that existed on the fringe of formal townships have grown in size and populations. With the increase in urbanisation, the proportion of urban population living in informal settlements has also grown tremendously (Jayaran 1979).

Urban development policies

Since independence, the main concern of the government's urban development in the country has been on correcting the segregated pattern of towns and cities inherited from the colonial authorities and further to provide adequate housing for the fast-growing urban population. The 1968 Integrated Housing Policy addressed the physical pattern of racial and class segregation. This housing policy required that new townships would be designed as residential units of communities that are integrated and provided with nursery schools and open space for play, and a neighbourhood would constitute a few of such communities provided with a breadth of necessary services (Makasa 2019).

Housing policies saw a departure from low-cost rental housing to home ownership and building of houses on self-help basis on serviced plots. In respect to low-coast housing, government adopted the site and services scheme as official policy. In line with government policy, local authorities received grants to meet the costs of essential services and amenities. Even given the site and service schemes of the 1970s, the housing situation in the urban areas of the country did not improve. The country still experienced a situation where a large part of low-cost housing stock was in 'squatter' settlements. To date, the government has recognised that informal settlements will require improvement and remain part of the urban areas (Jayaran 1979).

The Legal Basis for City Planning Process in Zambia

The urban planning process in Zambia started about 100 years ago with the creation of some towns in the country by the colonial administration. The planning process or comprehensive planning only started after independence. Accordingly, the First Town Planning Ordinance of Northern Rhodesia today Zambia was enacted in 1929. It served as a legal basis for the town planning schemes prepared during the colonial era and regulated development control. After Independence, the Town and Country Planning Act (TCPA) Chapter 283 of the laws of Zambia was enacted to provide a legal basis for spatial planning in the country. The Act provides for appointment of planning authorities; establishment of a Town and Country Planning Tribunal; preparation, approval and revocation of development plans, the control of development and subdivision of land. Further, assessment and payment of compensation in respect of planning decisions; the preparation, approval and revocation or modification of regional plans; and for matters connected with and incidental to the foregoing (Republic of Zambia 1962).

The TCPA served as a basis for town planning until 2015 with the enactment of the new Urban and Regional Planning Act number 3 of 2015. The TCPA was blamed for being outdated (Berrisford 2011; Banda et al. 2021) and not able to respond to the current challenges of urbanisation. The law vests administrative and legal powers for planning in the country in the Minister responsible for urban and rural planning. The Minister in turn delegates the powers of preparation of an integrated development and control of development to statutory bodies called planning authorities to work within the framework of the law. The URP Act provides details for planning authorities to follow on planning management and administration, planning framework and systems, improvement areas, planning applications and permission, and the planning process. Further, the URP Act provides for the appointment of a planning appeals tribunal and planning control and compensation. It also deals with appeals from developers whose applications for planning permission are not successful. Until 2014, the TCPA applied only to towns and cities on State Land constituted by about 10% of the country. This is land directly under the control of the State. Otherwise, plans outside State Land could only be advisory and not mandatory meaning that planning controls could not have much effect. The enactment of the URP Act brought a change in that now planning covers the whole district inclusive of customary lands through planning agreements. Joint integrated development planning across districts is included, and the shift is towards integration in the management of cities and urban areas in a sustainable manner.

A Shift to Integrated Development Planning

The URP Act of 2015 was a shift away from the British colonial system blamed for being responsible for segregated settlements. The current legislative provisions mandate local municipalities to manage urban planning through integrated development plans. Banda et al. (2021), suggest that integrated development planning (IDP) is both parts of the broader municipal strategic planning and the spatial development planning. The integrated development planning approach limits organic development of settlements (Chigudu and Chirisa 2020). Since the enactment of the new Act in 2015, only 10 municipalities in Zambia have developed the IDPs owing to lack of financial support, inadequate internal capacity/skills and delayed guidelines to guide the development process (Banda et al. 2021). In the past, spatial planning was guided by structure plans which are static maps with limited forecasting capabilities (Banda et al. 2021) with limited forecasting capabilities guided spatial planning. Further, these development plans at local level had little interpretation into the national development planning. Thus, majority of Zambian cities continue to develop without the benefit of a spatial framework which situation is lacking in curbing the ills of urban sprawl.

Section 35(1) of the Urban and Regional Act No. 3 of 2015 provides that an ‘integrated development plan shall be the principal planning instrument to guide and inform all planning and development in the area of the local authority and all planning decisions of a planning authority' (Republic of Zambia 2015; Banda et al. 2021). The URP Act further directs that within 6 months after a general election; the local authority shall initiate the process of developing an integrated development plan or adopt the already existing plan (Republic of Zambia 2015). The process undertaken to produce the IDP consists of interlinked phases; the planning survey and issues report, the development framework, the spatial development framework and implementation programme and finally approval and implementation (Republic of Zambia 2019). It is cardinal that public participation and engagement of other stakeholder are encouraged in the IDP preparation and implementation process. With the inclusion of the community participation and the integration of utility providers, the IDP approach pushes the agenda of planning more sustainable cities.

The urban and regional planning of Zambia stipulates procedures concerning development control in urban areas of Zambia. Under the law, 'development' means: *"the carrying out of any building, rebuilding, mining or other works or operations on or under land, including the subdivision of land or a change in the use of land"* (Republic of Zambia 2015).

Construction only starts after the planning authority grants planning permission. This is to ensure that the developer conforms to the development plan stipulation of land use. The procedures for government projects are simplified but not for private developers. The array of controls and ignorance of planning procedures can lead to unauthorised development. For such developments without prior planning permission, the planning authority has legal powers to serve notice on the developer and demolish the structure. The developer in such cases may make a formal appeal to the planning tribunal to arbitrate and take a final decision. Formal urban development is subject to planning control however, it is not the case with informal settlements, as they do not adhere to organised official procedures of development. The act mandates planning authorities to upgrade informal settlements through preparation on a local area plan or resettle the squatters in other locations within their jurisdiction. The reality is that illegal divisions are going on without the approval of the planning authorities. The sequence of steps followed by planning authorities in urban plan implementation may be summed-up as follows:

a. Layout plans showing plot subdivisions are prepared;
b. Cadastral surveying based on the layout plan;
c. Plot allocation;
d. Servicing of plots with infrastructural services (road networks, water supply and sewerage facilities; drainage and other facilities); Provision of social services and amenities;
e. Developments (construction of houses, shops, offices, industries, etc.).

Inadequate finance coupled with shortage of trained staff impedes the sequence of steps. Developers can barely wait for the services and amenities before they can start development. It may take several years before planning authorities provide services and amenities for completed projects. Such delays have resulted in individual house builders constructing houses in informal settlements rather than in formal housing areas. The lack of resources also lowers the standard of services provided. This is the prevailing situation in both small councils under rural councils and in city municipal areas.

Urban Sprawl in Kitwe

This section starts with understanding the nature and characteristics of sprawl in the City of Kitwe, followed by urban sprawl spatial trend analysis of the city and urban spatial analysis based on landscape metric. It concludes with urban sprawl detailed analysis in residential areas, river buffers and in green open spaces. A mere shift in approach towards integrated planning without clear policies that promote compact developments may not see a major shift in the patterns of growth in Kitwe. The IDP guidelines do not provide the need for analyses and review of urban sprawl to understand how the cities have been growing and compliance to development control. Over the past 32 years, the challenges of urban sprawl in Kitwe have remained despite several development plans. The city still experiences, mushrooming unplanned settlements, uncoordinated developments and increasing residential developments in environmentally sensitive areas and power utility way—leaves and forests.

The Nature and Characteristics of Sprawl in Kitwe

Kitwe city is a rapidly rising urban region that has seen rapid population increase over the last three decades, owing mostly to migration from nearby minor cities and rural areas. As a result, various environmental issues have arisen and grown over time (Lusaka Times 2022). Kitwe City Council (KCC) is facing serious challenges of guiding the physical growth of the city and providing adequate services for the ever-growing urban population. Therefore, measurement of urban sprawl in Kitwe will help the local authorities to guide and manage the spatial development of the city. Kitwe has been on a path of dispersed and sprawled developments as discussed earlier. Sprawl development is evident in Kitwe. City of Kitwe sprawl development is usually by urban agglomeration with adjacent suburban areas, and its growth is unsystematic and uncoordinated.

In the City of Kitwe, urban growth has been synonymous with economic growth in many ways. The underlying causes of sprawl include availability of economic opportunities and an expression of both planning regulation or a lack of it. The population of Kitwe estimated at 709,854 (World Population Review 2021) has grown by 23,946 since 2015, which represents a growth rate of 3.46 as shown in Table 14.2.

The nature and cause of urban sprawl in Kitwe have been due to the pressure of increased population and the constraints in the provision of urban services. The need for residential housing has pushed the city residents into the periphery in planned neighbourhoods and unplanned informal settlements. The lack of affordable housing close to the city centre pushes most urban residents into the periphery on land meant for agriculture, mining or forestry. In Kitwe, development seems to progress ahead

Table 14.2 Kitwe population and growth rates from 2011 to 2021

Years	Population	Growth	Growth rate
2011	512,876	16,216	3.27
2012	529,621	16,745	3.26
2013	546,914	17,293	3.27
2014	564,770	17,856	3.26
2015	583,210	18,440	3.27
2016	602,252	19,042	3.27
2017	621,916	19,664	3.27
2018	642,221	20,305	3.26
2019	663,455	21,234	3.31
2020	685,908	22,453	3.38

Source World Population Review (2021)

of the planning process and as such often leading to uncoordinated and unplanned settlements (Sudhira et al. 2007). In the growing city of Kitwe, car-centred urban models are still the widespread norm, with strict zoning policies dividing urban space into residential, commercial and industrial. The hypothetical understanding is that, these horizontally sprawling cities like Kitwe gradually find it harder to deal with an ever-increasing urban population and are not sustainable over the long term, owing to overwhelming negative externalities such as congestion, infrastructure issues, pollution and social disaggregation (UN Habitat 2009b). More than 60% of the city's population resides in informal settlements and some in environmentally sensitive areas.

The lack of a clear spatial framework to guide development leads to a dispersed and sporadic pattern of development in Kitwe. The focus of the development is residential areas with single story low densities, and a rise in commercial strip development. The proponents for compact development appeal for an integrated rapid public transport as a way of managing the environmental pollution that come with long travel distances caused by urban sprawl. However, there is no integrated bus rapid transit in Kitwe and urban development in is dependent on private cars. The concept of compact development counteract the negative effects of urban expansion and sprawl (Haaland and Bosch 2015).

Additionally, there is little evidence of infill mixed use development that is more as a response from the real estate market than it is a direct response of planning approach or policy. The surrounding rural areas are also not well-protected as these are seen as potential zones for new residential development both for the planned and informal settlements that spring up in the city. In a place where there are no explicit policies directly contributing towards compact development and moving away from the sprawl, developments remain unsustainable. With this absence of policies that call for compactness, the urban planning approach is merely to foster some kind of a 'planned sprawl'.

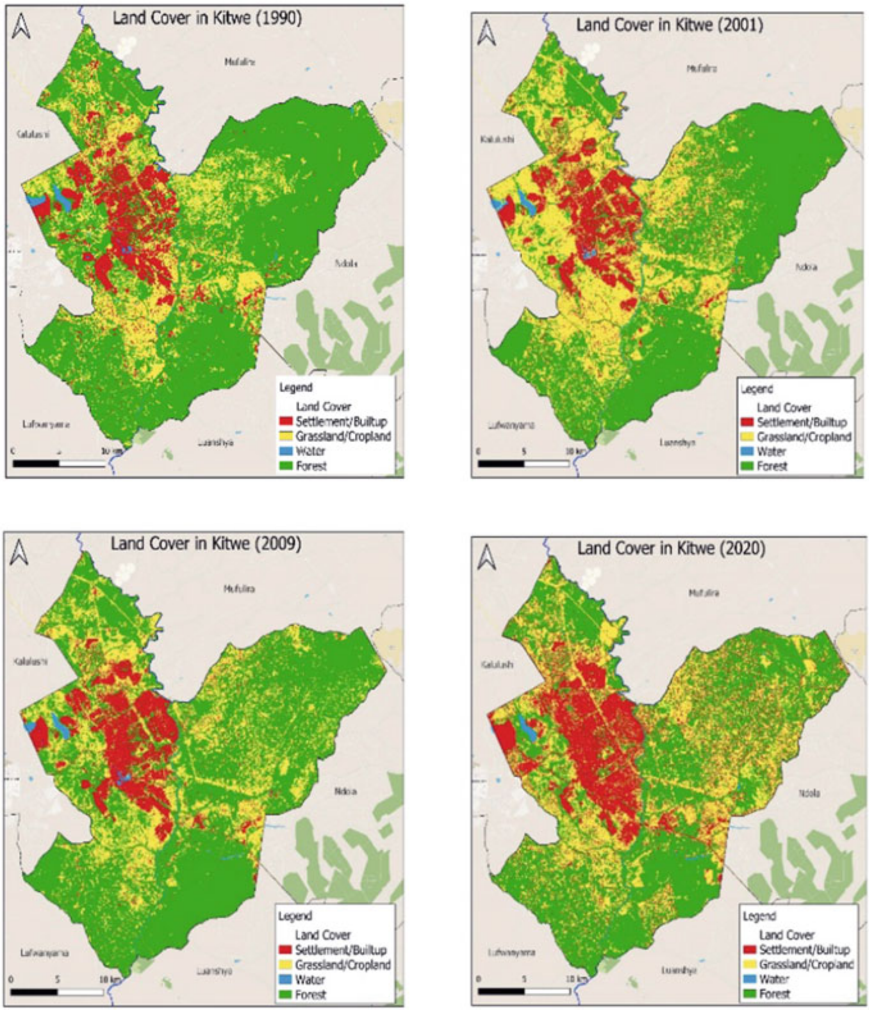


Fig. 14.1 Urban sprawl in Kitwe in 1990, 2001, 2009 and 2020. *Source* Authors (2022)

Urban Sprawl Spatial Trend Analysis

Three urban sprawl change maps shown in Fig. 14.1 demonstrate the progression of urban sprawl in Kitwe from 1990 to 2020. The first map shows urban sprawl from 1990 to 2001, second map urban sprawl as a progression from 1990 to 2009 and the third a progression from 1990 to 2020 shown by the built-up area, used as a proxy for urban sprawl. At district level, there has been increase in urban sprawl in all directions (north, west, east and south). Analysis between the 1990 to 2020 shows that built-up area increased from only occupying 11% of the total district area in 1990 to 12.2% in 2001. Between 2001 and 2009, the built-up area remained

Table 14.3 Land cover area table from 1990 to 2020

Class/Year	1990		2001		2009		2020	
	Area (m^2)	%	Area (m^2)	%	Area (m^2)	%	Area (m^2)	%
Built-up	91,662,416.1	11.4	98,024,137.69	12.2	98,242,868.56	12.2	162,361,624.1	20.1
Other land use	178,864,659.4	22.2	261,807,821.2	32.5	199,075,230.4	24.7	238,372,279.3	29.6
Water	4,835,896.27	0.6	5,044,925.523	0.6	4,914,392.477	0.6	3,663,737.921	0.5
Forest	530,938,722.6	65.8	441,424,809.4	54.7	504,069,201.1	62.5	401,906,052.5	49.8
Total	**806,301,694**	**100**	**806,301,694**	**100**	**806,301,692.5**	**100**	**806,303,694**	**100**

Source Authors (2021)

the same, but later in 2020 built-up area increased from to occupying 20% of the total district area. Apart from the conversion from different land uses to built-up areas, more and more grassland/cropland were being converted to built-up areas, especially in the north-eastern and north-western part of Kitwe. This has caused the reduction in the forest cover, which previously covered an area of approximately 65% in 1990 to covering 49% in 2020 of the total district area. Furthermore, more forest is changing to cropland/grassland, hence causing an increase grassland/cropland area from covering 22% in 1990 to covering 29% in 2020. Grass and cropland later convert to built-up area as urban sprawl continues to increase (Table 14.3).

Urban Spatial Analysis Based on Landscape Metric

Shannon Entropy measures the level of spatial concentration or dispersion. The Shannon Entropy calculation in this case used four (4), 21 km length grids, similar to Hamad (2019) and Roy and Kasemi (2021). The higher the calculated value of the Shannon Entropy the more the urban dispersion experienced as opposed to compact urban sprawl (Rastogi and Jain 2018). The results of the Shannon Entropy analysis show an increase in Shannon Entropy values from 0.56 in 1990 to 0.8 in 2020 as shown in Fig. 14.2. This result shows that the predominately type of sprawl in Kitwe more dispersed growth happening on the edges of existing built-up area and settlements than it is compact in nature.

FRACTUAL landscape metrics complimented the Shannon Entropy results as they provide a more detailed analysis of urban sprawl complexities as compared to Shannon Entropy metric. ArcGIS 10.8 Patch analysis extension calculated the FRACTUAL landscape metric. The results also showed continuous increase in both spread and compactness type of urban sprawl. Specifically, the following FRACTUAL landscape analysis were used to explain the landscape complexities and measure urban spread; Number of Patches (NUMP), Patch Size Variation Coefficient (PSCoV), Total Edge (TE) and Mean Total Edge (MPE) metrics were used to measure spread. NUMP result showed an increased from 34,435 in 1990 to 37,786 in 2020 which

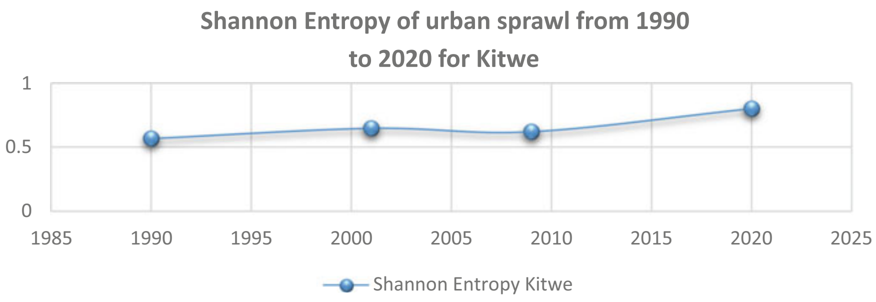


Fig. 14.2 Shannon entropy results for Kitwe from 1990 to 2022. *Source* Authors (2022)

Table 14.4 Landscape metrics of Kitwe built-up area (1990–2020)

Name of metric	AWMSI	AWMPFD	TE	MPE	MPS	NumP	PSCoV
1990	16.19	1.40	4,305,299.60	424.38	9.39	10,145.00	9466.89
2001	25.30	1.44	6,594,580.36	369.05	5.33	17,869.00	12,337.38
2009	20.92	1.43	5,715,964.35	384.01	6.40	14,885.00	11,135.25
2020	65.32	1.53	18,357,697.08	384.97	2.00	47,686.00	17,068.37

Source Authors (2022)

shows increase in the number of new settled areas mushrooming, the Patch Size Variation Coefficient (PSCoV) from 6125 in 1990 to 9271 in 2020 which implies increase in both the patch distribution and size. However, the TE reduced from 14,516,126 to 13,542,157 and also MPE reduced from 421 to 358 and Average Patch Size (MPS) reduced from 2.34 in 1990 to 2.13 in 2020 implying that the sprawls also show some compact sprawl and increase in a number of smaller settlements. This urban sprawl trend analysis shown by both landscape metrics (Table 14.4) and the maps shows that more predominately urban sprawl is compact sprawl.

Complexity analysis (Table 14.4) of the urban sprawl results calculated shows the similar trend. Here we selected the Area-Weighted Mean Shape (AWMSI) and Area-Weighted Patch FRACTUAL Dimension (AWMPFD) to illustrate the urban sprawl dynamics from 1990 to 2020. The variable AWMSI measures irregularity increased from 16 to 65 indicating increasing in irregularity of patches of urban settlements, and also the AWMPFD values increased from 1.45 to 1.49 indication increase in irregularity and complexity of the built-up patches. This shows that Kitwe has been experiencing irregular, uncoordinated and unplanned urban growth in addition to the predominately sprawled and compact growth from the Shannon Entropy results in Fig. 14.2.

To respond to this predominant uncoordinated, irregular urban sprawl growth Kitwe needs to include plans for urban intensification and densification to be able to achieve sustainable urban development. In practice, the current Kitwe development models that are private car centred does not encourage mixed-use development, or the placing of agriculture area as urban growth limits and has little focus on quality urban design that manifests traits of sustainable development.

One other strategy that helps mere containment of urban growth is through the improvement of the quality of life and attractiveness of the urban centres through urban renewal programmes and infill development (Fertner et al. 2016). This can help the City of Kitwe to move towards more sustainable developments. Infrastructure upgrades and compact urban design help to hinder urban sprawl. To sustain agricultural areas in the urban fringes, subdivision, zoning and protection acts maybe used. Fertner et al. (2016), suggest that urban growth can be managed using market-based incentives such as taxes, subsidies and transferable growth rights with the participation of private developers. These proposals are similar to the policy actions proposed by OECD (2018). These are relaxing maximum densities, reform urban policies and remove tax incentives for the development of land on the outskirts of the city. Further, shifting the cost of the infrastructure to the developer, stream line land use taxation, reform the tax resume such that more tax is placed on the value of land than the building, introduce road pricing mechanism, reform parking policies and invest more in sustainable forms of infrastructure. Some of these policies do not apply to the Zambian context and when implemented it is for reasons unrelated to sustainable urban development. These include payment of tolls, parking fee, taxes on fuel but in their current state do not hinder or discourage the general-public from owning private vehicles and living in peripherals of the city. Importantly, the concept of relaxing the densities, mixed-use and compact-oriented land use are some of the proposals for Kitwe.

Urban Sprawl Detailed Analysis in Residential Areas and River Buffers

To understand where exactly urban sprawl is happening, we further analysed urban sprawl in more details by looking at urban sprawl, formal residential areas, open spaces, unplanned settlements and in stream and river 50 m buffer. Chimwemwe residential area was analysed as one of the representative low-density residential areas to understand urban sprawl in a formal residential area and immediately surrounding area.

Figure 14.3: map shows urban sprawl (red pixels) in Chimwemwe residential shown with the black boundary and surrounding areas. Further, a 50 m buffer to the Mindolo stream, which discharge its water to the Kafue River, the second longest River in Zambia and the Copperbelt Energy Corporation Power line in the eastern direction in white. The result shown on Fig. 14.3 shows both in-fill (densification) and sprawl on the edges of the boundaries is being taking place since 1990 happening within Chimwemwe residential neighbourhood area and in the surrounding area. Furthermore, after overlaying with the Mindolo stream buffer of 50 m, we observed sprawls within 50 m to Mindolo stream.

On the eastern part of Chimwemwe, a lot of housing construction has even over spilled into the reserved power line leave way land, which should not be allowed for the safety of the residents. Figure 14.4: shows urban sprawl around the Mulenga

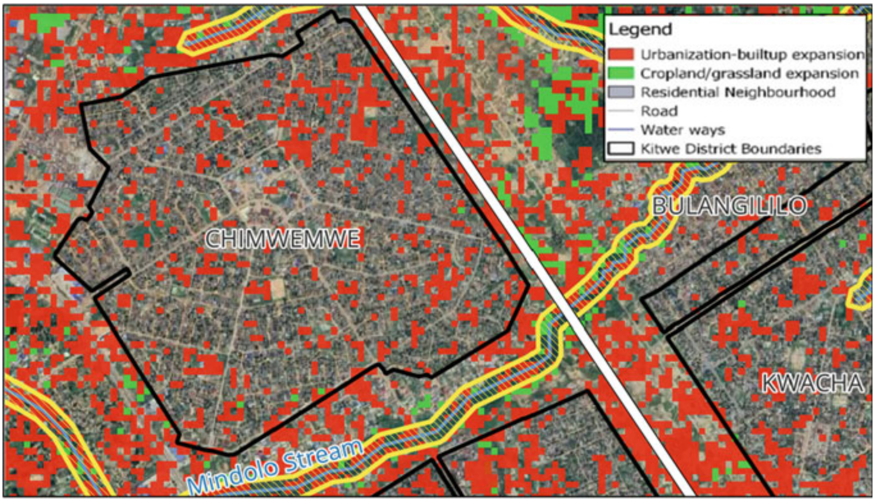


Fig. 14.3 Urban sprawl in Chimwemwe and surrounding residential areas. *Source* Authors (2022)

unplanned settlement in Kitwe. Surrounding areas including in the western side have seen the settlement expand north-west wise and encroach into the 50 m Mulenga stream buffer. The analysis along the Kafue River indicates a mixed situation, with the 50 m buffer we see that the river bank is not yet settled, unlike in the surrounding streams, but there are a lot of threats coming from both formal residential expansion and expansion of unplanned settlements. We have also observed increase in crop cultivation in these areas, which also have an effect on the river itself.

Urban Sprawl in Green Open Spaces

Green and open spaces drawn in 1961 Kitwe layout plan were used as a baseline, to assess the status of open spaces in Kitwe from 1990 to 2020. High-resolution Google Map accessible in QGIS shows that a number of the planned open and green spaces in Kitwe have been converted to other uses without being replaced as shown in Figs. 14.5 and 14.6. Most of the open space that has remained are mostly the ones used for sports and a few in high-cost residential areas such as those in Riverside and Nkana East residential neighbourhoods. Conversion to religious, commercial and residential uses have taken place in most green opens spaces in Chimwemwe low-cost-township (see Fig. 14.6). Big open space conversions are mostly from the 1960s. The Freedom Park and the Old Kitwe Zoo provided an inhabitant and important ecosystem shown in Fig. 14.5. Part of the Freedom Park and most of the Zoo are now shopping malls.

Figures 14.3, 14.4, 14.5 and 14.6 show a typical example of failed development control system in Kitwe which has caused continuous mushrooming and expansion of unplanned and serviced settlements, depletion of green open spaces, encroachment in environmental sensitives river banks and ecological significant places like the

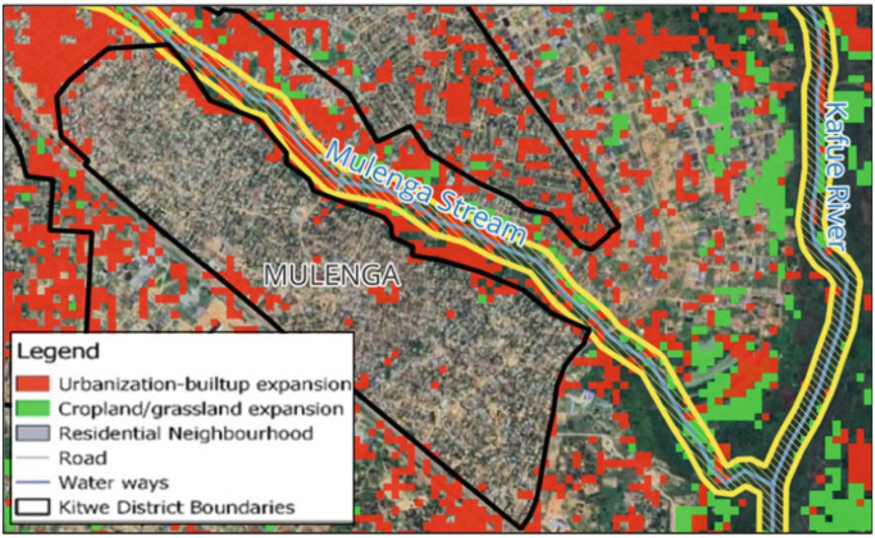


Fig. 14.4 Urban sprawl in Mulenga unplanned settlement and surrounding areas. *Source* Authors (2022)

Fig. 14.5 Part of Freedom Park and Old Kitwe Zoo converted to shopping malls. *Source* Authors (2022)

Fig. 14.6 Open space in Chimwemwe being converted to other land uses. *Source* Authors (2022)

old Kitwe Zoo. From the IDP preparation perspective, this is due to the lack of detailed urban sprawl analysis and modelling during plan preparation which has led to the cities like Kitwe not being able to practically find solution to addressing the urban sprawl challenge (Taylor and Banda 2015; Chigudu and Chirisa 2020). If the current urban sprawl remains unabated, it threatens the attainment of the two Sustainable Development Goals (SDGs) that apply to cities. The SDG 11 aims at making cities, and human settlements inclusive, safe, resilient and sustainable by year 2030, and SDG 15 aims to protect, restore and promote sustainable use of terrestrial ecosystem, sustainable forest management, combat desertification, halt or reverse land degradation and biodiversity loss (Shao et al. 2021).

Conclusion

Historical urban planning practices and colonial legislation have had tremendous effects on the patterns of growth experienced today in Zambia. With the information presented in this chapter, it is our hope that discussions emerge among urban planners that will inform rethinking urban planning practice with a view to move towards sustainable urban settlements.

We note that the IDP approach offers possibilities in moving towards sustainable urban settlements yet this requires coordinated efforts of many actors. The estimations show that Kitwe's population will continue to increase and therefore there is need for a planning framework that is future-oriented. This should change the direction and provide an integrated approach to development. Ineffective planning, inappropriate standards and unenforceable regulations (UN Habitat 2009a) largely, are blamed as the basis for informal and unplanned settlements in Kitwe. The majority, close to 60% of all residential development, takes place outside of the planning control and regulations. It may be necessary to propose guidelines on how to spatially review and forecast future growth patterns as part of the preliminary stages during the IDP preparation process if we are to achieve sustainability. The integrated approach will provide a future-oriented planning, well-coordinated transport patterns and promote compact growth. This begs for more emphasis on spatial planning that promotes mixed developments, strengthens implementation and emphasis on development control to restrict unsustainable expansion in environmental sensitive areas such as river/stream buffers. For planning to be sustainable, it is imperative that uncontrolled and unsustainable expansions of both formal and unplanned settlements developments are restricted.

Acknowledgements We wish to thank the Urban and Regional Planning and the Real Estate Research Groups at the Copperbelt University, School of the Built Environment for providing us with the working space.

References

Banda B, van Niekerk D, Nemakonde LD, Granvorka CG (2021) Integrated development planning in Zambia: ideological lens, theoretical underpinnings, current practices, views of the planners. Dev South Afr 39:338–353

Berrisford S (2011) Revising spatial planning legislation in Zambia: a case study. Urban Forum 22:229–245

Changula MN (2015) Public finance and urban growth: the case for a national urban policy for Zambia. Presentation to the IGC cities research conference: 21st to 22nd may 2015 held at the London School of Economics. https://zm.linked.com. Accessed 22 May 2022

Chigudu A, Chirisa I (2020) The quest for a sustainable spatial planning framework in Zimbabwe and Zambia. Land Use Policy 92:104442. ISSN 0264-8377. https://doi.org/10.1016/j.landusepol.2019.104442. https://www.sciencedirect.com. Accessed 22 May 22

Cutsinger J, Galster GC (2006) There is No sprawl syndrome: a new typology of metropolitan land use patterns. Urban Geogr 27:228–252

Fertner C, Jørgensen G, Nielsen TA, Nilsson K (2016) Urban sprawl and growth management—drivers, impacts and responses in selected European and US cities. Future Cities Environ 2:1–13

Fuseini I, Kemp J (2016) Characterising urban growth in Tamale, Ghana: an analysis of urban governance response in infrastructure and service provision. Habitat Int 56:109–123

Fuseini I, Yaro JA, Yiran GA (2017) City profile: Tamale, Ghana. Cities 60:64–74

Haaland C, Bosch CC (2015) Challenges and strategies for urban green-space planning in cities undergoing densification: a review. Urban Forest Urban Greening 14:760–771

Hall T (1972) Zambia 1890–1964: the colonial period. Longmans, Lusaka

Hamad R (2019) A remote sensing and GIS-based analysis of urban sprawl in Soran District, Iraqi Kurdistan. SN ApplSci 2(24):1–9. https://doi.org/10.1007/s42452-019-1806-4

Home R (1997) Of planting and planning: the making of British colonial cities. Routledge, Oxford

Jayarajan CK (1979) Some aspects of urban planning in Zambia. Department of Town and Country Planning, Research Unit, Lusaka

Johnson MP (2001) Environmental impacts of urban sprawl: a survey of the literature and proposed research agenda. Environ Planning A 33(4):717–735

Knauder S (1982) Shacks and mansions: an analysis of the integrated housing policy in Zambia. Multimedia Publications

Liu Y, Yue W, Fan PS (2011) Spatial determinants of urban land conversion in large Chinese cities: a case of Hangzhou. Environ Plann B Plann Des 38(4):706–725

Lusaka Times (2022) Kitwe council to demolish illegal structures. https://www.lusakatimes.com/2022/07/13/kitwe-council-to-demolish-illegal-structures/. Accessed 22 May 22

Makasa P (2010) The 1996 Zambia national housing policy. Delft, Delft Centre for Sustainable Urban Areas, Delft University of Technology

Makasa PLK (2019) Housing economics and policies in Zambia. A&S Printers, Port Elizabeth

Magidi J, Ahmed F (2019) Assessing urban sprawl using remote sensing and landscape metrics: a case study of City of Tshwane, South Africa (1984–2015). Egypt J Remote Sens Space Sci 22:335–346, Article ID 1110-9823. Accessed 22 May 22

Mersal A (2016) Sustainable urban futures: environmental planning for sustainable urban development. Procedia Environ Sci 34:49-61

Moghadam SA, Mofrad SS (2018) Urban sprawl trend analysis using statistical and remote sensing approach case study: Mashhad City. Creative City Design 1(1):1–8

Mvunga MP (1980) The colonial foundations of Zambia's land tenure system. National Education Company of Zambia, Lusaka

Mvunga MP (1982) Land law and policy in Zambia. Mambo Press, Gweru

Mutale E (2004) The management of urban development in Zambia: international land management series. Aldershot, Ashgate

OECD (2018) Causes and consequences of urban sprawl. In: Rethinking urban sprawl: moving toward sustainable cities. OECD Publishing, Paris. https://doi.org/10.1787/9789264189881-6-en

Rakodi C (1986) Colonial urban policy and planning Northern Rhodesia and its legacy. Third World Plann Rev 8(3)
Rastogi K, Jain G (2018) Urban sprawl analysis using Shannon's entropy and fractal analysis: a case study on Tiruchirappalli City, India. In: ISPRS—International archives of the photogrammetry, remote sensing and spatial information sciences, vol XLII-5, pp 761–766. https://doi.org/10.5194/isprs-archives-XLII-5-761-2018
Roy B, Kasemi N (2021) Monitoring urban growth dynamics using remote sensing and GIS techniques of Raiganj Urban Agglomeration, India. Egypt J Remote Sens Space Sci 24:221–230, Article ID 1110-9823. https://doi.org/10.1016/j.ejrs.2021.02.001
Republic of Zambia (1962) Town and country planning act chapter 283 29 of 1995. Government Printers, Lusaka
Republic of Zambia (1975) Housing (Statutory and Improvement Areas) Act, chap 194 of the laws of Zambia. Government Printers, Lusaka
Republic of Zambia (1990) 1990 census of population, housing and agriculture. Central Statistical Office, Lusaka
Republic of Zambia (2001) Republic of Zambia 2000 census of population and housing. Central Statistical Office, Lusaka
Republic of Zambia (2011) Urban and regional planners act, no 4 of 2011 of the laws of Zambia. Government Printers, Lusaka
Republic of Zambia (2014a) National urban policy (NUP) discussion paper 2014. Ministry of Local Government and Housing, Lusaka
Republic of Zambia (2014b) Sixth national development plan 2013 to 2016. National Planning Department Ministry of Finance, Lusaka
Republic of Zambia (2015) Urban and regional planning act no 3. Laws of Zambia, Lusaka
Republic of Zambia (2019) Integrated development planning guidelines. Ministry of Local Government, Lusaka
Roberts A (1996) A history of Zambia. Heinemann, London
Saghir J, Santoro J (2018) Urbanization in Sub-Saharan Africa meeting challenges by bridging stakeholders. CSIS, Washington DC
Shao Z, Sumani NS, Portnov A, Ujoh F, Musakwa W, Mandela P (2021) Urban sprawl and its impact on sustainable urban development: a combination of remote sensing and social media data. Geo-spat Inf Sci 24(2):241–255. https://doi.org/10.1080/10095020.1787800
Sudhira HS, Ramachandra TV, Mungila Hillemane B (2007) Integrated spatial planning support systems for managing urban sprawl
Tait J (1997) From self-help housing to sustainable settlement: capitalist development and urban planning in Lusaka, Zambia. Aldershot, Avebury
Taylor TK, Thole CB (2015) Re-thinking town and country planning practice in Zambia. Develop Country Stud 5(10):34–43
Tipple A (1981) The colonial housing policy and the "African Towns" of the Copperbelt: the beginning of self-help. Afr Urban Stud 11
UNECA (2017) Economic report on Africa 2017: urbanization and industrialization for Africa's transformation. Addis Ababa
UN-Habitat (2009a) Planning sustainable cities: global report on human settlements 2009: Earthscan
UN-Habitat (2009b) Zambia: Kitwe urban profile. United Nations Human Settlements Programme (UN-HABITAT), Nairobi
UN-Worldometer (2022) Zambia Population (Live). https://www.worldometers.info/world-population/zambia-population/. Accessed June 2022
World Population Review (2021) Kitwe population 2021. [Online] Available at: https://worldpopulationreview.com/world-cities/kitwe-population. Accessed May 2022
Yiran GAB, Ablo AD, Asem FE, Owusu G (2020) Urban Sprawl in sub-Saharan Africa: a review of the literature in selected countries. Ghana J Geogr 12(1):1–28

Chapter 15
Geospatial Technology for Analysing the Dynamics in Microclimate with Special Reference to Land Surface Temperature of Tropical Cities: A Case Study

K. P. Shimod, T. K. Prasad, V. Vineethkumar, R. Akhil, and G. Jayapal

Abstract The environmental implications of aggravating urbanisation associated with the alteration of landscape are of grave concern of urban planners now. This crisis is acute in many regions in the world, especially in the highly populated tropics. Urban geographers and planners are centring on climatically receptive designs to reduce undesirable microclimates. It demands scientific studies to address the problems related to the ill effect of unplanned developmental activities in the city. This study is an attempt to examine the spatio-temporal changes in the land use and land cover especially the built-up area and their impact in the land surface temperature (LST). Landsat imageries of 2000, 2010 and 2020 have been used to estimate the LULC, LST, NDVI and NDBI. The chapter shows that there is a remarkable increase in the built-up area and the land surface temperature for the last two decades. The mean temperature in the district was 26.76 °C in 2000, 28.54 °C in 2010 and 30.38 °C in 2020. The study suggests that it is necessary to have more focus on policies which will give more emphasis to urban greenery or urban forest concept in the upcoming years in order to reduce the land surface temperature in the district.

Keywords Microclimate · Land surface temperature (LST) · Normalised differential built-up index (NDBI) · Normalised differential vegetation index (NDVI) · Urbanisation

K. P. Shimod (✉) · T. K. Prasad · G. Jayapal
Department of Geography, Kannur University, Payyanur Campus, Edat, Kannur, Kerala 670327, India
e-mail: skp.orgin@gmail.com

T. K. Prasad
e-mail: tkprasadgeo@kannuruniv.ac.in

V. Vineethkumar
Department of Physics, Government College Kasaragod, Vidhya Nagar, Kasaragod, Kerala 671123, India

R. Akhil
Department of Geography, Himalayan University, Itanagar, Arunachal Pradesh 791111, India

U. Chatterjee et al. (eds.), *Urban Commons, Future Smart Cities and Sustainability*, Springer Geography, https://doi.org/10.1007/978-3-031-24767-5_15

Introduction

The rapid rate of urban growth and population pressure on land keep on altering the physical environment and resulting significant increase thermal environment of urban areas (Li et al. 2010). Urbanisation is the change from rural to urban, and its impact on environment has been widely assessed and studied for an effective resource management. Urbanisation has led to change in land use land cover especially in the peri-urban area frequently due to the rapid economic development. The process of urbanisation leads to the increasing in atmospheric as well as surface temperature and air quality in different ways to form urban heat island (Shimod et al. 2022a). This has a direct impact on human life and comfort, air pollution, energy management, climatic changes and urban planning policies (Fallmann et al. 2016). These changes can be ideally spotted and observed using the remote sensing images as they are comparatively up to date and provide a synoptic view of the area. The land surface temperature (LST) retrieved from the thermal band of satellite sensor provides scientific support to evaluate if the urban development is amenable with the environmental sustainability (Fan et al. 2010). Land use land cover changes have different kinds of environmental implications and the process of urbanisation which leads to the conversion of natural land cover to man maid land use has an immense impact on the urban climate. The decrease in the land surface temperature leads to the increases in albedo of the built-up surface, (Baldinelli et al. 2017) but the air temperature is not followed by same trend. The urban studies required accurate spatial information to observe the dynamics in land use land cover and the surface temperature (Xu 2011). Remote sensing products in the form of aerial photographs and satellite images provide data over a large area and are usually converted into useful information. Suitable image processing techniques and statistical analysis are used to extract the spatial parameters which are useful for detecting changes in urban extend as well as the thermal statistics. In several studies, different types of analysis are used to find out the relation between urban land use change and LST. These studies state that there is a direct impact of land use change in the variation of land surface temperature. When the area becomes urbanised, there will be an excess number of buildings for administration, industrial and residential purpose and transportation routes which will lead to increase in the temperature in and around the built-up regions (Prasad and Jishnu 2022; Jayalakshmy et al. 2021). The vegetative covers of regions are replaced by concrete materials in the urban area, and the density of vegetative cover will be reduced in its density and which will make the environment hotter. This will significantly increase the temperature of surface and affect the land use pattern. Hence, it is essential to understand the correlation between different land use land cover types and land surface temperature.

Knowledge of what others have found out in the related field of study and how they have done is a significant concern of a researcher. The different methodologies adopted by scholars like Slonecker et al. (2001), Dash et al. (2002), Jiang et al. (2006), Yuan and Bauer (2007), Mallick et al. (2008), Lu (2011a; 2011b), Sastry et al. (2013), Orhan et al. (2014), Chithra et al. (2015), Ivan and Benedek (2017), carried out studies in relation with different aspects and impacts of urbanisation especially in the field of land surface temperature, differential vegetation index, built-up index, etc. These kinds of research practice with remotely sensed data have involved interest since the 1970s and proved that, it is proficient in fetching out the trend and variations of results from time to time.

The studies on land surface temperature have received worldwide attention because of its importance and timely advancement and new innovations in different filed of urban studies. These kinds of studies related to LST can also provide useful awareness in many sorts of analysis like that of urban heat island, drought, forest fire monitoring and detection of thermal anomalies related to earthquakes (Wan 1999). This chapter discusses the changing land surface temperature over different period in the study area and its effects on different land use land cover in the district from 2000 to 2020.

Methodology

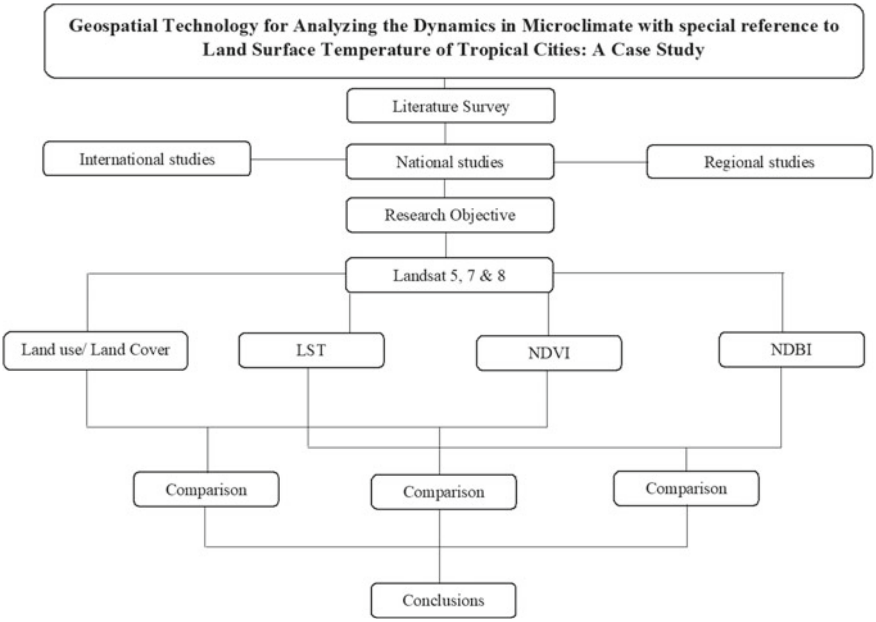
This study was carried out with the help of Geographical information system and remote sensing. Different time periods Landsat images (2000, 2010, 2020) were obtained from the official website of United States Geological Survey (USGS). These images are used for the calculation of different indices, i.e. LST, NDVI and NDBI. The location of the area under investigation falls in the Landsat path 145 and row 52 with UTM 43N WGS 1974.

Data Processing and Analysis

Cloud-free Landsat images downloaded from USGS for the years 2001, 2010 and 2020. The images were downloaded based on the percentage of cloud cover. As per the meta data, all the three images for the years 2001, 2010 and 2020 cloud cover are less than 20%.

ArcGIS 10.4 and ERDAS IMAGINE 2014 were used for data processing and analysis. The downloaded bands of different satellite images were layer stacked to obtain false colour composite (FCC), and also, processing of images includes geometric correction, unsupervised classification, band rotation and reclassifications and was done in ERDAS software. The output image is processed in ArcGIS platform, and different shapefiles were generated. The extraction of study area from the satellite images is performed using the district boundary shapefile.

Flowchart-methodology



Measurement of Land Surface Temperature (LST)

Many researches carried out studies in the recent years-related deriving LST using satellite data. The technological advancement in geospatial studies allows examining the changes in land surface temperature over different period of time this helps the researchers to make inferences in the relationship between land use changes over LST. In the earlier days, NOAA data was used to obtain LST for regional scale studies because of the resolution of the images attained from the satellite series. Nowadays, the Landsat satellite series, i.e. Thematic Mapper and Enhanced Thematic Mapper Thermal and Landsat 8 OLI Infrared band, has been used for studies in small-scale units.

Normalised Difference Vegetation Index (NDVI), Normalised Difference Built-up Index (NDBI) have also been calculated in order to inspect the correlation between LST. All these indices are calculated using Landsat 5, Landsat 7 and Landsat 8.

Retrieval of Land Surface Temperature

The Landsat images of 2000 which belong to Landsat 5 TM and 2010 of Landsat 7 ETM+ and 2020 of Landsat 8 OLI TIRS have been used for calculating LST. From Landsat 5 and 7, band 6 (thermal infrared band) has been used to calculate LST for 2000 and 2010. From Landsat 8, band number 10 has been used to estimate LST. Band 6 of Landsat 5 and 7 has a spectral range of 10.4–12.5 μm, and Band 10 of Landsat 8 has a spectral range from 10.60 to 11.19 μm. LST calculated from the thermal infrared band undergone radiometric calibration, emissivity and atmospheric correction. Landsat TM, ETM+ and OLI TIR are used for LST calculation.

Study Area

For the present investigation, Kannur District of Kerala (Fig. 15.1) has taken as the study area. Kannur District is typical tropical setting that lies between latitudes 11° 40′–12° 48′ N and longitude 74° 52′–76° 07′ E. The district is bound by the Western Ghats in the east (Coorg District of Karnataka State), Kozhikode and Wayanad district, in the south, Lakshadweep Sea in the west and Kasaragod, the northern-most district of Kerala, in the north.

Kannur District is one of the northern districts of Kerala, with a total geographical area of 2966 km^2 which accounts about 7.64% of the total area of Kerala state. It is ranked as in 6th position in areal extent. As per the 2011 census the total population of the district is about 2,523,003 persons, Kannur District ranks 8th in population among the districts of Kerala. Among the total population, 65.04% lives in the urban area, i.e. 1,640,986 persons. The region accounts 4th rank in the percentage of urban population in the state.

Spatial Pattern of LST

The spatial variation of the land surface temperature has been studied from 2000 to 2020. The values of LST distribution have shown in Fig. 15.2. After the retrieval of LST values from the satellite data using the above-mentioned formula, it shows the changes in the temperature values of last two decades in the district. The temperature range experienced in the district in 2000 is about 19.46–34.07 °C. In 2010, the range has increased to 20.38–36.69 °C. In 2020, the variation is 21.37–38.79 °C. This change in temperature ranges from time to time mainly due to the uneven trend of urbanisation pattern in the district. One of the most noticeable facts that all the Class II and Class III towns in the district are located very close to the major rivers flowing in the district that helped the district in lowering down the temperature up to an

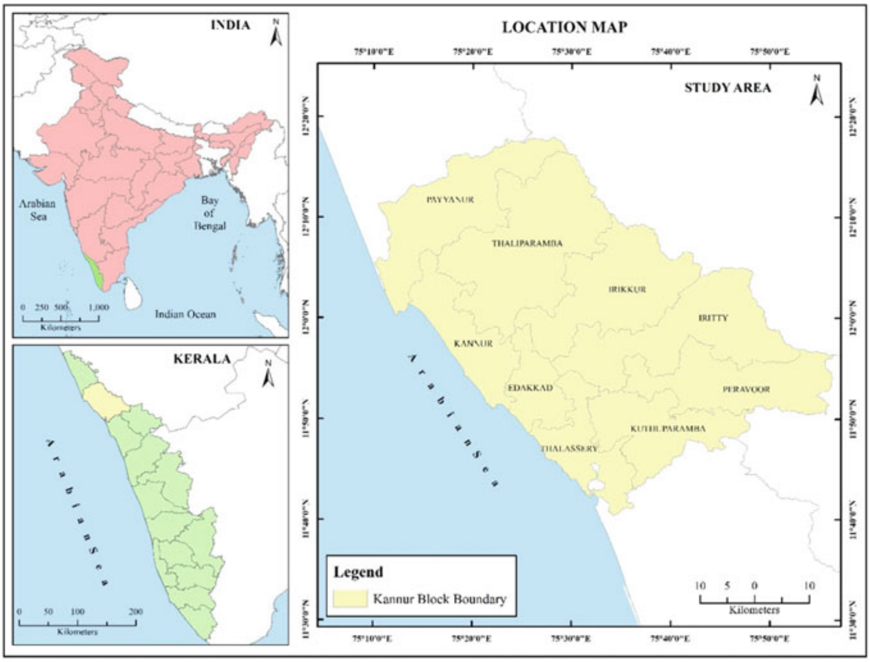


Fig. 15.1 Location map

extent. Even then the intensity of temperature gradually increases in the subsequent years.

The LST map shows colour variation from red to green, where the red shades show the areas recorded with high temperature and intensity or in other term the red decreases with the decrease in temperature. The areas of low temperature are shown with the green colour shades. The red shades mainly correspond to the built-up areas, open spaces such as grounds, construction sites and bare hill slopes. The green shade mainly shows the water bodies, forested tracts and agricultural lands. From this analysis, it has been identified that there is increase in the minimum and maximum temperatures recorded from 2000 to 2020.

Land Cover Type and Land Surface Temperature

There is a significant relation between land use land cover and land surface temperature of a region because change in the land use land cover has a direct impact on the temperature of that region. Different land use land cover types such as water bodies, built-up lands, vegetative covered areas and barren lands are the areas where the heat signature recorded by the satellite images and post-processed using remote

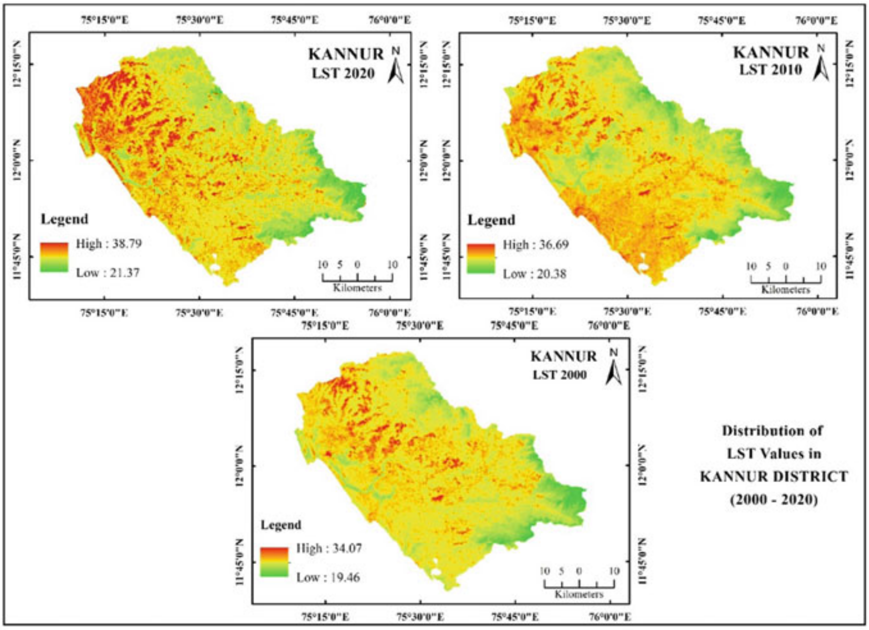


Fig. 15.2 Distribution of LST in Kannur district 2000–2020

sensing (Ibrahim et al. 2016). In the present study, analysis was done to find out the correlation between land use land cover and land surface temperature as well (Rajasekar and Weng 2009). The present study examines the change of temperature over different land use land cover type in the district over two decades, from 2000 to 2020. For that, the land use land over of the district had broadly classified under five categories (Table 15.1), they are vegetation, agriculture, water body, built-up and barren land (Fig. 15.4). Their area in different time period is shown in Table 15.2 and Fig. 15.3.

The temperature has increased in all the land cover type even in the vegetative covered regions and water bodies from 2000 to 2020. This shows the indication

Table 15.1 Land cover description

Land cover	Description
Vegetation	Trees, natural vegetation, mixed forest, grassland, vegetated lands
Agriculture	Agriculture lands, irrigated tracts, crop fields
Water bodies	River, lakes, ponds, canals, low lying areas, marshy land and swamps. seasonal wetlands
Barren land	Fallow land, open space, bare soils and rocky outcrops
Built-up	All Infrastructure-residential, commercial and industrial use, settlements, villages, road network, pavements and other manmade structures

Table 15.2 Land use/land cover types 2000–2020

LULC	2000	%	2010	%	2020	%
Vegetation	1491.8	50.30	1143.71	38.56	879.36	29.65
Agriculture	1259.3	42.46	1582.62	53.36	1783.8	60.14
Water bodies	75.8	2.56	64.82	2.19	52.81	1.78
Barren land	51.8	1.75	38.33	1.29	26.6	0.90
Built-up	87.3	2.94	136.52	4.60	223.43	7.53

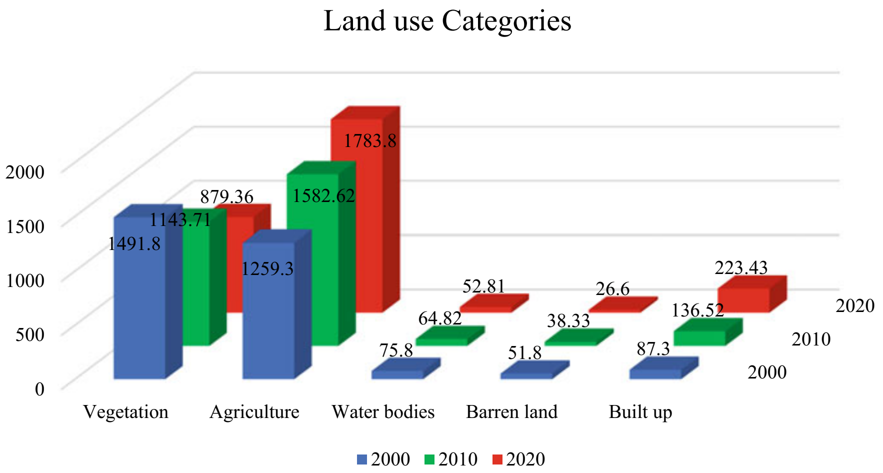


Fig. 15.3 Land use/land cover types 2000–2020

of change in the processes of different developmental activities and increase in the area of built-up. However, the change in the temperature range has more seen in the major cities' centres of the district and along the National Highway passing through the district. Urban areas in the district experience a considerable expansion of imperviousness as a result of the developmental activities of urban infrastructures which eventually leads to increase in surface temperature of that region. These kinds of urban expansion result in the growth of imperviousness surface, and the LST will be severely affected in different land use land cover types of the study area.

Table 15.3 and Fig. 15.5 show the average LST values of different land use classes in the district. Twenty training samples were taken from each land use land cover category to get the average temperature values in each category. The land surface temperature values show an increasing trend in all the five land use categories which is a clear indication of development in the built-up area and other associated infrastructures like that of roads and buildings. The built-up area has recorded the highest amount of temperature in all the three periods taken for the study, and it ranges from 34° to 39 °C. However, all other categories of land use land cover also show increasing trend in temperature but not as same phase with that of the built-up land.

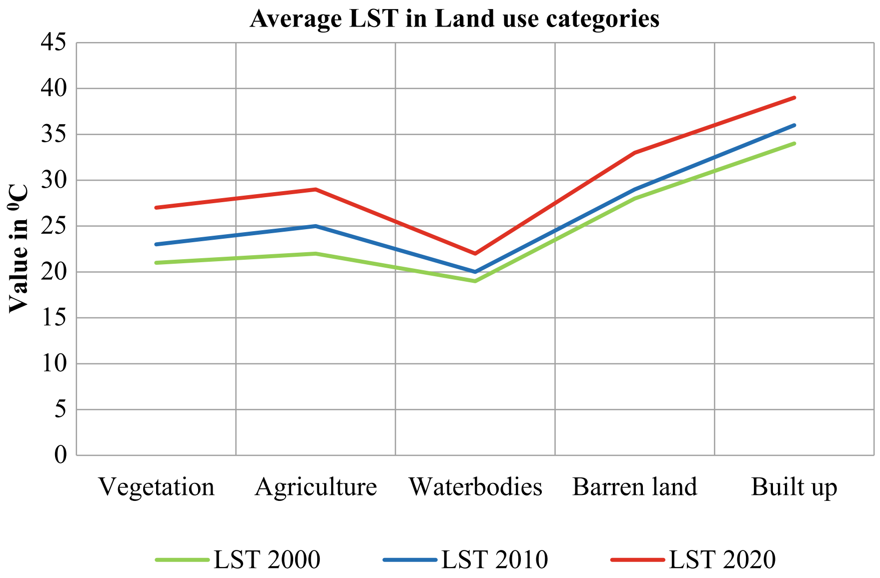


Fig. 15.4 Land use/land cover in Kannur district 2000–2020

Table 15.3 Average LST in land use categories

Land use category	Avg. LST in °C		
	2000	2010	2020
Vegetation	21	23	26
Agriculture	22	25	28
Water bodies	19	20	22
Barren land	28	29	33
Built-up	34	36	38

Vegetation

Vegetative cover in the district is more in the eastern high land regions with compared to the mid-lands and lowlands. High lands of the district are covered with mountain forest in the Western Ghats regions and which borders the district from nearby state. Few areas of the lowland regions are also covered with the vegetative cover in the form of mangrove forest in the river banks of major rivers flowing in the district. The average value of temperature over vegetative cover was 21 °C in 2000 which is slightly increased to 23 °C in 2010 and 26 °C in 2020, which indicates that the surface temperature has affected the vegetative cover over past two decades due to the expansion of land under developmental activities mainly in the built-up and other infrastructural developmental activities. This directly resulted in the increase in temperature of the areas under vegetative cover.

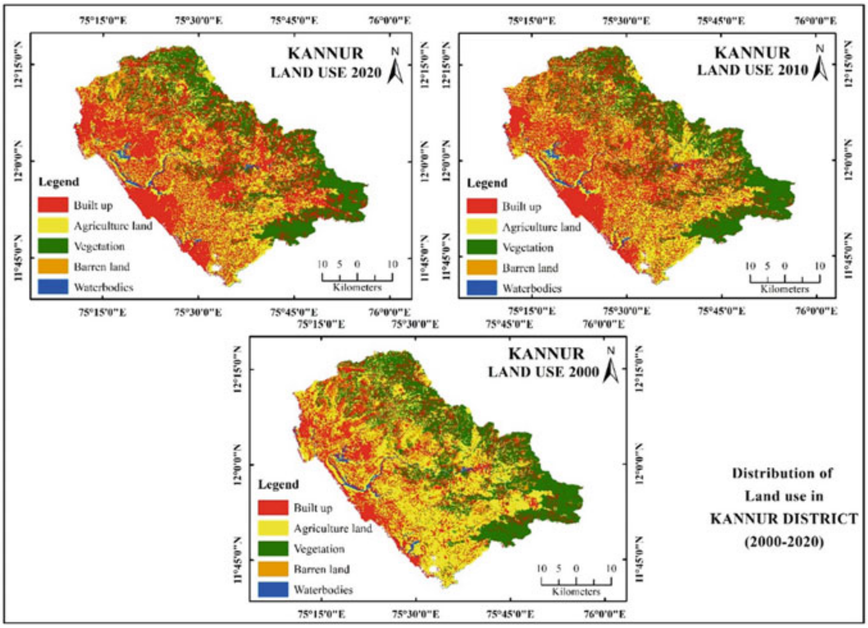


Fig. 15.5 Average LST values in land use categories

Agriculture

The agricultural lands in the study area are mainly come in the mid-land and lowland regions. The district has got a sound base in the agricultural sector. Paddy, coconut, arecanut, pepper, cashew and rubber are the major agricultural crops in this area. Due to these variation in cash crop cultivation and the presence of water content in the irrigated tracts of the paddy fields along with other farming practices agricultural land also shows lesser LST values. In 2000, the average temperature recorded from the agricultural land is 22 °C, 25 °C in 2010 and 28 °C in 2020. Decline in agricultural area and developmental activities in agricultural lands leads to the trend of increasing temperature in the district.

Waterbodies

The waterbodies are characterised with low-temperature values in usual scenario of LST studies. But in this study, due to the urban expansion and infrastructural development lead to the increase of temperature in the waterbodies of the district. Mainly because of all the class I and class II towns in the district are located in the banks of the major rivers. In 2000, the average temperature shown in the water body is 19 °C and slightly increased to 20 °C in 2010. By 2020, the LST has amplified to 22 °C. The waterbodies like Valapatanam, Kuppam and Peruvamba show increasing trend in the temperature values due to the developmental activities and concentration of industries in these river banks. All these reasons lead to the increase of LST values in the waterbodies of the study area in the last two decades.

Barren Lands

The areas of open spaces record different temperature values according to the nature of the land. Because of its absorption and reflection characteristics is different from one another. There was not much imperviousness expansion in 2000 so that the average value of temperature recorded was low and it shows the land surface value as 28 °C. In 2010, it increased to 29 °C and 33 °C in 2020. This shows that the developmental activities are taken over to the open spaces in the study area in order to expand the infrastructural facilities. This resulted in the overall increase in average temperature.

Built-Up

The major land cover type shows high rate of land surface temperature throughout the period. This is mainly due to the large-scale urban developmental activities in the district. The process of urbanisation is a never-ending process and the infrastructural development will be an ongoing process with variations in the intensity which causes fluctuation in the land surface temperature values over the built-up regions in the district. In 2000, the LST values recorded as 34 °C and in 2010 temperature increased to 36 °C by the year 2020 the temperature increased to 38 °C.

Significance of Different Land Cover Indices on LST

Considerable effort has been taken into simplify the process of map making to analyse the different parameters which affect the land use land cover of a particular area and also to find out the changes over different period of time. In this study, three land cover indices were derived to examine the relation between LST and indices and their distribution over the different land cover types in the study area. Among the various indices studied in the district, Normalised Difference Vegetation Index (NDVI) and Normalised Difference Built-up Index (NDBI) correlate strongly with LST.

Normalised Difference Vegetation Index—NDVI

Vegetation is a significant component of global environment and knowledge about the vegetative cover in the surface of the earth is vital to comprehend land–atmosphere relations and their impacts on climate. Changes in vegetative cover in the environment directly influence the surface water and energy budgets by plant transpiration, emissivity, surface albedo and roughness (Aman et al. 1992). The amount of vegetation is usually assessed through the tiny area of the vegetation inhabiting each grid cell (horizontal density) and the leaf area index (LAI), i.e. the quantity of leaf layers of the vegetated part (vertical density). Both photosynthesis and evapotranspiration are managed by these two parameters (Gujman and Jgnatov 1999). The satellite date will deliver a spatial and periodical interpretation of land under vegetation cover. There are numerous spectral vegetation indices developed in the last couple of decades to estimate the vegetation, canopy and biophysical properties such as LAI, biomass and vegetation cover percentage (Huete 1988). Many GIS and remote sensing studies have utilised the vegetation indices to examine and evaluate the properties of the background which are same or the variations are normalised by the particular indices used for the study (Hanan et al. 1991). By estimating the ratio of red and NIR bands from the satellite images, the index of vegetation 'greenness' can be calculated. The Normalised Difference Vegetation Index (NDVI) is perhaps the most commonly used indices for calculating vegetative cover. This is calculated using the following formula:

$$\mathrm{NDVI} = \frac{\mathrm{NIR} - \mathrm{RED}}{\mathrm{NIR} + \mathrm{RED}}$$

where NIR is the near-infrared band and RED is the red band.

The output of NDVI values ranges from -1 to $+1$, and the values less than zero do not have any environmental meaning, so the value range of the indices is shortened from 0.0 to $+1.0$.

Higher values obtained from the indices indicate a greater change between red and near-infrared radiation recorded by the satellite sensor. This condition is associated with extremely photosynthetically active vegetation cover. Low NDVI value indicates that there is slight difference between the red and NIR signals received by the satellite sensor. This occurs when there is very low photosynthetic activity, or when there is only a very little reflectance (i.e. NIR reflection is very little in the water).

The NDVI classification creates a single band data. In Landsat 5 and 7, Band 3 and 4 are used to derive NDVI, where Band 3 is the red band in the visible spectrum (0.63–0.69 μm) and Band 4 is the near-infrared (0.76–0.90 μm). In Landsat 8, Band 4 and 5 are used to derive NDVI, where band 4 is the red band (0.64–0.67 μm) and Band 5 is the near-infrared band (0.85–0.88 μm).

Estimation of NDVI for Landsat 5, 7 and 8

Formula for NDVI calculating using Landsat 5 and 7

$$\mathrm{NDVI} = (\mathrm{Band}\ 4 - \mathrm{Band}\ 3)/(\mathrm{Band}\ 4 + \mathrm{Band}\ 3)$$

Formula for NDVI calculating using Landsat 8

$$\mathrm{NDVI} = (\mathrm{Band}\ 5 - \mathrm{Band}\ 4)/(\mathrm{Band}\ 5 + \mathrm{Band}\ 4)$$

Distribution of NDVI Values in Kannur District

The NDVI (Fig. 15.6) value in the district ranges from 0.56 to −0.611 in 2000, 0.533 to −0.42 in 2010 and 0.486 to −0.144 in 2020, respectively. The least value of greenness recorded more in and around built-up area, mainly in the major class towns in the district and the highest values recorded in the agricultural lands. But gradually due to rapid urbanisation, the trend of NDVI gradually decreased to −0.52 in 2010 and further the value of NDVI drop down to −0.144 in 2020.

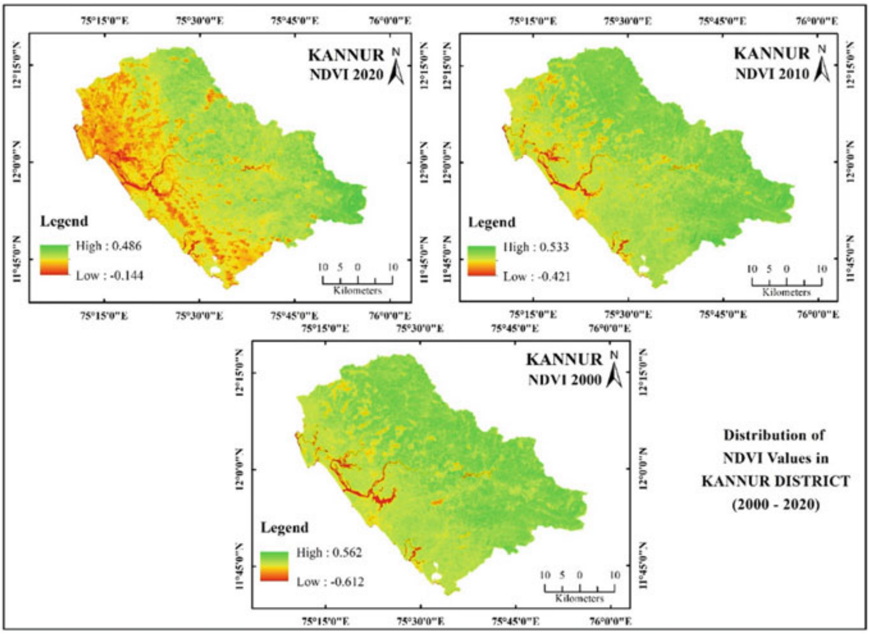


Fig. 15.6 Distribution of NDVI values in Kannur district 2000–2020

Table 15.4 NDVI values over land cover types (2000–2020)

Land use category	Range of NDVI		
	2000	2010	2020
Vegetation	0.41	0.21	0.2
Agriculture	0.15	0.14	0.11
Waterbodies	0.13	0.1	0.09
Barren land	0.09	0.08	0.06
Built-up	0.05	0.04	0.02

Distribution of NDVI Values on Land Use Land Cover

The range of NDVI (Table 15.4) values over different land use land cover in different years indicates the level of the intensity of vegetation in the district from 2000 to 2020. To calculate the level of vegetative cover in each land use land cover type in the district, 20 training sample points have been taken from each land cover types and checked the NDVI values of the same. The average NDVI value from the collected sample points from each land use class, which shows the intensity of vegetative cover during this period.

The intensity of vegetative cover is high in 2000, it is about 0.41. The index value derived from the average values of the sample points taken from all the parts of the district to represent the entire vegetative cover in the district. It is well noted that the high lands regions of the district have recorded the highest greenness value and its decreases towards mid-land and lowland regions of the district. The index values decreased to 0.21 in 2010 and 0.2 in 2020. Agriculture area has an index value ranges from 0.15 in 2000, 0.14 in 2010 and 0.11 in 2020. Waterbodies with 0.13 in 2000, 0.1 in 2000 and 0.09 in 2020. Barren land records the index values of 0.09 in 2000, 0.08 in 2010 and 0.06 in 2020. Built-up land has the lowest index values in last two decades with 0.05 in 2000, 0.04 in 2010 and 0.02 in 2020.

Relationship Between NDVI and LST

To test the relation between NDVI and LST (Fig. 15.7), correlation analysis was carried out for different time periods taken for the analysis. Figure 15.7 shows the NDVI and LST relationship. In 2000, NDVI value ranges from −0.511 to +0.56 and it gradually decreased to −0.42 to 0.533 and later in 2020 the values drastically reduced to −0.14 to 0.48. This has a clear indication of decrease in the vegetation index in the study area. The correlation shows a negative trend between NDVI and LST. When the land surface temperature increases, the vegetative cover decreases and that leads to the increasing of temperature in the district. This shows that this trend will also keep on going in future scenario.

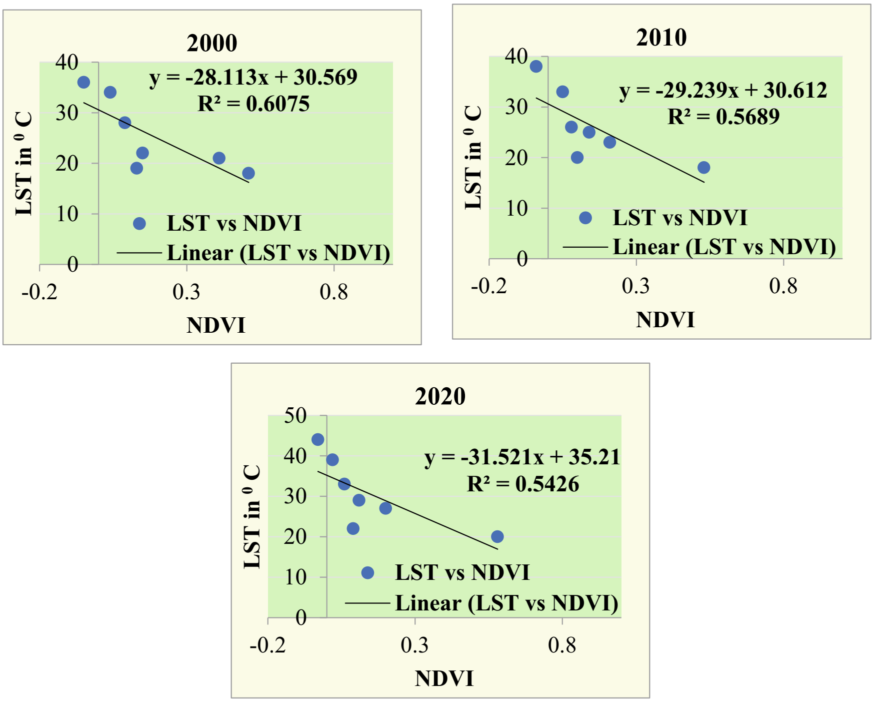


Fig. 15.7 Correlation between LST and NDVI values 2000–2020

Normalised Difference Built-Up Index (NDBI)

This index is used to classify built-up land. NDBI has been used recently as a major indicator to project the extent of built-up land. The output values lie between -1 and $+1$. The negative value represents waterbodies, whereas the highest value represents built-up land. The value for vegetation in NDBI is low.

$$\text{NDBI} = \frac{\text{SWIR} - \text{NIR}}{\text{SWIR} + \text{NIR}}$$

Estimation of NDBI for Landsat 5, 7 and 8

Formula for NDBI calculating—Landsat 5 and 7

$$\text{NDBI} = (\text{Band 5} - \text{Band 4})/(\text{Band 5} + \text{Band 4})$$

Formula for NDBI calculating—Landsat 8

$$\text{NDBI} = (\text{Band } 6 - \text{Band } 5)/(\text{Band } 6 + \text{Band } 5)$$

Distribution of NDBI in Kannur District

The NDBI (Fig. 15.8) values of the district for the two decades (2000–2010–2020). In 2000, the values of the built-up indices vary from −0.582 to 0.288, this increased to −0.442 to 0.356 in 2010 and then to −0.337 to 0.439 in 2020. This gives an indication of expansion built-up land, especially in the coastal regions of the district, where the districts major towns are located like that of Thalassery, Kannur and Payyanur. National and State Highway corridors are also showing an increasing trend in the process of urbanisation which is clearly visible in the Taliparamba, Iritty, Irikkur and Sreekandapuram areas. In the last decade, there is a remarkable development in the Mattanur region where the Kannur International Airport (KIAL) is located. This growing trend in the built-up regions of the district will surely keep more phases than the last two decades of urban growth because of the well-connected transportation network. The high land regions of the district are connected with the hill highway which gave people more access to their developmental needs.

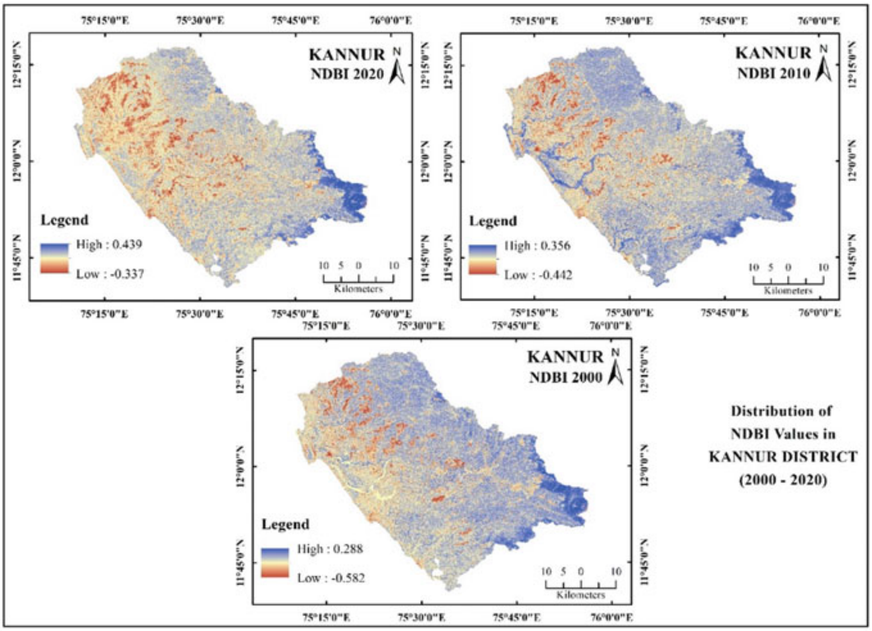


Fig. 15.8 Distribution of NDBI values in Kannur district 2000–2020

Table 15.5 NDBI values over land cover types (2000–2020)

Land use category	Range of NDBI		
	2000	2010	2020
Vegetation	0.16	0.14	0.12
Agriculture	0.12	0.1	0.09
Waterbodies	0.08	0.07	0.04
Barren land	0.19	0.18	0.15
Built-up	0.14	0.18	0.27

Distribution of NDBI Values on Land Use Land Cover

All land use types other than built-up shows a decreasing trend in the index values (Table 15.5). Waterbodies have the lowest index values ranges from 0.08 in 2000, 0.07 in 2010 and 0.04 in 2020. Barren land recorded the highest index values in 2000 (0.19) and 2010 (0.18) and second highest index value in 2020 (0.15). Agricultural area in the district has minimum index value ranges from 0.12 in 2000, 0.1 in 2010 and 0.09 in 2020. Vegetation category has an index value ranges from 0.16 in 2000, 0.14 in 2010 and 0.12 in 2020. But in built-up land cover the index value shows an increasing trend throughout the period with index value range from 0.14 in 2000, 0.18 in 2010 and 0.27 towards 2020.

Relationship Between NDBI and LST

This is the most common and efficient indices used to discriminate built-up from other land use land cover type. Exact mapping of the built-up area is very much necessary to have a well developmental plan or to make urban development strategies. This signifies the importance of knowing relationship between NDBI and LST.

Figure 15.9 shows the correlation between NDBI and LST in the study area for different period of time. It shows a positive relation from 2000 to 2020 values ranges from −0.5 to −0.3 in minimum and 0.2 to 0.4 to its maximum. Thus, it can be said that there exists a strong correlation between NDI and LST in the last two decades. These indices are derived and explained to know their drive on different land use land cover types in the study area. Different studies show that these indices have firm relationship with land surface temperature. Correlation has been conducted to identify the connection between different land cover indices over LST for different period of time (2000, 2010 and 2020) in order to examine their relationship during this time frame.

The study states that there are statistically significant correlations observed and hold over the years in the study area. The correlation between NDVI and LST shows a negative correlation, because when the values of LST getting increased over year the NDVI value gets decreased. This shows that the vegetative cover of the district

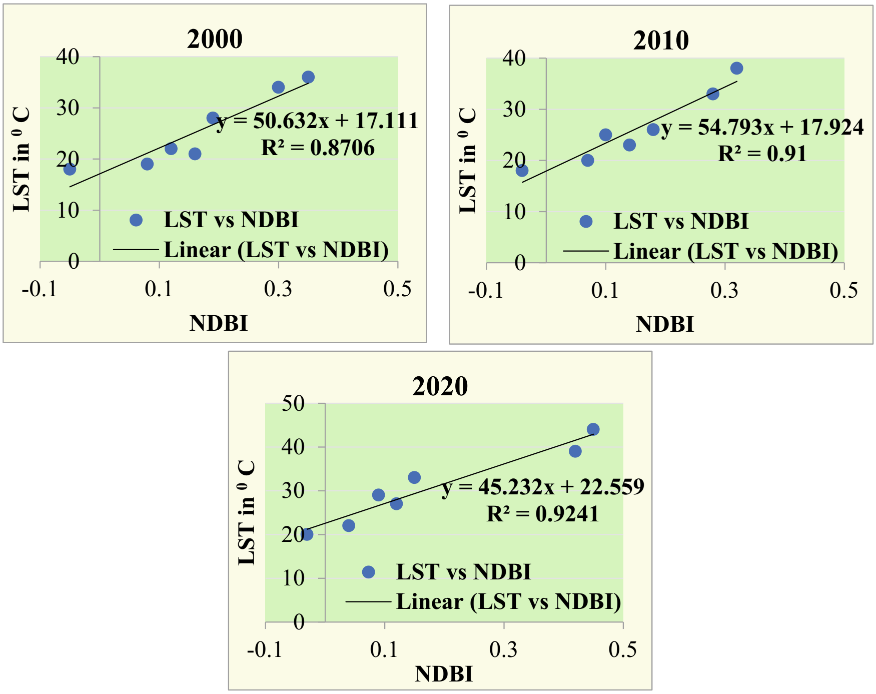


Fig. 15.9 Correlation between LST and NDBI values 2000–2020

is getting reduced from year to year mainly due to the cutting down of vegetative cover for developmental activities. But in the case of NDBI and LST, there exists a positive correlation, due to expansion of built-up area in the district, which has a direct influence on the land surface temperature. Thus, it can be summarised that all these two indices have strong correlation with LST. When NDVI shows a negative correlation or inversely propositional to LST, the NDBI shows a positive correlation or directly propositional to LST.

Conclusion

Urbanisation is a grave reality and is fast progressing in developing countries. In tropical areas, urbanisation is an extreme way that human activities have changed the land cover according to their needs and desire which have made multifaceted impacts on local environment. Urbanisation alters the urban canopy, modifies the radiation, germinate layers of buildings, changes the local land cover and thermal and dynamic characteristics of the underlying surface. The effect of urbanisation on micro-climate of tropics and its adverse effects are yet to be analysed extensively. The present study is an attempt to examine the impact of urbanisation on microclimate from a geographical standpoint. It is obvious from the study that the built-up area shown an increasing trend in the past two decades and which have a direct influence on the increasing of land surface temperature. The increase in the land surface temperature is mostly affected in the class I and class II towns in the district. All these towns are located in the western lowland regions of the district. These townships are well-connected with good transportation facilities; however, it is very much essential to have fast growth of urban infrastructure to address the demand of growing urban population and settlements. Planned development and policies should be adopted to reduce the population pressure on land and also to preserve the greenery, which will consequently help to reduce the land surface temperature. It is the high time where the planning strategies should give more emphasis to adopt environment-friendly approach. In addition, policies should not limit to horizontal management but also it should consider the vertical growth of cities as it influences the local temperature of urban areas.

References

Aman A, Randriamanantena HP, Podaire A, Frouin R (1992) Upscale integration of normalized difference vegetation index: the problem of spatial heterogeneity. IEEE Trans Geosci Remote Sens 30(2):326–338. https://doi.org/10.1109/36.134082

Baldinelli G, Bonafoni S, Rotili A (2017) Albedo retrieval from multispectral Landsat 8 observation in urban environment: algorithm validation by in situ measurements. IEEE J Sel Top Appl Earth Obs Remote Sens 10(10):4504–4511. https://doi.org/10.1109/JSTARS.2017.2721549

Chithra SV, Harindranathan Nair MV, Amarnath A, Anjana NS (2015) Impacts of impervious surfaces on the environment. Int J Eng Sci Invention 4(5):27–31

Dash P, Göttsche F-M, Olesen F-S, Fischer H (2002) Land surface temperature and emissivity estimation from passive sensor data: theory and practice-current trends. Int J Remote Sens 23(13):2563–2594. https://doi.org/10.1080/01431160110115041

Fallmann J, Forkel R, Emeis S (2016) Secondary effects of urban heat island mitigation measures on air quality. Atmos Environ 125:199–211. https://doi.org/10.1016/j.atmosenv.2015.10.094

Fan J, Wang H, Chen D, Zhang W, Wang C (2010) Discussion on sustainable urbanization in Tibet. Chin Geogra Sci 20(3):258–268. https://doi.org/10.1007/s11769-010-0258-y

Gujman G, Jgnatov A (1999) The derivation of the green vegetation fraction from NOAA/AVHRR data for generating weather prediction models. Int J Remote Sens 19:1533–1543

Hanan NP, Prince SD, Hiernaux PHY (1991) Spectral modeling of multicomponent landscapes in the Sahel. Int J Remote Sens 12(6):1243–4258. https://doi.org/10.1080/01431169108929724

Huete AR (1988) A soil-adjusted vegetation index (SAVI). Remote Sens Environ 25(3):295–309. https://doi.org/10.1016/0034-4257(88)90106-X

Ibrahim I, Abu Samah A, Fauzi R, Noor NM (2016) The land surface temperature impact to land cover types. In: ISPRS International archives of the photogrammetry, remote sensing and spatial information sciences, vol XLI–B3, pp 871–876. https://doi.org/10.5194/isprsarchives-XLI-B3-871-2016

Ivan K, Benedek J (2017) The assessment relationship between land surface temperature (LST) and built-up area in urban agglomeration. Case study: Cluj-Napoca, Romania. Geographia Tech 12(1):64–74. https://doi.org/10.21163/GT_2017.121.07

Jayalakshmy SS, Prasad TK, Mereena CS (2021) Spatial aeolotropy of urban intensity index based on buffer gradient analysis on urban sprawl of two metropolitan cities of Kerala. J City Dev 3(2):91–100

Jiang Z, Huete AR, Chan J, Chan Y, Li J, Yan G, Zhang X (2006) Analysis of NDVI and scaled difference vegetation index retrieval of vegetation fraction. Remote Sens Environ 366–378

Li S, Zhao Z, Miaomiao X, Wang Y (2010) Investigating spatial non-stationary and scale-dependent relationships between urban surface temperature and environmental factors using geographically weighted regression. Environ Model xix and Softw 25(12):1789–1800. https://doi.org/10.1016/j.envsoft.2010.06.011

Lu D, Moran E, Hetrick S (2011a) Detection of impervious surface change with multitemporal Landsat images in an urban–rural frontier. ISPRS J Photogramm Remote Sens 66(3):298–306. https://doi.org/10.1016/j.isprsjprs.2010.10.010

Lu L, Venus V, Skidmore A, Wang T, Luo G (2011b) Estimating land-surface temperature under clouds using MSG/SEVIRI observations. Int J Appl Earth Obs Geoinf 13(2):265–276. https://doi.org/10.1016/j.jag.2010.12.007

Mallick J, Kant Y, Bharath BD (2008) Estimation of land surface temperature over Delhi using Landsat 7 ETM 12(3):131–140

Orhan O, Ekercin S, Dadaser-Celik F (2014) Use of landsat land surface temperature and vegetation indices for monitoring drought in the salt lake basin area, Turkey. Sci World J 2014:142939. https://doi.org/10.1155/2014/142939

Prasad TK, Jishnu JS (2022) Towards eco-sustainability: scope and significance of designing green buildings for urbanizing Kerala, India. In: Contemporary issues of urban development in 21st century: planning and practices. Rajesh Publication

Rajasekar U, Weng Q (2009) Application of association rule mining for exploring the relationship between urban land surface temperature and biophysical/social parameters. Photogramm Eng Remote Sens 75(4):385–396. https://doi.org/10.14358/PERS.75.4.385

Sastry M, Majumdar M, Kumar P, Kiran Kumar DEVS (2013) Sustainable urban development—minimising urban heat island effect and imperviousness factor. Working paper published by the South Asian Network for Economic Research Institutes (SANEI)

Shimod KP, Vineethkumar V, Prasad TK, Jayapal G, Vishnu CV (2022a) Radiological threat to the human in the context of alarming urbanization: a geographical enquiry on concentration of radionuclides in building materials used in Kannur district, Kerala, India. J Radioanal Nucl Chem 1–11

Slonecker ET, Jennings DB, Garofalo D (2001) Remote sensing of impervious surfaces: a review. Remote Sens Rev 20(3):227–255. https://doi.org/10.1080/02757250109532436

Wan Z (1999) MODIS land-surface temperature algorithm theoretical basis document version 3.3. NASA Documents

Xu Y, Chan EHW (2011) Community question in transitional China, a case study of state-led urbanization in Shanghai. J Urban Plann Dev 137(4):416–424. https://doi.org/10.1061/(ASCE)UP.1943-5444.0000077

Yuan F, Bauer ME (2007) Comparison of impervious surface area and normalized difference vegetation index as indicators of surface urban heat island effects in Landsat imagery. Remote Sens Environ 106(3):375–386. https://doi.org/10.1016/j.rse.2006.09.003

Chapter 16
Assessment of LULC Changes and Its Impact on Agricultural Landscape in Peri-urban Space of Bolpur Town, West Bengal (India)

Sanu Dolui and Sumana Sarkar

Abstract As the cityscape of large metropolitan cities gets increasingly supersaturated, policymakers and developers are being compelled to transform undeveloped land and the natural landscape of peri-urban areas into urban fabrics. Industrial developers and entrepreneurs' first choice was the peri-urban spaces where land is readily available for construction without a hassle of complicated legal restrictions; furthermore, government's supportive policies on infrastructure development may have exacerbated the impacts of urbanisation on the ecological and agricultural areas. After the beginning of the economic liberalisation and more import friendly policies in the early 1990s resulted in massive socioeconomic growth and infrastructure developments untimely led urban land use spread out of the city into the peri-urban area along the major highways. Therefore, this study aimed at quantifying and evaluating the trends of urban growth and how it affects farmland in the peri-urban areas of Bolpur town using an integrated approach of GIS tool and support vector machine (SVM) learning algorithms. Comprehensive LULC maps were generated for four distinct years during a 30-year span using a multi-temporal (1990–2020) Landsat dataset, following that, classified images were validated with actual G.P.S data. Kappa statistics indicate a satisfactory result with more than 86% accuracy for all those images. Observations derived from present study reveal that over the past 30 years a significant change occurred in the LULC; a major portion of agricultural land and forested area was converted into a residential area for developing tourism and township projects.

Keywords Peri-urban · GIS · Landsat dataset · LULC change · Kappa statistics · SVM algorithms

S. Dolui (✉) · S. Sarkar
Department of Geography, The University of Burdwan, Burdwan, West Bengal, India
e-mail: sanudolui902@gmail.com

S. Sarkar
e-mail: ssarkar@geo.buruniv.ac.in

U. Chatterjee et al. (eds.), *Urban Commons, Future Smart Cities and Sustainability*, Springer Geography, https://doi.org/10.1007/978-3-031-24767-5_16

Introduction

Land has always been crucial to sustain life on earth as well as the advancement of human civilisation. Alteration in LULC is acknowledged as a basic contributor to climatic change and biodiversity loss, and it has been one of the most pressing concerns in the contemporary decade that is predicted to be continue in future also (Mustard et al. 2012; Li et al. 2013). Only a few landscapes remained on the planet that has not been impacted by human activities, either located in remote locations or in exceedingly difficult terrain (Ritchie and Roser 2021). Urbanisation has become a universal phenomenon; an emerging problem particularly for developing nations experiencing a staggering increase in the proportion of people that resides in urban areas. This bewilderingly expansive process of disorderly growth is unpredictable, often leading to profligate and disastrous patterns of urban development (Travisi and Camagni 2005). Peri-urban expansion is very common pheno menon in Indian cities, where rural and urban traits tend to overlap on the outskirts and urban areas are substantially advancing towards adjacent rural places. A multitude of effects have been resulted from peri-urbanisation, including habitat destruction, ecological degradation, obliteration of agriculturally productive lands, as well as the transformation of desolate and natural vegetation lands into human-built landscapes (Afriyie et al. 2013; Seifollahi-Aghmiuni et al. 2022). Increased anthropogenic activities resulting from population growth have triggered speedy alteration of LULC. However, these consequences are most severe for those people who belong to economically disadvantaged group and totally reliant on the agriculture and forest for their livelihood (Acheampong et al. 2022). This trend will necessitate in the spatial expansion of urban centres outside respective administrative boundaries into their rural outskirts in order to make way for the expanding population in respective cities (Mosammam et al. 2016). Peri-urban land use change issues have recently attracted the attentions of academics who are interested in gaining a deeper comprehension about the causes and environmental repercussion of LULC change**.** As a consequence, monitoring of LULC changes is inexorably intertwined to continue human wellbeing and development projects, particularly in peri-urban areas where LULC changes have been exacerbated by due unplanned population growth (Wilson and Chakraborty et al. 2013; Mundia and Aniya 2005;keshtkar et al. 2017).

During the recent decades, most of the medium-sized Indian cities have experienced extraordinary spatial growth of urban land usage in peri-urban spaces, unfolding in a fragmentated, chaotic, distorted fashion (Feola et al. 2019; Follmann et al. 2018). Future commercial and residential townships, green infrastructure, new towns development, planned city expansions, infrastructure upgrades and transit corridors all represent this peri-urban reality, posing new challenges to urban administration and ecological sustainability (Mortoja et al. 2020). As a result, peri-urban areas are expected to grow endlessly, possibly even faster than large urban areas in the near future. Peri-urbanisation has increased the demand for land, thus triggering landscape modification and increasing the likelihood of land fragmentation (Appiah et al. 2015; Dutta 2012; Shaw and Das 2018; Ghosh et al. 2018). A number of researches had been carried out on peri-urban LULC changes, as well as the implications of these changes on farmland natural vegetation cover (Appeaning Addo 2010; Otunga et al. 2014; Alam et al. 2019; Ayele and Tarekegn 2020). The growth of cities has led to a reduction in the amount of land that is suitable for agricultural use, it has had a disastrous effect on farmers in the peri-urban areas, leaving relatively few croplands available for farmers. Further expansion of urban fabric onto arable land, have a harmful impact on the size, intensity, productivity, and profitability of that land (Atu et al. 2012; Sankhala and Singh 2014). Large tracts of valuable farmland are frequently sacrificed to make way for the expansion of urban infrastructure and the development of new townships (Fazal 2000). Agricultural landowners in peri-urban areas are primarily motivated by maximising profits as land value increases; as a result, they ignore the ecological consequences of their decisions (Adelaja et al. 2011). While some studies have found beneficial results from the conversion of agricultural land that had a positive effect on the economy of the surrounding area because it has made local communities more accessible to new employment opportunities (Wang and Qiu 2017). It has been observed that there are no stringent regulations regarding the encroachment of unplanned housing on agricultural land (Ayele and Tarekegn 2020). In most circumstances, there may be restrictions that are intended to limit these conversions, but local politicians and real-estate agents frequently avoid these regulations. As a consequence, agricultural land, which is the primary source of livelihoods for the majority of people in the country, is declining day by day.

Land use denotes to how humans utilise (anthropogenic utilisation) the biophysical components of land, whereas land cover denotes geophysical and ecological landscape which covers the earth land surface (Islam et al. 2018). It is vital to have a solid understanding of the dynamics, amplitudes and rates of LULCC change in order to generate helpful information for the development professionals and governments (Padmanaban et al. 2017). Notably, remote sensing technique and geospatial approaches have been demonstrated as a valuable and efficient method of LULC monitoring which investigated the modification of urban landscapes in a scientific and repetitive manner (Liu et al. 2005). A significant amount of study had been conducted over the past three decades in the topic of detecting urban land changes using remotely sensed imagery (Sun et al. 2020; Hegazy and Kaloop 2015; Dutta et al. 2015). Numerous studies reported that LULC classification with low- and mid-resolution images have a number of spectral and spatial deficiency which negatively affect classification accuracy (Akar and Gormus 2021). Consequently, academics have been employing machine learning algorithms in an effort to reduce the constraints of medium- and low-resolution images previously mentioned and in order to produce high-precision LULC images. In recent times, machine learning algorithms purposefully utilised for LULC mapping of remotely sensed images have gained a significant amount of attention among researchers (Jamali 2019; Abdi 2019; Talukdar et al. 2020; Roy 2021). This domain is rapidly evolving, and new algorithms and applications are constantly being developed. One of the machine learning algorithms that have been used most frequently is support vector machine (SVM) construct the best separating of hyperplane based on optimal demarcation line between two different classes. SVM algorithms are basically a novel machine learning algorithm which proved their effectiveness by demonstrating their durability in pattern recognition in mapping extremely heterogeneous urban landscapes over other conventional classifiers though the remote sensing domain has not yet fully embraced (Shi and Yang 2015). SVM the performance of SVM algorithms has been superior to that of other classifiers due to their excellent ability to generalise complicated attributes (Shao and Lunetta 2012; Lefulebe et al. 2022; Abbas and Jaber 2020; Rana and Venkata Suryanarayana 2020).

In the present study, Bolpur basically a university-centric town with several popular tourist spots in Birbhum District has been selected. This town had experienced rapid changes over the last three decades due to tourism, township and industrial development, and these new developments are mostly taking place at the expense productive agricultural land. To be more specific, the following objectives will be accomplished through the course of research (i) To capture the spatio-temporal pattern of LULC for four different years, viz. 1990, 2000, 2010 and 2020 using Landsat images, (ii) to demonstrate the direction, nature, rates and dynamism of changing landscape and (iii) Change detection and accuracy assessments of the produced output, i.e. classified images.

About Study Areas

Bolpur town and its surrounding fringe areas were located in the southernmost part of West Bengal's Birbhum District, roughly extended from 87° 35″ E to 87° 48″ E to 23° 35″ N to 23° 47″ N.

This area is a part of the ancient ***Rarh*** region in the lower Ganga track, geologically a flat terrain with a slight undulating topography with an altitude ranges from 46 to 62 m. The present study area Bolpur City situated at the confluence of the ***Mayurakshi*** and **Ajay rivers** and encompassing by rich agricultural rural hinterland. New townships and industrial estates constructed on rural landscapes as a result of peri-urban expansion lead the existing cropland and forest landscape to be fragmented and which has ramifications for ecological, socioeconomic and urban governance. Bolpur being a popular tourist destination in West Bengal, a decent number of tourists are visiting in this town all through the years to facilitate them, and a number of tourist hotels and resorts as well as government housing units were developed at the edge of the city, keeping in view the tourism potentiality of this town. In this context, therefore, this study sought to determine thirty-year past land use and land cover trajectory, as well as its repercussions on greenery in Bolpur and its peripheral settlement (Fig. 16.1).

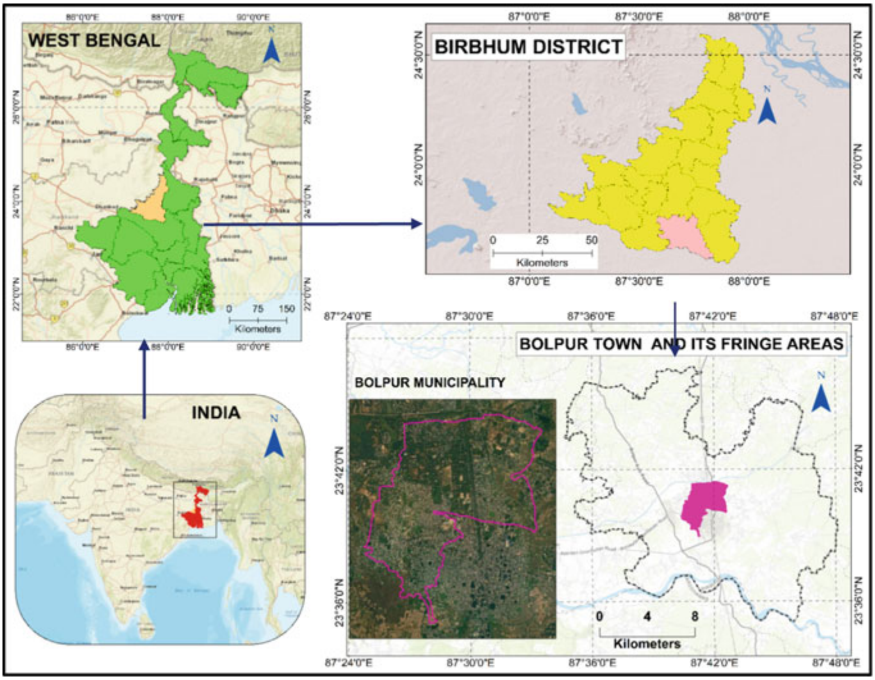


Fig. 16.1 Location map of Bolpur City and its surroundings

Methodology

Spatial Data

In this study, three different sets of Landsat TM images and one set of Landsat 8 OLI images were (path/row 139/44) retrieve from the USGS website (https://earthexplorer.usgs.gov). In order to improve the visualisation and interpretation of the images, a 15-m panchromatic band of Landsat 8 was fused with multispectral bands of 30-m resolution**.** For the evaluation and quantification of the spatial and temporal dynamics of the LULC, historical and contemporary Landsat satellite images for the years 1990 (date: 1990-10-20), 2000 (date: 2000-10-31), 2010 (date: 2010-11-12) and 2020 (2020-11-07) were used for the study. The images were taken for the similar month in different years as well as based on availability and less than 10% cloud cover to minimise the effects of seasonal changes as well as impact of and changing position of sun. Pre-processing of satellite images was required because differences between the two dates caused by atmospheric or sensor oscillations needed to be reduced or eliminated. For this reason, atmospheric, geometric and radiometric corrections were performed on the images as part of the pre-processing step. The FLAASH®

Table 16.1 Details of Landsat images data used for the analysis of land use and land cover (LULC) in the study area

Town name	Satellite	Acquisition date	Resolution (m)	User band	Sensor	Row/Path	Sources
Bolpur	Landsat 5	1990-10-20	30	1-5,7	Thematic mapper	Path: 139 Row: 44	USGS
		2000-10-31	30	1-5,7			USGS
		2010-11-12	30	1-5,7			USGS
	Landsat 8	2020-11-07	30.15	1-7,8,9	Operational land imager (OLI)		USGS

model technique was employed in this study for the purpose of addressing particularly taxing atmospheric conditions, such as the presence of clouds and surface reflectance. For the purpose of geometric registration, the 2020 image was georeferenced utilising G.P.S. points and registered with the standard Universal Transverse Mercator (UTM) 45 N zone. Prior to performing the supervised classification, a classification scheme was developed on the basis of supportive evidences (Table 16.2), field study, experience of local dwellers and visual assessments of each LULC class was verified through Google Street View imagery. Hybrid SVM classifier employed in order to extract LULC information as several researchers have popularly used this SVMs algorithm to separate LULC features robustly (Guo and Boukir 2015; Huang et al. 2007; Nooni et al. 2014) (Table 16.1; Fig. 16.2).

Adaptation of Classification Scheme

A classification approach was devised for the purpose of this study after Anderson et al. (1976) and the Food and Agriculture Organization (Di Gregorio and Jansen 2000) classification scheme as well as information from earlier investigations for the identification of the prevalent LULC classes. In addition, informations are gathered from the different stakeholders such as farmers, property dealers and local inhabitants in order to verify data derived from satellite images, and to explore the reasons, type of changes in the land use and land cover pattern and its impacts, in and around Bolpur City. Different LU/LC types and their basis of classification employed in this study are outlined below (Table 16.2).

Table 16.2 Description of land use/land cover (LULC) classes

Serial number	Land use/Land cover types	Item included	Description
1	Built-up areas	Mainly including residential, commercial centers, industrial zones, railways, highways, expressways and others, rural settlements	Built-up the land type is distinguished by extensive land use, where anthropogenic activities have changed the landscape
2	Agricultural land	All cultivated and uncultivated arable land areas, such as croplands, irrigated paddy fields, potatoes cropland, and grazing land, among other types of agricultural land	The grounds that are classed as agricultural lands are those that have a few scattered communities surrounded by agricultural lands
3	Forest and reserved forest	Area include national forest, sanctuaries, reserved forest protected forests, deciduous forest, mixed forest lands	A reserved forest (also called protected forest) or protected forest denoting forests accorded a certain degree of protection
4	River and canal	The streams and canals category includes major and minor river and canals permanent and seasonal	This is a natural course of water following a linear contiguous pattern that have a minimum width of 80 feet
5	Water bodies	Open water, lakes, ponds, and various reservoirs	Reservoirs, naturally occurring lakes, and other types of water bodies that are not open to the flow of water are examples of water bodies that are non-flowing and naturally enclosed
6	Barren land/Bare soil	Exposed and bare soils included in this category are open spaces, places with exposed soils, landfills, fallow land, earth and sand land in-fillings, and land that has not been planted with vegetation	In a context that is not urban, barren areas are characterised by thin soil, sand, or rocks, as well as an absence of vegetation cover. If vegetation is present, it is dispersed extensively

LULC Classification Based on Support Vectors Machine Learning Algorithms

In recent years, there has been an effort to develop more trustworthy and efficient classification algorithm. Support vector machines are one of the most prevalent and

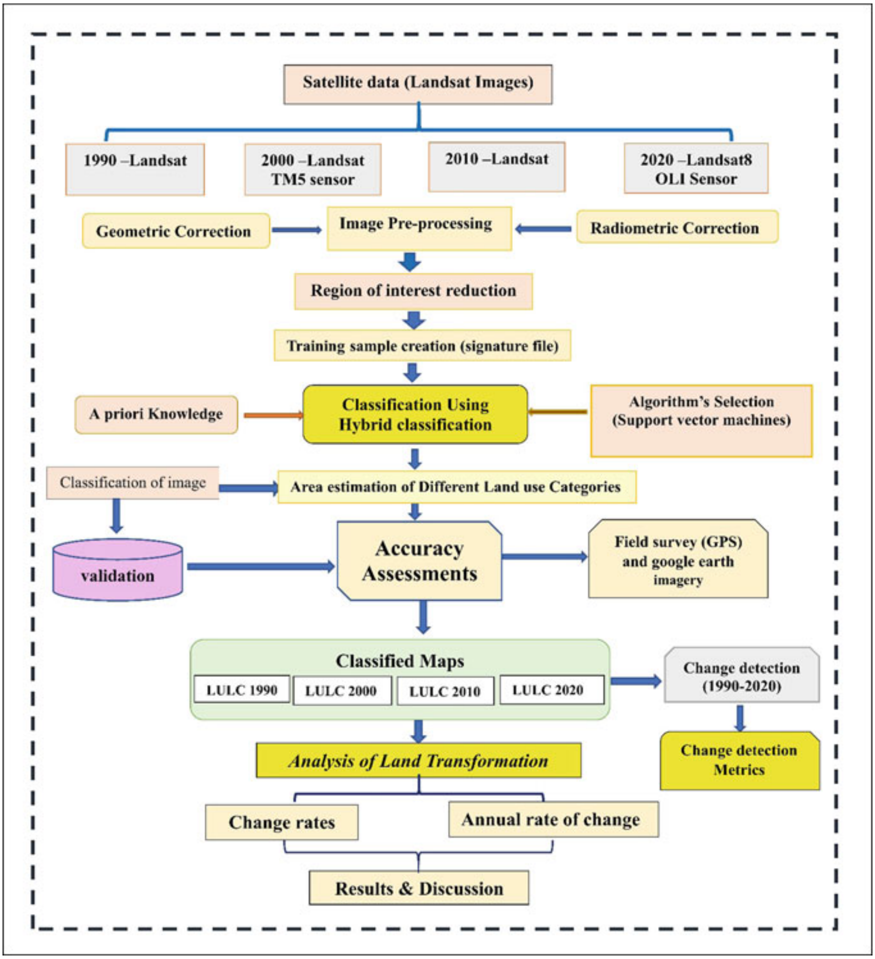


Fig. 16.2 Methodology of the study

recommended machine learning algorithms based on the principle to build an optimal decision boundary (a separating hyperplane) to separate (or classify) the data for different classes (Mountrakis et al. 2011). Nonparametric classifiers like SVMs that do not reliant on any preconceptions from the dataset and also have the potential to overcome the restrictions that are associated with parametric classifiers (Kavzoglu and Colkesen 2009; Ustuner et al. 2015; Pal 2012). Existing literature on the detection of LULC changes reveals that support vector machines learning algorithms are the most stable and frequently used algorithms successfully classified LULC with high accuracy, that is why in the present study SVM classification has been used to classify the Landsat images of Bolpur for the year 1990, 2000,2010 and 2020 (Fig. 16.3).

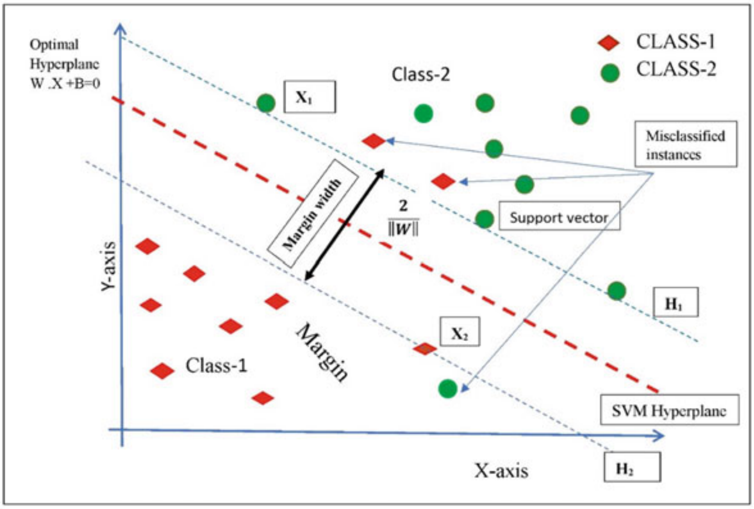


Fig. 16.3 Support vector machines—examples of optimal decision boundaries

Accuracy Assessment

A crucial stage in LULC change analysis is the assessment of an image's accuracy due to the uncertainty in the selection of the training and reference samples (Congalton 1991). Cohen's kappa coefficient (K) is a powerful statistical tool for assessing the agreement between anticipated and observed categorisations of a dataset. If the accuracy of a classified images is more than 75%, overall accuracy is considered as adequate (Tilahun 2015). For evaluation of the overall accuracy, kappa statistics, producer's and user's accuracy were used. An evaluation of the accuracy of the LULC change analysis was carried out by constructing a confusion/error matrix in each LULC. For the 2020 image, 247 GPS points acquired using Garmin G.P.S (eTrex-30), purposefully to ensure sufficient representation of each LULC types. For rest of year, 200 reference points were generated for the years 2010, 2000 and 1990 as reference samples over the study area for the individual Landsat images. The equation suggested by Jensen and Cowen (1999) was utilised in the computation of the Kappa coefficient. Kappa coefficients typically lie between 0 and 1, if the value of the kappa coefficient is less than 0.4, the level of agreement is considered to be weak; if the value is between 0.4 and 0.8, the level of agreement is considered to be moderate; and if the value is larger than 0.8, the level of agreement is considered to be strong. Kappa coefficient was determined by using equation (Table 16.3).

Table 16.3 Algorithms for accuracy assessment

Overall accuracy (OA)	$\frac{\text{Total number of correctly classified pixel(diagonal)}}{\text{Total number of Reference pixel}} \times 100$
User accuracy (UA)	$\frac{\text{Number of correctly classified pixel in each categories}}{\text{Total number of classified pixel in that categories(row total)}} \times 100$
Producer accuracy (PA)	$\frac{\text{Number of correctly classified pixel in each categories}}{\text{Total number of classified pixel in that categories(Column total)}} \times 100$
Kappa coefficient (T)	$\frac{(\text{Total sample} \times \text{Total corrected sample}) - \Sigma(\text{Column total} \times \text{row total})}{\text{Total sample}^2 - \Sigma(\text{Column} \times \text{row total})}$
Commission error	$\frac{\sum \text{Off Diagonal element of Row}}{\text{Row Total}} \times 100$
Omission error	$\frac{\sum \text{Off Diagonal element of Column}}{\text{Column Total}} \times 100$

Analysis of Urban Expansion by Change Assessment

Land use change assessment is the process of detecting distinct land use patterns and phenomena through observing at multiple timeframe (Singh 1989). This analysis makes LULC research interesting since it not only investigates changes that have occurred but also determines their nature and trend. Techniques like GIS and remotely sensed satellite database have now been extensively employed to determine changes in LULC, especially urban growth (Das and Angadi 2021) and cropland transformation (Mazumder et al. 2021). The following equations have been used to track changes in LULC throughout the mentioned timeframe (1990–2020).

$$\text{Decadal LULC Gain/Loss} = \text{Final LULC Area} - \text{Initial LULC Area} \tag{16.1}$$

$$\text{LULC Gain/Loss(in \%)} = \frac{(\text{Final LULC Area} - \text{Initial LULC Area})}{\text{Initial LULC Area}} * 100 \tag{16.2}$$

The Urban Expansion Index (UEI) which was introduced with the purposes of quantification of urban expansion was calculated for the periods: 1990–2000, 2000–2010, 2010–2020 and 1990–2020 using equations below:

$$\text{UEI} = \frac{\text{UL}_{T_2} - \text{UL}_{T_1}}{n \times \text{TA}} \tag{16.3}$$

where UL represents urban land; T_2 denotes succeeding year; T_1 represents initial years; time gap between T_2 and T_1, in years; and TA represents total area of the landscape.

Results and Discussion

Land Cover Maps and Status

The surrounding peri-urban villages of Bolpur with substantial land resource potential have become an appealing location desired by young inhabitants and property dealers for accommodation and business developments. SVM algorithms were adopted for the purpose of performing supervised classification on Landsat images (TM and OLI/TIRS) for the years 1990, 2000, 2010 and 2020 to quantify the urban expansion of Bolpur City over the past 30 years. Major six land use land cover types were identified and extracted to prepare four classification maps for Bolpur town and its surroundings. These were categorised as follows: (a) agricultural land, (b) built-up areas, (c) forest areas, (d) barren/exposed soil, (e) river and canal and (f) water bodies (Fig. 16.4).

Land Use and Land Cover (LULC) Change

Here in this following section, a summary of the results for each LULC class and their fluctuation of changes underwent discussed separately. Observation can be drawn that due to the attractive natural landscape and spectacular village ambience surrounded by forest and agricultural land, and there have been decent amounts of agricultural land converted into residential apartments and eco-tourism resorts in the study area. As a result, other urban development activities based on tourism activities have been observed throughout the study area. Changes in land use in each category are discussed separately as LULC information derived from multi-temporal Landsat images by an SVM–supervised classifier (Fig. 16.5).

The sprawling of built-up areas: Bolpur City has experienced astonishing and chaotic urban growth over the past 30 years as a direct consequence of an increase in population. Agricultural land fragmentation can be witnessed from satellite images and ground-based observations. The amount of built-up land in 1990 was 28.93 km^2 accounting only (10.03%) of the total area, while in year 2000 (12.41%) and in 2010 (17.10%) and finally in 2020 (24.49%) area cover with built-up land, it can be noticed a substantial rise in built-up area with 132.32% increase in last three decades (Tables 16.4 and 16.5).

Change in agricultural area: Percentage of agricultural area steadily decrease from 1990s 198.30 (68.73%) km^2 to 2020 159.92 (55.43%) km^2. Initially, the positioning of the agricultural land in the vicinity of Bolpur City, as well as the increasing rates of urbanisation in the area and the presence of a large number of agro-based industries and industrial estates, were the primary reasons for the drop in agricultural land.

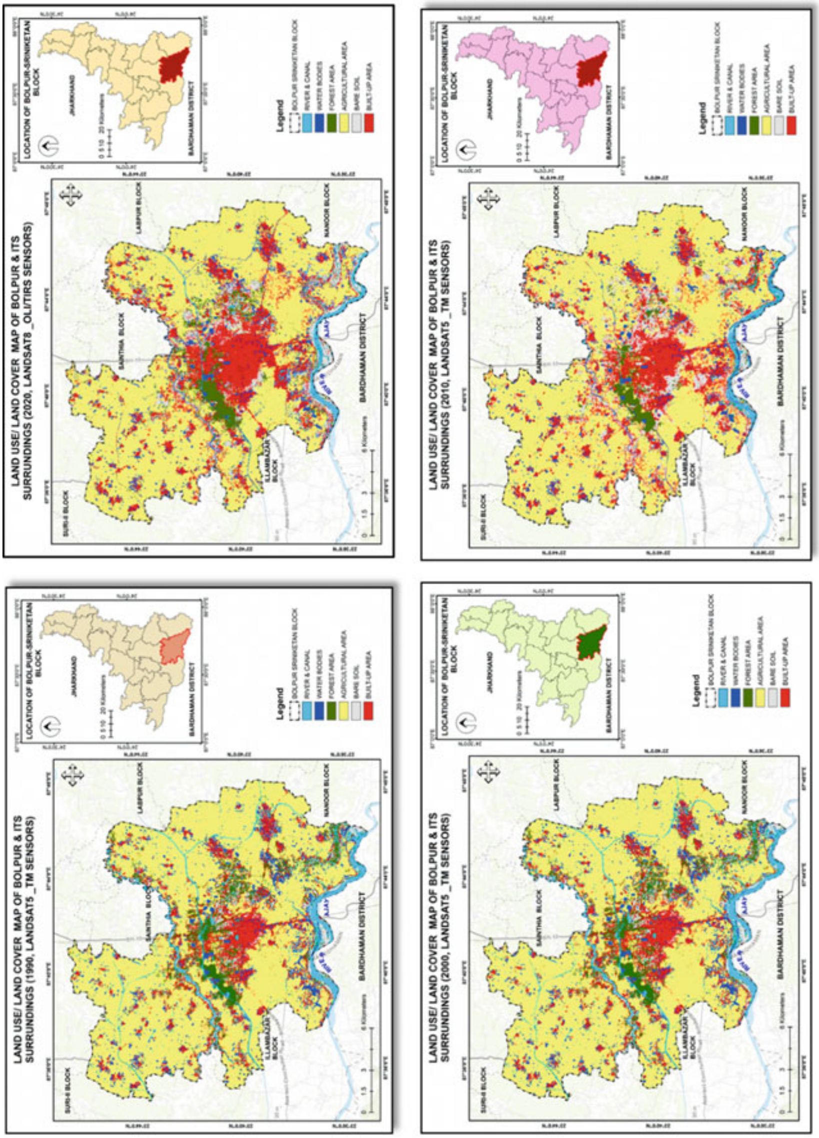


Fig. 16.4 Land use and land cover map of Bolpur town for the year (1990, 2000, 2010 and 2020) (compiled by the author)

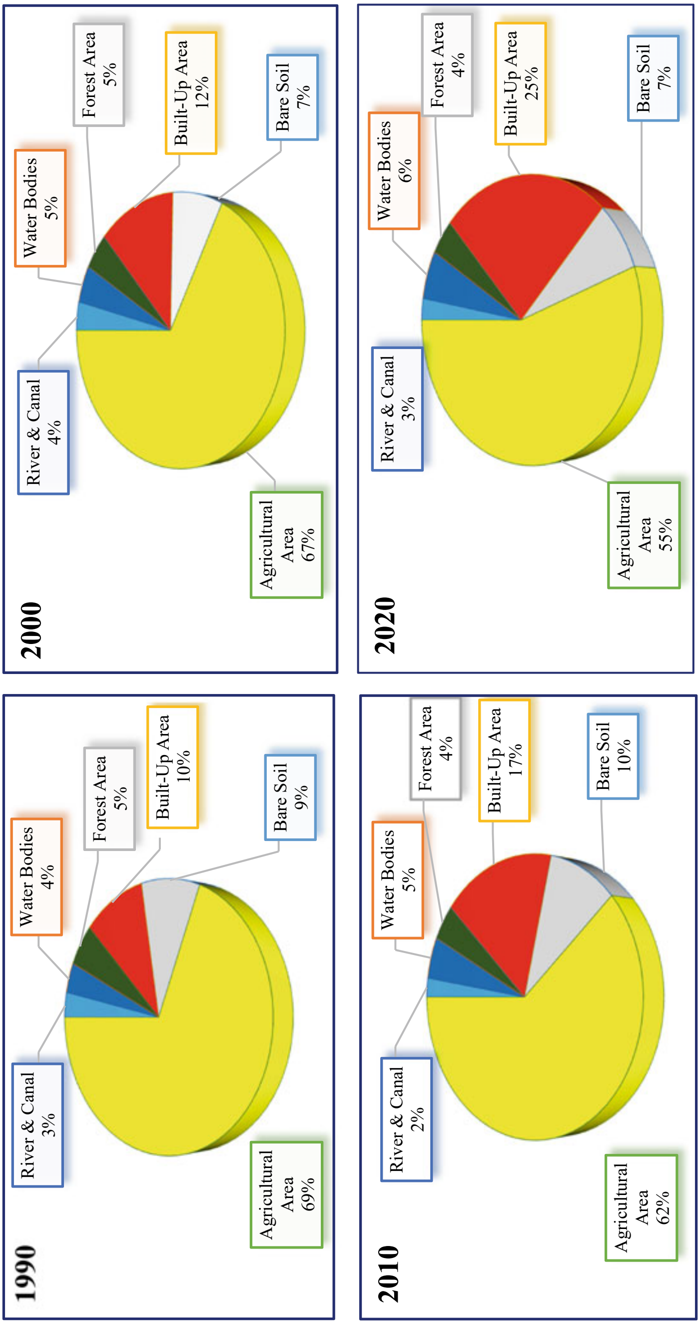


Fig. 16.5 Proportion of different types of LULC in different years of Bolpur town (1990–2020)

Table 16.4 Comparison of areas based on the six LULC classes and annual rate of change between (1990–2000), (2000–2010), (2010–2020), (1990–2020) of Bolpur town and its fringe areas

Land use classes	Year 1990		Year 2000		Year 2010		Year 2020		Change between 1990 and 2000 ($T_2 - T_1$)		Annual rate of change	
	Area in km^2	(%) LU/LC	Area in km^2	(%) LU/LC	Area in km^2	(%) LU/LC	Area in km^2	(%) LU/LC	Area in km^2	(%) LU/LC from initial	Per year km^2	(%) of change
River and canal	9.14	3.17%	10.53	3.65%	6.75	2.34%	7.53	2.61%	1.39	15.26	0.14	1.53
Water bodies	11.01	3.82%	13.56	4.70%	14.62	5.07%	17.02	5.90%	2.55	23.19	0.26	2.32
Forest area	15.18	5.26%	13.24	4.59%	12.67	4.39%	12.14	4.21%	−1.94	−12.78	−0.19	−1.28
Built-up area	**28.93**	**10.03%**	**35.81**	**12.41%**	**49.33**	**17.10%**	**70.66**	**24.49%**	**6.87**	**23.76**	**0.69**	**2.38**
Bare/Exposed soil	25.94	8.99%	21.74	7.54%	27.88	9.66%	21.23	7.36%	−4.20	−16.20	−0.42	−1.62
Agricultural area	198.30	68.73%	193.62	67.11%	177.25	61.44%	159.92	55.43%	−4.68	−2.36	−0.47	−0.24
SUM	288.50		288.50		288.50		288.50					

Land use classes	Change between 2000 and 2010 ($T_3 - T_2$)		Annual rate of change		Change between 2010 and 2020 ($T_4 - T_3$)		Annual rate of change		Change between 1990 and 2020 ($T_4 - T_1$)		Annual rate of change	
	Area in km^2	Percentage of change	Area in km^2	Percentage of change	Area in km^2	Percentage of change	Area in km^2	Percentage of change	Area in km^2	Percentage of change	Area in km^2	Percentage of change
River and canal	−3.79	−35.94	−0.38	−3.59	0.78	11.62	0.08	1.16	−1.61	−17.59	−0.05	−0.59
Water bodies	1.06	7.80	0.11	0.78	2.40	16.42	0.24	1.64	6.01	54.60	0.20	1.82
Forest area	−0.57	−4.31	−0.06	−0.43	−0.53	−4.18	−0.05	−0.42	−3.04	−20.03	−0.10	−0.67

(continued)

Table 16.4 (continued)

Land use classes	Change between 2000 and 2010 ($T_3 - T_2$)		Annual rate of change		Change between 2010 and 2020 ($T_4 - T_3$)		Annual rate of change		Change between 1990 and 2020 ($T_4 - T_1$)		Annual rate of change	
	Area in km^2	Percentage of change	Area in km^2	Percentage of change	Area in km^2	Percentage of change	Area in km^2	Percentage of change	Area in km^2	Percentage of change	Area in km^2	Percentage of change
Built-up area	**13.53**	**37.79**	**1.35**	**3.78**	**21.33**	**43.24**	**2.13**	**4.32**	**41.73**	**144.25**	**1.39**	**4.81**
Bare/Exposed soil	6.14	28.24	0.61	2.82	−6.65	−23.85	−0.67	−2.39	−4.71	−18.16	−0.16	−0.60
Agricultural area	−16.37	−8.46	−1.64	−0.85	−17.33	−9.78	−1.73	−0.98	−38.38	−19.36	−1.28	−0.64

Source Computed by researcher

Table 16.5 Trend of urbanisation in Bolpur (expansion of built-up land)

Land use classes	1990	2020	Change between 1990 and 2020		Annual rate of change	
	Area in km^2	Area in km^2	Area in km^2	Percentage of initial	UEAR = $U_1 - U_2/T_1 - T_2$ (km^2)	Percentage
Built-up area	28.93	70.66	41.73	144.25	1.39	4.81

Changes in river areas: Nothing significant has changed within this 30-year time span in river course through LULC monitoring; however, there are certain areas where the river banks are showing evidence of having dried up. In **Ajay River**, there was a shift in river channel during the late quaternary era; numerous paleochannels, oxbow lakes and elongated sediment fills are observed there (Roy and Sahu 2016), and those remnants of paleochannels are exploited for agricultural and residential purposes. Mainly differentiation in areas of river bed occurs due to seasonal variation of water and excessive sedimentation. In 1990, the area under the river channel was 09.14 km^2; in the year 2000, it was 10.53 km^2; after that in 2010, it was 6.75 km^2, and finally in 2020, area under river course is 07.53 km^2.

Area under exposed/bare soil: The majority of the barren or exposed soil is laterites deposition in forest areas, as well as those exposed soil located in eastern parts of Bolpur town; subsequently, industries and other economic activities have been developed on those places. There is a marked decline in exposed soil over these time periods. The area under exposed soil has decreased from 25.94 km^2 in 1990 to 21.23 km^2 in 2020, a decrease of (−19.35%) in the last 30 years.

Increase in water bodies: As the population of surrounding village increases, therefore, demand for freshwater for household and other activities increases which illustrates why the area under water bodies has grown on a regular basis. Between 1990 and 2020, the area covered by water bodies increased from 11.01 km^2 in 1990 to 17.02 km^2 in 2020, a 54.59% increase in the proportion of water bodies throughout this time period.

Forest area decreases in slower space: A small patch of forest cover along the **Amar Kuthir** Road areas, including ***Ballavpur Wildlife Sanctuary & Sonajhuri*** Forest, located a bit away from Main Bolpur town. Over the course of the past thirty years, there has not been a notable shift in the forest cover. In 1990, the area covered by forest cover was 15.18 km^2, and by 2020, the area covered by forest was approximately 12.18 km^2 representing a drop-in forest cover of approximately −20.02% during 30 years (Fig. 16.5).

Land Use and Land Cover (LULC) Change Detection

The LULC change matrix (Tables 16.4 and 16.5) demonstrates that the distribution of primary transitions in each of the six (6) LULC categories differed between 1990 and 2000, 2000 and 2010, 2010 and 2020, and 1990 and 2020, respectively. According to the findings of the study, there were significant shifts and transitions among the six LULC groups.

The analysis of the classified image of **1990 reveals** that agricultural land accounted for approximately 68.73% (198.30 km^2) of the total land area which demonstrates the widespread involvement of people in agricultural activities as well as the predominance of the agro-based economy. Whereas built-up area, the second most prevalent land cover, accounted for 10.03% (28.93 km^2) of the total land, bare soil accounting for 8.99% (25.94 km^2, forest and protected areas occupied 5.26% (15.18 km^2), respectively, waterbodies accounting for almost 3.82% (11.01 km^2), and the remaining 3.17% (9.14 km^2) areas of the total geographical area are occupied by river and canal.

Moreover from the **classified images 2000**, agricultural land accounted for approximately 67.11% (193.62 km^2) indicating slightly decreases (− 4.68 km^2) from the previous year 1990, whereas built-up area accounting for 12.41% (35.81 km^2) of the total land areas, bare soil accounting for 7.54% (21.74 km^2), forest and protected areas occupied 4.59% (13.24 km^2), respectively, waterbodies accounting for almost 3.82% (13.56 km^2), and the remaining 3.65% (10.53 km^2) areas of the total geographical area are occupied by river and canal.

The assessment of classification results **from 2010 discloses** that, agricultural land was still remains main land cover, accounting for approximately 61.44% (177.25 km^2) of the total land area, whereas the second most important land use type is a built-up area, accounting for 17.10% (49.33 km^2) which indicating drastic increases from the year 2000 (12.41%), bare soil accounting for 9.66% (27.88 km^2), forest and protected areas occupied 4.39% (12.67 km^2), respectively, waterbodies accounting for almost 5.07% (14.62 km^2), and the remaining 2.34% (6.75 km^2) areas of the total geographical area are occupied by river and canal.

The observation of SVM classifier **from 2020 demonstrates that**, agricultural land was the dominant land cover accounting for nearly 55.43% (159.92 km^2) of the total land area, while built-up area accounted for 24.49% (70.66 km^2) revealing substantial increases from the year 2010, bare soil accounting for 7.36% (21.23 km^2), forest and protected areas occupied 4.21% (12.14 km^2), respectively, waterbodies accounting for almost 5.90% (17.02 km^2), and the remaining 2.61% (7.53 km^2) areas of total geographical area are occupied by river and canal (Fig. 16.6; Table 16.6).

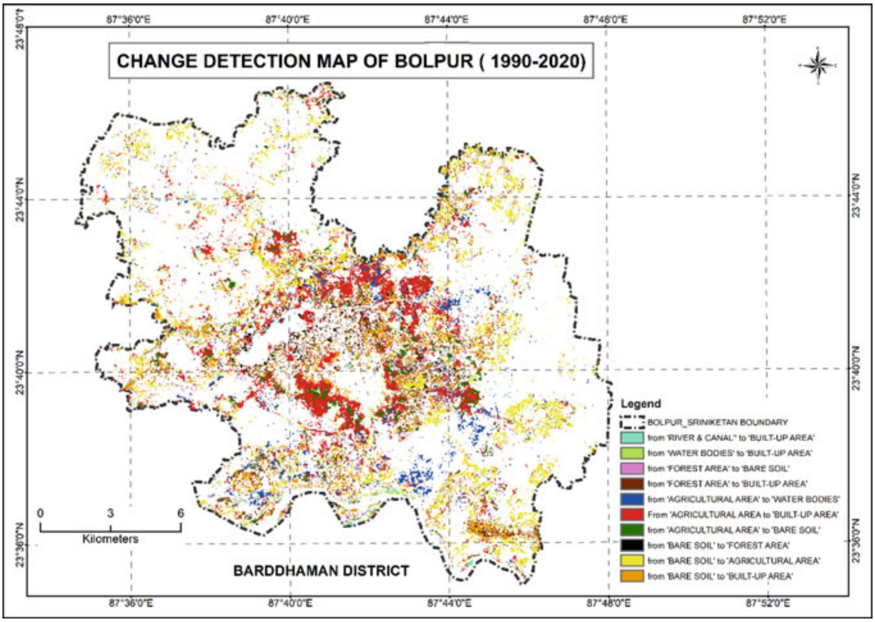


Fig. 16.6 Change detection map of Bolpur town

Table 16.6 Computation of change detection matrix between 1990 and 2020 for Bolpur town

Final state 2020 (km^2)	Land use types	Initial state-1990 (km^2)						
		River and canal	Water bodies	Forest area	Agricultural area	Bare/Exposed soil	Built-up area	Row total
	River and canal	**6.43**	1.39	0.34	0.79	1.13	0.57	**10.65**
	Water bodies	0.48	**5.71**	0.53	4.48	3.73	2.87	**17.79**
	Forest area	0.09	0.59	**8.83**	1.61	1.20	1.48	**13.79**
	Agricultural area	0.29	2.19	3.27	**151.80**	1.11	1.03	**159.68**
	Bare/Exposed soil	1.23	0.68	1.31	3.11	**12.28**	3.35	**21.96**
	Built-up area	4.25	2.39	5.67	23.68	5.89	**23.75**	**65.63**
	Class total	**12.77**	**12.94**	**19.96**	**185.46**	**25.33**	**33.04**	**289.50**
	Class changes	6.34	7.23	11.12	33.66	13.05	9.29	0.00
	Image difference	− 2.121	4.854	− 6.164	− 25.780	− 3.372	32.584	0

Gain–Loss Analysis

Based on the results of SVMs classification, a change analysis process in LCM on IDRISI was used to obtain the data on land gain and loss as well as the net change for each LULC type for the period of 1990–2000 ($\boldsymbol{T_2 - T_1}$), 2000–2010 ($\boldsymbol{T_3 - T_2}$), 2010–2020 ($\boldsymbol{T_4 - T_3}$) and 1990–2020 ($\boldsymbol{T_4 - T_1}$), respectively. For the periods (1990–2020), Water bodies gaining 54.60% (11.01–17.02 km^2) while a significant gain was observed in built-up area which is about 144.25%, (28.93–70.66 km^2), on that same time the highest loss is recorded in the agricultural land decreasing 19.36% (198.30–158.92 km^2), followed by forest area decreases 20.03% (15.18–12.14 km^2), bare soil/barren land decreases 18.16% (25.94–21.23 km^2) and finally area under river and canal decreases 17.59% (9.14–7.53 km^2). In Bolpur town, the area under built-up area increased 41.73 km^2 during 1990–2020 years, and the agriculture area decreased around 38.38 km^2. Most of the agricultural land was converted to built-up land during this period. Other land uses like water bodies, forest area, river and canal have recorded minimum changes during this period (Fig. 16.7).

Agricultural Land Fragmentation

This town is known as the cultural hub of West Bengal influenced by Nobel laureate Rabindranath Tagore's ideology; peoples feels an emotional touch with this area making it a favourite destination for residential township development. Recently, governments projects on housing development (**Gitabitan Township**), Construction of Educational institution (**Biswa Bangla university**), Bolpur Industrial estate and Tourism Development have boasted the recent fast-spaced urbanisation process mainly in peri-urban areas. Spotting from satellite images it was proved that the majority of these projects were developed on fertile agricultural land, and arising issues like land fragmentation, irregular shape of agricultural land, increased land value, encroachment, and unscientific construction which undermines building regulations and standards are the major impact of peri-urbanisation on agricultural land. The real-estate agents and property dealer taken away vast portion of land with minimum land price and after the installation of basic amenities, the land was sold at extremely high prices, increasing the overall area valued of this agricultural land to a considerable extent. Besides that fragmentation of agricultural land makes cultivation less profitable on the other hand increased land value tempted the peri-urban farmer to sold their land which negatively affects the principle of sustainability. The consequences of widespread land expansion have resulted in an incursion of residential uses into an agriculturally dominated rural area that is not yet ready to accommodate urban growth. This peri-urban area actually falls under the rural jurisdiction area (Gram Panchayat) lack of manpower and economic feasibility and dispersed nature of residential space, installation of civic amenities and facilities, household waste collection is exceptionally difficult. For detecting urban expansion between 1990 and

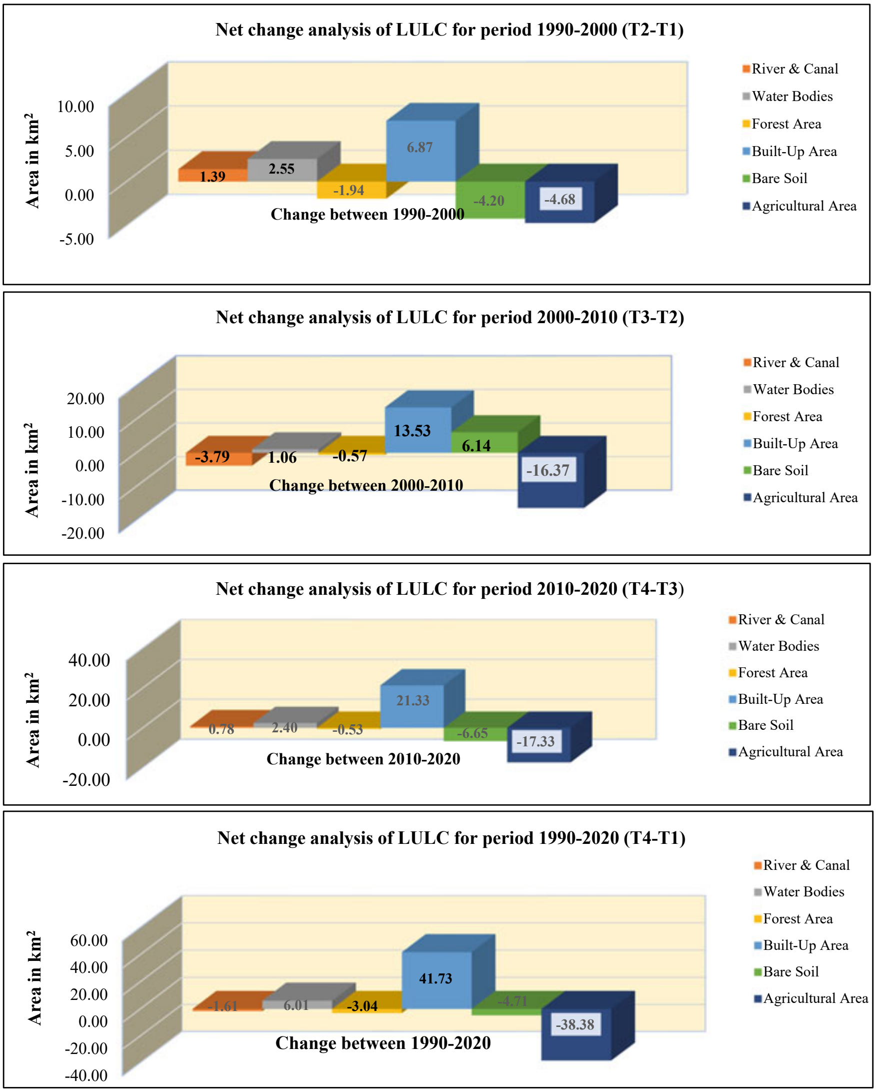


Fig. 16.7 Land gain and loss analysis for periods 1999–2000 ($T_1 - T_2$), 2000–2010 ($T_2 - T_3$), 2010–2020 ($T_3 - T_4$) and 1999–2020 ($T_1 - T_4$)

2020, the total built-up areas increased in that period was 41.43 km^2, with 1.39 km^2 annual increase, whereas within the same time frames agricultural areas decreased 1.18 km^2 per years, which is an alarming situation and a negative imputes of urbanisation. As most of land is privately owned government has lesser scope to intervene, on the other hand local inhabitant found that agricultural activities no longer profitable as the compared value of the land. Local farmers, particularly small-scale household

Fig. 16.8 Township development on agricultural land. *Source* Google Earth images (2020)

Fig. 16.9 Fragmentation of agricultural land. *Source* Google Earth images (2020)

farmers, feel that selling those lands to private developers would be a good deal in terms of securing their future (Figs. 16.8 and 16.9).

Accuracy Assessment of the Classification

When it comes to satellite image classification, the accuracy assessment will be the last step to take into consideration. As has been mentioned before, in order to validate the classification results, GPS points are gathered at randomly using a Garmin eTrex 30x GPS device for performing the accuracy assessment. The below confusion matrix table for 2020 describes that six different classes of LU/LC. In the year 2020 for accuracy assessment, 247 ground truth points were generated through personal field visit with GPS accuracy. For rest of the years (2010, 2000, 1990), 200 validation points were developed based on information of unchanged LULC cover through interviews with local residents and finally accuracy assessment points were verified with high-resolution Google Earth images**.**

Results of **user's accuracy** in this investigation revealed that in the year 2020, the maximum class accuracy was 96.61% for built-up area where correctly classified while the river and canal class had the lowest rate of accuracy at 82.00%, results are shown in (Tables 16.7 and 16.8). In 2010, the class accuracies range from 82.76 to 92.50% (Tables 16.9 and 16.10). In 2000, it ranges from 80.65 to 93.18% as indicated in Tables 16.11 and 16.12 whereas in the period 1990, the accuracy for different classes ranges from 80.65 to 97.67%, respectively (Tables 16.13 and 16.14).

Results of Producer's accuracy showed that in 2020 the maximum class accuracy near about 100% was found in river and canal area while the minimum was bare/exposed soil class with an accuracy of 73.91% as presented in Table 16.8. In 2010, the class accuracies range from 80.00 to 93.75%, whereas in the period 2000, it ranges from 82.14 to 92.59%. In the year 1990, the class accuracies range from 86.67 to 95.45%, as indicated in tables (Tables 16.10, 16.12 and 16.14), respectively.

Finally, **overall accuracy** for the year 2020 classification map was computed as 90.69% with overall kappa coefficient (T) value of 88.58%. During this year 2010, overall accuracy was 88.00%, with kappa coefficient (T) 85.38%, whereas in the period 2000, overall accuracy was 87.50% with kappa coefficient (T) 84.80%. Lastly, in the year 1990, the accuracies classes range from 82.14 to 90.24%, respectively; in this study period 1990, the overall accuracy was 90.50%, with kappa coefficient (T) value of 88.52% (Tables 16.8, 16.10, 16.12 and 16.14) The outcomes demonstrate that this classifier is capable of producing high classification accuracy and has a good level of agreement between ground truth and categorised data.

Discussion

Following the start of economic liberalisation and more pro-import policies in India in the early 1990s, which resulted in enormous socioeconomic growth and infrastructure advances, urban land use unpredictably led to the spread of the city into the peri-urban (Chadchan and Shankar 2012; Sarkar 2019). Being in a state of transition peri-urban spaces characterised by negligence, especially in underdeveloped countries. Owing to the fact that it was neither entirely urban nor entirely rural, and therefore, it does not fall under the jurisdiction of the authorities on either side. Nevertheless, it continues to accommodate the population that overflows from the surrounding urban areas despite the fact that it does not have the requisite infrastructure support. Up-to-date knowledge on urban landscape modification and its consequence on peri-urban greenery are utmost important to gaining our comprehension of the nexus between urban expansion and land use/cover change which may effective for environmental decision-making in peri-urban areas. A substantial portion of **Santiniketan** and the nearby **Prantik Station** area eco-tourism resorts are

Table 16.7 Computation of confusion matrix SVM algorithm for accuracy assessment of LULC map 2020, Bolpur town

Classified data (image to be evaluated)	Reference data (ground truth data)								
	Land use categories	River and canal	Water bodies	Forest area	Agricultural area	Bare/Exposed soil	Built-up area	Total (user)	Commission error
	River and canal	**41**	4	0	0	4	1	**50**	0.180
	Water bodies	0	**32**	1	0	0	1	**34**	0.059
	Forest area	0	2	**25**	0	1	0	**28**	0.107
	Agricultural area	0	0	3	**53**	0	1	**57**	0.070
	Bare/Exposed soil	0	0	0	2	**17**	0	**19**	0.105
	Built-up area	0	0	1	0	1	**57**	**59**	0.034
	Total (producer)	**41**	**38**	**30**	**55**	**23**	**60**	**247**	
	Omission error	0.000	0.158	0.167	0.036	0.261	0.050		

Table 16.8 Comparison of the different accuracy parameter, overall accuracy and kappa coefficient (2020)

Land use categories	User accuracy calculation	Producer accuracy calculation	Overall accuracy	Kappa coefficient (T)
River and canal	82.00	100.00	90.69%	88.58%
Water bodies	94.12	84.21		
Forest area	89.29	83.33		
Agricultural area	92.98	96.36		
Bare/Exposed soil	89.47	73.91		
Built-up area	96.61	95.00		

sprouting in an unplanned manner. The findings of the study confirm that contemporary biophysical transformations in this urban area of Bolpur town, as well as the expectation of increased pressure on peripheral urban green spaces. Furthermore, a decent number of colleges, university, teacher training colleges, institutes of technology and academic institutions located in Bolpur have resulted in an influx of students from different parts of India. Recently, the construction or real-estate industry, the hospitality sector, and marketing have all been in great demand, and as a result, employment opportunities have increased. Census data also confirmed recent growth; Bolpur City had a population of 52,760 in 1991, but the present urban population (2011) is approximately 112,591 including Bolpur City and surrounding census towns (Census of India 2011).

The percentage area of each class in 1990 and 2020 showed that agricultural area had the largest share in 1990 representing 68.73% (198.30 km^2) of the total LULC categories assigned. This class faced a steady decrease, and it was reduced to 55.43% (159.92 km^2). Built-up area experienced the highest rise, increasing from 10.03% (28.93 km^2) in 1990 to 24.49% (70.66 km^2) in 2020. Despite the fact that these transformations are creating opportunity for locals, there are negative repercussions that are showing adversely on the ecosystem. According to census information, a sizeable quantity of ecological landscapes has been transformed into urban settings as a direct result of the explosive growth of the human population and migration. In this study, SVM algorithms produced overall good amount of accuracy for each year over 86% indicate that SVM successfully classified those images.

Conclusion

The study attempts to comprehend the expansion of urban fabric in the peri-urban areas of Bolpur town using multi-temporal Landsat imagery. Bolpur town witnessed significant LULC changes between 1990 and 2020, with a decrease in the forest, agricultural land and exposed soil surface categories. The validation output reveals~~,~~ that

Table 16.9 Computation of confusion matrix SVM algorithm for accuracy assessment of LULC map of 2010, Bolpur town

Classified data (image to be evaluated)	Reference data (ground truth data)								
	Land use categories	River and canal	Water bodies	Forest area	Agricultural area	Bare/Exposed soil	Built-up area	Total (user)	Commission error
	River and canal	**30**	3	0	0	2	1	**36**	0.166
	Water bodies	2	**22**	1	0	0	1	**26**	0.153
	Forest area	0	2	**24**	2	1	0	**29**	0.103
	Agricultural area	0	0	3	**45**	0	1	**49**	0.081
	Bare/Exposed soil	0	0	0	2	**18**	0	**20**	0.100
	Built-up area	0	0	2	0	1	**37**	**40**	0.075
	Total (producer)	**32**	**27**	**30**	**49**	**22**	**40**	**200**	
	Omission error	0.062	0.185	0.200	0.081	0.181	0.075		

Table 16.10 Comparison of the different accuracy parameter, overall accuracy and kappa coefficient (2010)

Land use categories	User accuracy calculation	Producer accuracy calculation	Overall accuracy	Kappa coefficient (T)
River and canal	83.33	93.75	88.00%	85.38%
Water bodies	84.62	81.48		
Forest area	82.76	80.00		
Agricultural area	91.84	91.84		
Bare/Exposed soil	90.00	81.82		
Built-up area	92.50	92.50		

results of SVM algorithm with overall accuracy of 90.69% (2020), 88.00% (2010), 87.50% (2000), 90.50% (1990) and kappa coefficient of 0.88 (2020), 0.85 (2010), 0.84 (2000), 0.88 (1990) have achieved good level of accuracy. It has been suggested that this algorithm can be used as an optimal classifier for the extraction of land use maps due to the fact that it possesses a greater level of accuracy and a better level of consistency within the study area. This research highlighted the importance of remotely sensed data and SVM algorithms in determining and anticipating the transformation of peri-urban landscape. The SVM approach is recommended as one of the finest classifier algorithms for extracting the maps LULC; ideally, this study might be useful in tracking LULC alteration. This study is noteworthy since other cities have also witnessed similar phenomenon of urban development onto agricultural land in peri-urban settings (Beckers et al. 2020; Bonye et al. 2021). So, the outcomes may be helpful for planner and policymakers to handle land use problems of this city in a better way as most of Indian city are at verge of conversion from an agrarian economy to manufacturing and service-based activities in order to lessen the impact urbanisation on fertile land. Instead of haphazard arrangements of the building which create land fragmentation, compact housing development and planned townships should be encouraged to mitigate the impact of land fragmentation. In concluding remarks, agricultural land should be conserved from being transformed to other uses to maintain food production as much as feasible without jeopardising urban growth. Future research on peri-urban space prediction and surveillance using machine learning algorithms, particularly SVM, is recommended to address the uncertainties and detrimental effects of peri-urbanisation on LULC change.

Table 16.11 Computation of confusion matrix SVM algorithm for accuracy assessment of LULC map of 2000, Bolpur town

Classified data (image to be evaluated)	Reference data (ground truth data)								
	Land use categories	River and canal	Water bodies	Forest area	Agricultural area	Bare/Exposed soil	Built-up area	Total (user)	Commission error
	River and canal	**25**	3	0	0	2	1	**31**	0.193
	Water bodies	2	**25**	1	0	0	2	**30**	0.166
	Forest area	0	2	**23**	2	1	0	**28**	0.178
	Agricultural area	0	0	2	**41**	0	2	**45**	0.089
	Bare/Exposed soil	0	0	0	2	**20**	0	**22**	0.090
	Built-up area	0	0	2	0	1	**41**	**44**	0.068
	Total (producer)	**27**	**30**	**28**	**45**	**24**	**46**	**200**	
	Omission error	0.074	0.166	0.179	0.088	0.166	0.108		

Table 16.12 Comparison of the different accuracy parameter, overall accuracy and kappa coefficient (2000)

Land use categories	User accuracy calculation	Producer accuracy calculation	Overall accuracy	Kappa coefficient (T)
River and canal	80.65	92.59	**87.50%**	**84.80%**
Water bodies	83.33	83.33		
Forest area	82.14	82.14		
Agricultural area	91.11	91.11		
Bare/Exposed soil	90.91	83.33		
Built-up area	93.18	89.13		

Table 16.13 Computation of confusion matrix SVM algorithm for accuracy assessment of LULC map of 1990, Bolpur town

Classified data (image to be evaluated)	Reference data (ground truth data)								
	Land use categories	River and canal	Water bodies	Forest area	Agricultural area	Bare/Exposed soil	Built-up area	Total (user)	Commission error
	River and canal	**22**	3	0	0	2	2	**29**	0.241
	Water bodies	2	**27**	1	0	0	2	**32**	0.156
	Forest area	1	2	**23**	2	1	0	**29**	0.206
	Agricultural area	0	0	2	**37**	0	2	**41**	0.097
	Bare/Exposed soil	0	0	0	2	**26**	0	**28**	0.071
	Built-up area	0	0	2	0	1	**38**	**41**	0.073
	Total (producer)	**25**	**32**	**28**	**41**	**30**	**44**	**200**	
	Omission error	0.120	0.156	0.178	0.097	0.133	0.136		

Table 16.14 Comparison of the different accuracy parameter, overall accuracy and kappa coefficient (1990)

Land use categories	User accuracy calculation	Producer accuracy calculation	Overall accuracy	Kappa coefficient (T)
River and canal	84.62	88.00	90.50%	88.52%
Water bodies	87.88	90.63		
Forest area	80.65	89.29		
Agricultural area	94.87	90.24		
Bare/Exposed soil	92.86	86.67		
Built-up area	97.67	95.45		

References

Abbas Z, Jaber HS (2020) Accuracy assessment of supervised classification methods for extraction land use maps using remote sensing and GIS techniques. IOP Conf Ser Mater Sci Eng 745:012166. https://doi.org/10.1088/1757-899x/745/1/01216

Abdi AM (2019) Land cover and land use classification performance of machine learning algorithms in a boreal landscape using Sentinel-2 data. GISci Remote Sens 1–20. https://doi.org/10.1080/15481603.2019.1650447

Acheampong JO, Attua EM, Mensah M, Fosu-Mensah BY, Apambilla RA, Doe EK (2022) Livelihood, carbon and spatiotemporal land-use land-cover change in the Yenku forest reserve of Ghana, 2000–2020. Int J Appl Earth Obs Geoinf 112:102938. https://doi.org/10.1016/j.jag.2022.102938

Adelaja A, Sullivan K, Hailu YG (2011) Endogenizing the planning horizon in urban fringe agriculture. Land Use Policy 28(1):0–75. https://doi.org/10.1016/j.landusepol.2010.05.002

Afriyie K, Abass K, Adomako JAA (2013) Urbanisation of the rural landscape: assessing the effects in peri-urban Kumasi. Int J Urban Sustain Dev 6(1):1–19. https://doi.org/10.1080/19463138.2013.799068

Akar O, Gormus ET (2021) Land use/land cover mapping from airborne hyperspectral images with machine learning algorithms and contextual information. Geocarto Int. https://doi.org/10.1080/10106049.2021.1945149

Alam A, Bhat MS, Maheen M (2019) Using Landsat satellite data for assessing the land use and land cover change in Kashmir valley. GeoJournal 85:1529–1543. https://doi.org/10.1007/s10708-019-10037-x

Anderson JR et al (1976) A land use and land cover classification system for use with remote sensor data. Geological Survey Professional Paper No. 964, U.S. Government Printing Office, Washington DC, 28

Appeaning Addo K (2010) Urban and peri-urban agriculture in developing countries studied using remote sensing and in situ methods. Remote Sens 2(2):497–513. https://doi.org/10.3390/rs2020497

Appiah D, Schroder D, Forkuo E, Bugri J (2015) Application of geo-information techniques in land use and land cover change analysis in a peri-urban district of Ghana. Int J Geo-Inf 4:1265–1289. https://doi.org/10.3390/ijgi4031265

Atu JE, Offiong RA, Eni DI, Eja EI, Esien OE (2012) The effects of urban sprawl on peripheral agricultural lands in Calabar, Nigeria. Int Rev Soc Sci Humanit 2(2):68–76. https://catalog.ihsn.org/citations/48281

Ayele A, Tarekegn K (2020) The impact of urbanization expansion on agricultural land in Ethiopia: a review. Environ Soc-Econ Stud 8:73–80. https://doi.org/10.2478/environ-2020-0024

Beckers V, Poelmans L, Van Rompaey A, Dendoncker N (2020) The impact of urbanization on agricultural dynamics: a case study in Belgium. J Land Use Sci 1–18 15(5):626–643. https://doi.org/10.1080/1747423X.2020.1769211

Bonye SZ, Aasoglenang TA, Yiridomoh GY (2021) Urbanization, agricultural land use change and livelihood adaptation strategies in peri-urban Wa, Ghana. SN Soc Sci 1(1). https://doi.org/10.1007/s43545-020-00017-1

Chadchan J, Shankar R (2012) An analysis of urban growth trends in the post-economic reforms period in India. Int J Sustain Built Environ 1(1):36–49. https://doi.org/10.1016/j.ijsbe.2012.05.001

Congalton RG (1991) A review of assessing the accuracy of classifications of remotely sensed data. Remote Sens Environ 37:35–46

Das S, Angadi DP (2021) Land use land cover change detection and monitoring of urban growth using remote sensing and GIS techniques: a micro-level study. GeoJournal 87(3):2101–2123. https://doi.org/10.1007/s10708-020-10359-1

Di Gregorio A, Jansen LJM (2000) Land cover classification system (LCCS). Classification concepts and user manual for software version 1.0. FAO, Rome

Dutta V (2012) Land use dynamics and peri-urban growth characteristics: reflections on master plan and urban suitability from a sprawling north Indian city. Environ Urban ASIA 3(2):277–301. https://doi.org/10.1177/0975425312473226

Dutta D, Rahman A, Kundu A (2015) Growth of Dehradun city: an application of linear spectral unmixing (L.S.U.) technique using multi-temporal landsat satellite data sets. Remote Sens Appl Soc Environ 1:98–111. https://doi.org/10.1016/j.rsase.2015.07.001

Fazal S (2000) Urban expansion and loss of agricultural land—a GIS based study of Saharanpur city, India. Environ Urban 12:133–149. https://doi.org/10.1177/095624780001200211

Feola G, Suzunaga J, Soler J, Goodman MK (2019) Ordinary land grabbing in peri-urban spaces: land conflicts and governance in a small Colombian city. Geoforum 105:145–157. https://doi.org/10.1016/j.geoforum.2019.05.018

Follmann A, Hartmann G, Dannenberg P (2018) Multi-temporal transects analysis of peri-urban developments in Faridabad, India. J Maps 14(1):17–25. https://doi.org/10.1080/17445647.2018.1424656

Ghosh S, Chatterjee ND, Dinda S (2018) Relation between urban biophysical composition and dynamics of land surface temperature in the Kolkata metropolitan area: a GIS and statistical based analysis for sustainable planning. Model Earth Syst Environ 5:307–329. https://doi.org/10.1007/s40808-018-0535-9

Guo L, Boukir S (2015) Fast data selection for SVM training using ensemble margin. Pattern Recognit Lett 51:112–119. https://doi.org/10.1016/j.patrec.2014.08.003

Hegazy IR, Kaloop MR (2015) Monitoring urban growth and land use change detection with GIS and remote sensing techniques in Daqahlia governorate Egypt. Int J Sustain Built Environ 4:117–124. https://doi.org/10.1016/j.ijsbe.2015.02.005

Huang C-M, Lee Y-J, Lin DKJ, Huang S-Y (2007) Model selection for support vector machines via uniform design. Comput Stat Data Anal 52(1):335–346. https://doi.org/10.1016/j.csda.2007.02.013

Islam K, Rahman MF, Jashimuddin M (2018) Modeling land use change using cellular automata and artificial neural network: the case of Chunati Wildlife Sanctuary, Bangladesh. Ecol Indic 88:439–453. https://doi.org/10.1016/j.ecolind.2018.01.047

Jamali A (2019) Evaluation and comparison of eight machine learning models in land use/land cover mapping using Landsat 8 O.L.I.: a case study of the northern region of Iran. SN Appl Sci 1:1448. https://doi.org/10.1007/s42452-019-1527-8

Jensen J, Cowen D (1999) Remote sensing of urban/suburban infrastructure and socio-economic attributes. Photogramm Eng Remote Sens 5:611–622

Kavzoglu T, Colkesen I (2009) A kernel functions analysis for support vector machines for land cover classification. Int J Appl Earth Obs Geoinf 11:352–359. https://doi.org/10.1016/j.jag.2009.06.002

Keshtkar H, Voigt W, Alizadeh E (2017) Land-cover classification and analysis of change using machine-learning classifiers and multi-temporal remote sensing imagery. Arab J Geosci 10:1–15. https://doi.org/10.1007/s12517-017-2899-y

Lefulebe BE, Van der Walt A, Xulu S (2022) Fine-scale classification of urban land use and land cover with planet scope imagery and machine learning strategies in the city of Cape Town, South Africa. Sustainability 14(15):9139. https://doi.org/10.3390/su14159139

Li M, Wu J, Deng X (2013) Identifying drivers of land use change in China: a spatial multinomial logit model analysis. Land Econ 89(4):632–654. http://www.jstor.org/stable/24243695

Liu W et al (2005) Land use and land cover change in the tropical rainforest region of Southern Yunnan: a case study of Menglun, Xishuangbanna. J Mountain Res 23(1):71–79. https://doi.org/10.1016/j.landurbplan.2003.10.033

Mazumder S, Saha J, Nandi G, Naskar M, Gayen J, Datta D (2021) Long-term monitoring of cropland transformation in Kolkata metropolitan area, India using open-source geospatial technologies. SN Appl Sci 3:98. https://doi.org/10.1007/s42452-020-04064-4

Mortoja MdG, Yigitcanlar T, Mayere S (2020) What is the most suitable methodological approach to demarcate peri-urban areas? A systematic review of the literature. Land Use Policy 95:104601. https://doi.org/10.1016/j.landusepol.2020.104601

Mosammam HM, Nia JT, Khani H, Teymouri A, Kazemi M (2016) Monitoring land use change and measuring urban sprawl based on its spatial forms. Egypt J Remote Sens Space Sci. https://doi.org/10.1016/j.ejrs.2016.08.002

Mountrakis G, Im J, Ogole C (2011) Support vector machines in remote sensing: a review. ISPRS J Photogramm Remote Sens 66:247–259. https://doi.org/10.1016/j.isprsjprs.2010.11.001

Mundia CN, Aniya M (2005) Analysis of land use/cover changes and urban expansion of Nairobi city using remote sensing and G.I.S. Int J Remote Sens 26(13):2831–2849. https://doi.org/10.1080/01431160500117865

Mustard JF, Defries RS, Fisher T, Moran E (2012) Land-use and land-cover change pathways and impacts. Remote Sens Digit Image Process 411–429. https://doi.org/10.1007/978-1-4020-2562-4_24

Nooni IK, Duker AA, Van Duren IC, Addae-Wireko L, Osei Jnr E (2014) Support vector machine to map oil palm in a heterogeneous environment. Int J Remote Sens 35:4778–4794. https://doi.org/10.1080/01431161.2014.930201

Otunga C, Odindi J, Mutanga O (2014) Land use land cover change in the fringe of eThekwini municipality: implications for urban green spaces using remote sensing. South Afr J Geomatics 3(2):145. https://doi.org/10.4314/sajg.v3i2.3

Padmanaban R, Bhowmik AK, Cabral P, Zamyatin AV, Almegdadi O, Wang S (2017) Modelling urban sprawl using remotely sensed data: a case study of Chennai city, Tamilnadu. Entropy 19:163. https://doi.org/10.3390/e19040163

Pal M (2012) Advanced algorithms for land use and cover classification. In: Advances in mapping from remote sensor imagery. CRC Press, pp 69–90. https://doi.org/10.1201/b13770-4

Rana VK, Venkata Suryanarayana TM (2020) Performance evaluation of MLE, RF and SVM classification algorithms for watershed scale land use/land cover mapping using sentinel 2 bands. Remote Sens Appl Soc Environ https://doi.org/10.1016/j.rsase.2020.100351

Ritchie H, Roser M (2021) Biodiversity. Published online at OurWorldInData.org. Retrieved from: https://ourworldindata.org/biodiversity

Roy B (2021) A machine learning approach to monitoring and forecasting spatio-temporal dynamics of land cover in Cox's Bazar district, Bangladesh from 2001 to 2019. Environ Challenges 5:100237. https://doi.org/10.1016/j.envc.2021.100237

Roy S, Sahu AS (2016) Palaeo-path investigation of the lower Ajay River (India) using archaeological evidence and applied remote sensing. Geocarto Int 31:966–984. https://doi.org/10.1080/10106049.2015.1094526

Sankhala S, Singh BK (2014) Evaluation of urban sprawl and land use land cover change using remote sensing and GIS techniques: a case study of Jaipur City, India. Int J Emerg Technol Adv Eng 4:66–72

Sarkar R (2019) Urbanization in India before and after the economic reforms: what does the census data reveal? J Asian Afr Stud. 002190961986558. https://doi.org/10.1177/0021909619865581
Seifollahi-Aghmiuni S, Kalantari Z, Egidi G, Gaburova L, Salvati L (2022) Urbanisation-driven land degradation and socioeconomic challenges in peri-urban areas: insights from Southern Europe. Ambio 51(6):1446–1458. https://doi.org/10.1007/s13280-022-01701-7
Shao Y, Lunetta RS (2012) Comparison of support vector machine, neural network and cart algorithms for the land-cover classification using limited training data points. Photogramm Remote Sens 70:78–87. https://doi.org/10.1016/j.isprsjprs.2012.04.001
Shaw R, Das A (2018) Identifying peri-urban growth in small and medium towns using G.I.S. and remote sensing technique: a case study of English Bazar Urban Agglomeration, West Bengal, India. Egypt J Remote Sens Space Sci 159–172. https://doi.org/10.1016/j.ejrs.2017.01.002
Shi D, Yang X (2015) Support vector machines for land cover mapping from remote sensor imagery, chap 13, pp 265–279. https://doi.org/10.1007/978-94-017-9813-6_13
Singh A (1989) Digital change detection techniques using remotely sensed data. Int J Remote Sens 10(6):989–1003
Sun W, Shan J, Wang Z, Wang L, Lu D, Jin Z, Yu K (2020) Geospatial analysis of urban expansion using remote sensing methods and data: a case study of Yangtze river delta, China. Complexity 1–12. https://doi.org/10.1155/2020/3239471
Talukdar S, Singha P, Mahato S, Shahfahad, Pal S, Liou Y-A, Rahman A (2020) Land-use land-cover classification by machine learning classifiers for satellite observations—a review. Remote Sens 12(7):1135. https://doi.org/10.3390/rs12071135
Tilahun A (2015) Accuracy assessment of land use land cover classification using Google earth. Am J Environ Prot 4(4):193–198. https://doi.org/10.11648/j.ajep.20150404.14
Travisi CM, Camagni R (2005) Sustainability of urban sprawl: environmental-economic indicators for the analysis of mobility impact in Italy. Labor Human Capital. https://doi.org/10.2139/ssrn.812788
Urban agglomerations/cities having population 1 lakh and above. Provisional population totals, Census of India 2011. Retrieved 21 Mar 2021
Ustuner M, Sanli FB, Dixon B (2015) Application of support vector machines for landuse classification using high-resolution rapid eye images: a sensitivity analysis. Eur J Remote Sens 48:403–422. https://doi.org/10.5721/EuJRS20154823
Wang H, Qiu F (2017) Investigation of the dynamics of agricultural land at the urban fringe: a comparison of two peri-urban areas in Canada. Can Geogr/Le Géographe Canadien 61(3):457–470. https://doi.org/10.1111/cag.12
Wilson B, Chakraborty A (2013) The environmental impacts of sprawl: emergent themes from the past decade of planning research. Sustainability 5(8):3302–3327. https://doi.org/10.3390/su50833

Chapter 17
Exploring the Spatio-temporal Patterns and Driving Forces of Urban Growth in Dhaka Megacity from 1990 to 2020

Kazi Jihadur Rashid, Tahmina Akter, A. S. M. Imrul Kayes, and Md. Yachin Islam

Abstract Dhaka is one of the most populous megacities, facing rapid urbanisation and population growth. It has been undergoing vast territorial expansion and infrastructural development in recent decades. These uncontrolled changes in the city degrade the environmental quality and reduce the health status of city dwellers. Understanding patterns and drivers is critical to regulating these changes and practising sustainable management. Therefore, this chapter aims to identify urban growth patterns and their pivotal driving forces in the megacity. Landsat (TM, OLI sensors) satellite imageries from 1990 to 2020 were used at decadal intervals to identify change patterns. Urban LULC was prepared using a hybrid classification method (combining supervised and unsupervised techniques). Afterward, the driving forces of urban growth in the city were investigated using spatial data layers in *geodetector* and data obtained through questionnaires survey, and previous literature. According to the analysis, the urban area increased by 40%, whereas green space declined by 41%. Major driving forces are anthropogenic, such as economic opportunities, education, and medical facilities, which worked as pull factors for rural–urban migration resulting in urban population growth. Natural determinants, such as drainage systems, inundated lands, suitable soil types and textures for building infrastructures; artificial determinants, such as distance from the city core, roads and railways worked together in shaping the spatial locations of the city expansion. To transform Dhaka into a sustainable city, policymakers should regulate or control these determinants.

K. J. Rashid (✉)
Remote Sensing Division, Center for Environmental and Geographic Information Services, Dhaka 1212, Bangladesh
e-mail: jihadrashid.gis@gmail.com

T. Akter
Department of Geography and Environmental Studies, University of Chittagong, Chattogram 4331, Bangladesh

A. S. M. Imrul Kayes
Unnayan Prochesta, Satkhira, Bangladesh

Md. Yachin Islam
Graduate School of Bioresources, Mie University, Tsu City, Mie Prefecture 514-0102, Japan

U. Chatterjee et al. (eds.), *Urban Commons, Future Smart Cities and Sustainability*, Springer Geography, https://doi.org/10.1007/978-3-031-24767-5_17

Keywords Dhaka city · Driving forces · Factor analysis · Geodetector · Spatio-temporal pattern · Urban growth

Introduction

Worldwide Urbanisation Trend

Over the last few decades, urbanisation has sped up worldwide (Grimm et al. 2008; United Nations 2021). Though the global north has more urban areas, the global south tends to have more rapid and high dynamics of urbanisation (United Nations 2018a; Wolvers et al. 2015). The number of people living in cities has grown from 12% in 1990 (Grimm et al. 2008) to more than 50% in 2011 (United Nations 2012). Despite only covering roughly 0.5% of the terrestrial surface of the earth, urban areas have higher population densities and growth rates than other types of land (Schneider et al. 2009). The size of urban areas worldwide increased fourfold from 1970 to 2000 (Seto et al. 2011) and is projected to rise by another three-quarters from 2000 to 2030 (Seto et al. 2012). This dramatic surge is typically the result of rapid population growth. Population expansion over the past few decades has led to massive urbanisation, which is becoming more common in developing nations (Liu et al. 2011). More than fifty percent of the world's population already lives in the urban region, and by 2050, this percentage is anticipated to increase by more than 68% (Lutz et al. 2001; United Nations 2018b). Approximately, 90% of the increase in the urban population will tend to happen in Asia and Africa (Yadav and Ghosh 2021). This upsurge has led to the formation of megacities with populations exceeding 10 million (Aguilar et al. 2003). Megacities worldwide are seeing extremely high levels of urban expansion, both vertically and horizontally, along with an increasing population rate (Florczyk et al. 2019; Kraas 2003). In 1950, there were just two megacities: New York and Tokyo (Gurjar and Lelieveld 2005). The number of megacities had risen to 33 by 2018, with 43 expected by 2030 (United Nations 2018b). Urban growth is higher in emerging countries than in industrialised nations and the majority of the world's megacities will be in developing countries by 2030 (United Nations 2019). As a result of growing populations and urbanisation, the form and pattern of urban land use and land cover have changed significantly and are anticipated to continue in the future decades (Fang et al. 2005).

Process of Urbanisation

Urban expansion is a complex spatial pattern influenced by internal growth and immigration into existing urban areas. Substantial rural–urban migration frequently accompanies economic development, resulting in massive urban agglomerations

(Ramachandra et al. 2015). Urbanisation mainly refers to the economic transformation of an agriculture-based into manufacturing and service-based (Mandal 2000). However, urbanisation has led to a decline in the area of rural landform and a rise in the area of urban landform over the past few decades, particularly in developing countries (Dewan et al. 2012; Dewan and Yamaguchi 2009; Jat et al. 2008). Social, political and ecological systems have unavoidably changed due to these rapid population movements and their interactions with the natural and artificial environments (Ahmed et al. 2012). The main drivers of urban growth are biophysical, or natural, and socio-economical, or anthropogenic. Biophysical or natural elements such as climate, geomorphic processes, topography, soil type and drainage patterns are important determinants of urban expansion (Fu et al. 2006; Opršal et al. 2016; Serra et al. 2008; Thapa and Murayama 2010).

Moreover, population expansion, large-scale rural–urban movement, rural–urban income disparity, industrialisation, economic globalisation (Rimal et al. 2018; Schneider et al. 2015) and government policy and regulations supporting urban-centric economies influence the natural factors. New land development occurs dispersed and irregularly beyond the city centre in the first stage of urban growth (Schneider and Woodcock 2008). As the process proceeds, the urban fabric becomes more continuous. Spatially compact and continuous structures of settlements in cities may experience a movement of spread urbanisation followed by a fresh wave of continuous expansion, merging formerly dispersed communities (Salvati et al. 2013). These processes are contingent upon the history and prior formation of cities, and they are intrinsically linked to the land policies that permit or prohibit land dynamics driven by urbanisation affecting global climate (Ceccarelli et al. 2013; Yao et al. 2015). Along with worsening climate, the effects on a wide range of biophysical systems will last very long (Serneels et al. 2007). This unplanned urbanisation and the associated change in land cover are the leading causes of habitat alteration, biodiversity loss, extensive exploitation of valuable agricultural land (Lambin and Meyfroidt 2011), degradation and isolation of wildlife habitats (Serneels et al. 2007), disruption of hydrological processes (Brown et al. 2012), degradation of green space (Asgarian et al. 2015) and risk to human health (Moore et al. 2003a).

Characteristics of Urbanisation in Bangladesh

Rural to urban migration has increased quickly in developing nations because of poor planning principles and the driver of economic development (Black and Henderson 1999). Asia's developing nations have the fastest rate of urbanisation expansion among the world's developing nations (United Nations 2019). In the 1950s, only 4% of Bangladesh's total population resided in urban areas, indicating a surprisingly low level of urbanisation across the nation. This percentage gradually increased after the country's independence in 1971 to approximately 5%, then accelerated quickly (Ahmed et al. 2012). Since the urban population in this group of nations is expanding faster than the rural population for the first time in decades, a historical shift has occurred throughout the decade (2000–2010) for low-income countries like Bangladesh (Weiss and Khan 2008). Around 25% of the population in Bangladesh lives in the urban regions, with more than half residing in the four main cities: Dhaka, Chittagong, Khulna and Rajshahi (BBS 2015; Helal uz Zaman et al. 2010). Even though Bangladesh is a rural-based country with a low urbanisation level in comparison with other Asian nations, the megacity of Dhaka has been experiencing a higher rate of urbanisation (Hassan and Southworth 2017). The capital city Dhaka produces 36% of the country's overall GDP and total employment of 31.8% (RAJUK 2016). It has witnessed a significant development in human settlements within (new settlement areas of 116 km^2) and around (234 km^2) the city between 1991 and 2019 (Roy et al. 2021). It is one of the world's most densely populated and rapidly urbanised cities, with a population that exploded from roughly 1 million in 1972 to 20 million or more in 2018 (UN-Habitat 2021; United Nations 2018b). The mega-urban centre of Dhaka is anticipated to have an annual population growth rate of 2.98% by 2030, with the total population in the city zone topping 27.37 million and beating the growth rates of other major urban centres such as Beijing, Shanghai and Mexico City (Ahmed et al. 2014; United Nations 2019). It seems unlikely that the population will stabilise or drop until 2060, when it could reach 230 million, with more than 70% living in metropolitan areas (Islam 2013). However, one of the essential factors of Dhaka's explosive expansion is the unstable rural economy, which compels hundreds of thousands of rural people to migrate to the city in search of improved lifestyles and better employment possibilities (Dewan and Yamaguchi 2009). With its rapid and unregulated expansion, the current urbanisation pattern has put Dhaka's environment, ecology and land resources at greater risk, especially with the closeness of extremely ecosensitive wetland areas of the city (Ahmed et al. 2005). The above makes the city one of the least livable places on earth, along with its intolerable traffic congestion, high levels of pollution and inadequate infrastructure and housing development (UN-Habitat 2021).

Application of Remote Sensing in Urbanisation Research

The ability to track the worldwide urbanisation of megacities has been made possible by the long-term remotely sensed collection of global images (Sun et al. 2021). Remote sensing is an important source of current and historical information about the earth's surface because it provides spatially consistent imageries of huge areas with high spatial resolution and temporal frequencies (Xiao et al. 2006; Zhang and Seto 2011). Geospatial data and technologies are frequently used in urban expansion research, with a particular emphasis on urban area extraction and spatio-temporal land cover classification to quantify urban dynamics (Chen et al. 2013; Sun et al. 2015). Traditional surveying and mapping techniques make updating information in areas undergoing fast land use changes difficult and time-consuming, making RS data especially useful. Multi-temporal RS data for examining the structural variation of LULC patterns (Liu and Phinn 2003) can be used to avoid the cumulative and irreversible impacts of urban growth (Yang et al. 2008) and is crucial to optimising the allocation of urban services (Barnsley and Barr 1996). Based on land use and land cover changes retrieved from remote sensing data, prior research has measured and studied the spatio-temporal dynamics of the urban landscape, driving forces and impacts of urbanisation (Ahmed et al. 2012; Barnsley and Barr 1996; Yadav and Ghosh 2021; Yin et al. 2011). Remote sensing data on land use and land cover can also be used to plan sustainable urban development and environmental planning (Jensen and Im 2007).

Rationale of the Study

Urbanisation is a global phenomenon that possibly represents the most extreme kind of irreversible land modification. It is the process by which a more significant proportion of individuals living in densely populated areas gain access to public utilities (Murtaza 2012). Population concentration in urban areas is increasing significantly around the globe, placing enormous pressure on land resources in particular. Since urbanisation drives environmental change at diverse stages, rapid urbanisation resulting from large-scale land use change in developing nations is a cause for grave concern (Dewan et al. 2012). Long-term urban expansion may be a better way to measure visible and hidden socio-economic changes in both developed and developing countries than other demographic and geographical factors (Gong et al. 2012; Weber and Sciubba 2019; Zitti et al. 2015). In the last several decades, under the effect of population increase and global migration, urbanisation has altered natural and social conditions to produce spatial shifts that continue to occur (Angel et al. 2011; Chen et al. 2014). Increasing human activity in urban areas has resulted in substantial changes in land use and landscape patterns on both the global and regional scales and is having a profound effect on the structure, function and dynamics of the ecosystem rendering vulnerable regions of urban areas (Deng et al. 2009; Weng 2007).

It is essential to assess the mechanisms involved in urban growth during the past many decades, particularly in the case of megacities, and to identify the driving forces to reduce the destruction (Sun et al. 2021). Due to the rapid rate of urban expansion in developing countries like Bangladesh, where intra- and inter-annual variation in land use patterns is significant, decadal changes are no longer sufficient (Hassan and Southworth 2017). Consequently, a greater frequency and a longer temporal sequence are necessary to study urban expansion. A complete view of the current state of different land use types and the physical direction and variety of their development dynamics in response to changing social and biophysical elements is necessary to provide the relevant authorities. This requires constant monitoring and comprehension of the rate of urban growth to sustain natural resources. Understanding the urbanisation process's growth and characteristics requires understanding urban areas, mainly their growth magnitude, shape geometry, driving forces and spatial pattern (Ramachandra et al. 2015). It is necessary to comprehend these interactions to address the global urban changes created by a complex combination of political, economic, cultural and environmental challenges.

As an essential aspect of urbanisation, urban expansion processes have been extensively examined in prior research. Research on the spatio-temporal characteristics of urban areas and their patterns can provide basic information and references for comprehending the driving forces of urbanisation and its processes on multiple levels, including international (Chakraborty and Lee 2019; Yin et al. 2011); national (Ahmed et al. 2013, 2012; Dewan and Yamaguchi 2009; Hassan and Southworth 2017). According to Hassan and Southworth (2017), flood-free higher land, the availability of a transportation network and the concentration of manufacturing-based employment centres are the key factors driving the city's northward expansion in Dhaka. Thus, this work's thematic map and spatial data enable a thorough understanding of urban expansion dynamics and land cover change patterns in Dhaka. Byomkesh et al. (2012) assessed the temporal fluctuation of greenspace in the city using several landscape matrices, such as patch density, number of patches and largest patch index. Based on LULC change research and urban growth studies conducted in South Asian cities, it has been shown that open space and vegetation (cropland and forest land) are predominantly transforming into urban areas (Yadav and Ghosh 2021). Although urbanisation brings economic and social benefits, it also affects the ecological status of the place and its surroundings.

Dhaka metropolis and its peripheries have undergone an unexpected metamorphosis due to poor implementation of urban planning and a lack of long-term vision (Bhatta 2010). Thus, Dhaka, one of the world's fastest-growing cities, presents a fascinating case study for researchers (Dewan and Yamaguchi 2009; Rana and Parves 2011). As a result of its large population concentration and rapid development dynamics, Dhaka is attracting attention as the nation's economic, political and administrative centre. Hence, more research and analysis must be done on the trends, patterns and processes of urbanisation in their spatial and temporal context. Integrating remote sensing and spatial metrics enables the extraction of spatial information regarding urban expansion, structure, and dynamics, which contributes to the comprehension of urban growth processes (Deng et al. 2009; Ramachandra et al. 2012). This research felt the need to shed light on the spatio-temporal pattern, drivers and impacts of urbanisation scenarios in Dhaka. The primary objective of this chapter is, therefore, to investigate and analyse urban growth patterns using Landsat (TM and OLI sensors) satellite images from 1990 to 2020 that were prepared using a hybrid classification method (combining supervised and unsupervised techniques) and to identify the key driving factors that influence changes in Dhaka's built-up areas. A geographic statistical method called geodetector was also used to evaluate spatial factors, and factors from the questionnaire were ranked based on people's perceptions. Understanding the urbanisation process could help us deal with the rising difficulties connected to increased urban living, take advantage of the agglomeration benefits of city clusters and eventually construct a sustainable future.

Materials and Method

Study Area

The location of Dhaka is on the eastern bank of the Buriganga at 23° 42′ N 90° 22′ E (Fig. 17.1). The city has a tropical savanna climate (Köppen Aw) according to the Köppen-Geiger climate classification. It is one of the hottest regions in Bangladesh, with an average daily high temperature of 31 °C and annual rainfall of 2055 mm (Khatun et al. 2016; Rahman et al. 2017). The city has a natural boundary of rivers and 43 canals that are getting encroached and filled (Ishtiaque et al. 2014). Thus, the drainage system is getting worse, and the city suffers from flash floods during excessive rainfall. As Bangladesh's capital and primate city, Dhaka has experienced tremendous growth in different fields such as economic, social, industrial and educational and has become the hub after the liberation war of 1971. The level of urbanisation went up to 28.37% in 2011 from 7.78% in 1972, respectively (Panday 2017). Dhaka city provides many economic, environmental and social opportunities, a habitat of nearly 18 million residents (United Nations 2019); however, rapid population growth becomes a significant challenge. The population of Dhaka increased from 2.3 million in 1975 to around 15.4 million in 2011 (Trotter et al. 2017).

Data Description

Both secondary and primary data was used in this research. Secondary data such as satellite images for LULC and GIS layers for spatial factor analysis was used. A questionnaire survey as primary source data was used to understand the driving forces of urbanisation and its impact. Landsat is a widely used satellite for LULC classification in urbanisation research (Mushore et al. 2017). The US Geological Survey freely provides it for the most prolonged period among all the available satellites. Landsat (OLI and TM sensors) images at ten years intervals (1990, 2000, 2010, 2020) were used to retrieve information on the urban land cover of the recent three decades in the study area. All the images were collected in the same season to have fewer phenological variations, and the winter season was selected because of the cloud-free sky. SRTM elevation data was also collected from the US Geological Survey. Driving forces-related data such as inundation land type, soil characteristics, drainage system, water bodies and wetlands, roads and railways, city core and planned areas was collected from different GOs, NGOs and literature. These layers were selected based on empirical studies discussed by Kim et al. (2020). A semi-structured questionnaire survey was conducted to learn about city dwellers' experiences and perceptions of the factors driving Dhaka's urbanisation. The survey was distributed to 200 people via Google Forms, e-mail and in-person interviews. The survey was carried out using a technique known as probable random sampling. Data characteristics are shown in Table 17.1.

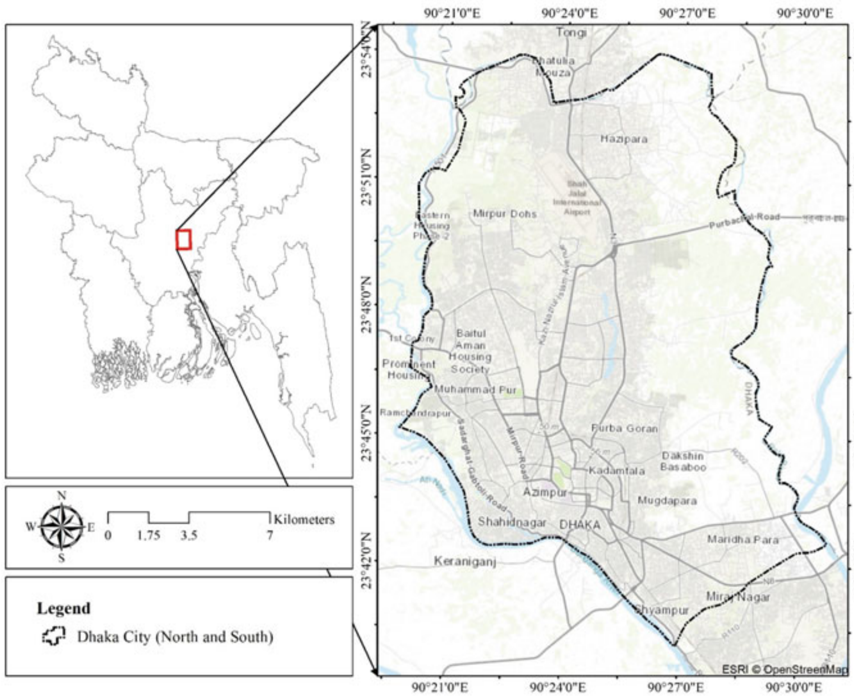


Fig. 17.1 Location map of the study area

Table 17.1 Description of data used in the study

Data type	Time	Source
Landsat OLI, ETM+ and TM sensors (30 m)	16 Jan 1990 13 Feb 2000 08 Feb 2010 06 Feb 2020	US Geological Survey
Inundation land type Topsoil texture General soil type Drainage	–	Bangladesh Agricultural Research Council (BARC)
Ponds and wetlands Rivers and canals	2020	WARPO/BWDB and Google map layer
Railway Major roads	2020	LGED
City core Planned area	2019 2020	Prepared by author based on Afrose et al. (2019) and Google map layer
Administrative boundaries		Govt. of Bangladesh (GoB)

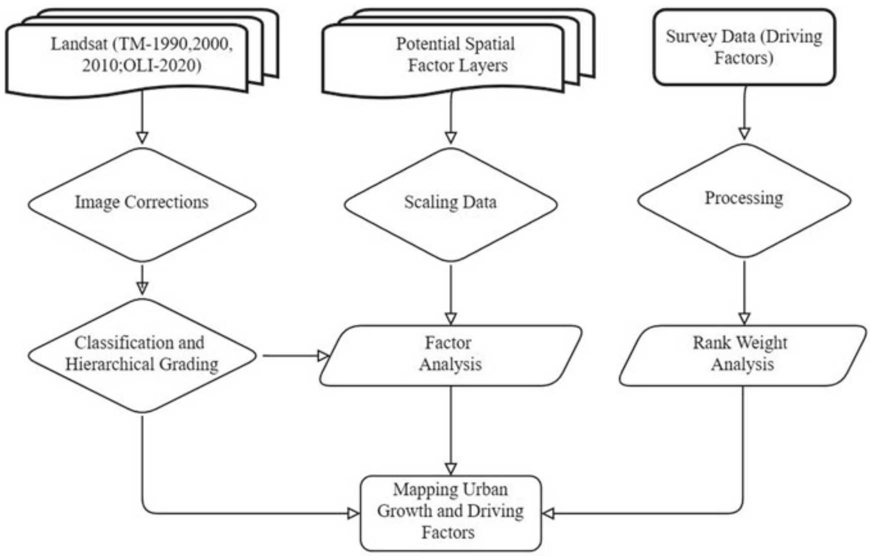
Methods

The data collection and processing procedures for the analysis and visualisation were carried out using ArcGIS, MS Excel and R programming. These tools were used based on their convenient application throughout the workflow (Flowchart 17.1).

Data processing

Landsat (TM and OLI/TIRS) data was collected from the US Geological Survey website. Level 1 terrain precision (L1TP) data was used in this study, which comes with geometric correction and is suitable for pixel-to-pixel change detection. Raw Landsat images were provided as DN (digital number) values. DN has no physical importance; thus, it must be converted into reflectance (Chavez 1989). The image was radiometrically calibrated and produced TOA (top of atmosphere) reflectance using the Semi-automatic Classification Plugin in QGIS (version 3.4). The TOA image was then corrected atmospherically using the DOS1 method (Pax-Lenney et al. 2001).

Natural and anthropogenic factors both have a significant impact on urban growth. This research examined the ten potential factors listed in Table 17.1 to see how they affected the urban growth pattern in Dhaka city. Euclidean distances were calculated for the spatial layers such as ponds and wetlands, rivers and canals, railways, major roads, city core and planned areas to generate continuous raster data. All the layers prepared for factor analysis were classified into four classes depending on their suitability for urbanisation. Figure 17.2 depicts the spatial distribution of all-natural



Flowchart 17.1 Methodological steps followed in this study

and anthropogenic factors. The questionnaire-derived data has been processed using MS Excel and R programming according to their ease of use.

Classification

For classification, this study used a hybrid classification method (combination of supervised and unsupervised techniques) for higher accuracy in classification results. Among different supervised methods, this study used the maximum likelihood classification (MLC) algorithm. MLC is one of the most popular and easy-to-use methods in remote sensing data analysis (Arai 2020; Tan et al. 2010). This method assumes a pixel's probability to a particular class based on multi-dimensional Gaussian probability density (Paola and Schowengerdt 1995). The mean vector and covariance matrix for the collected sample datasets are used to measure the probability density

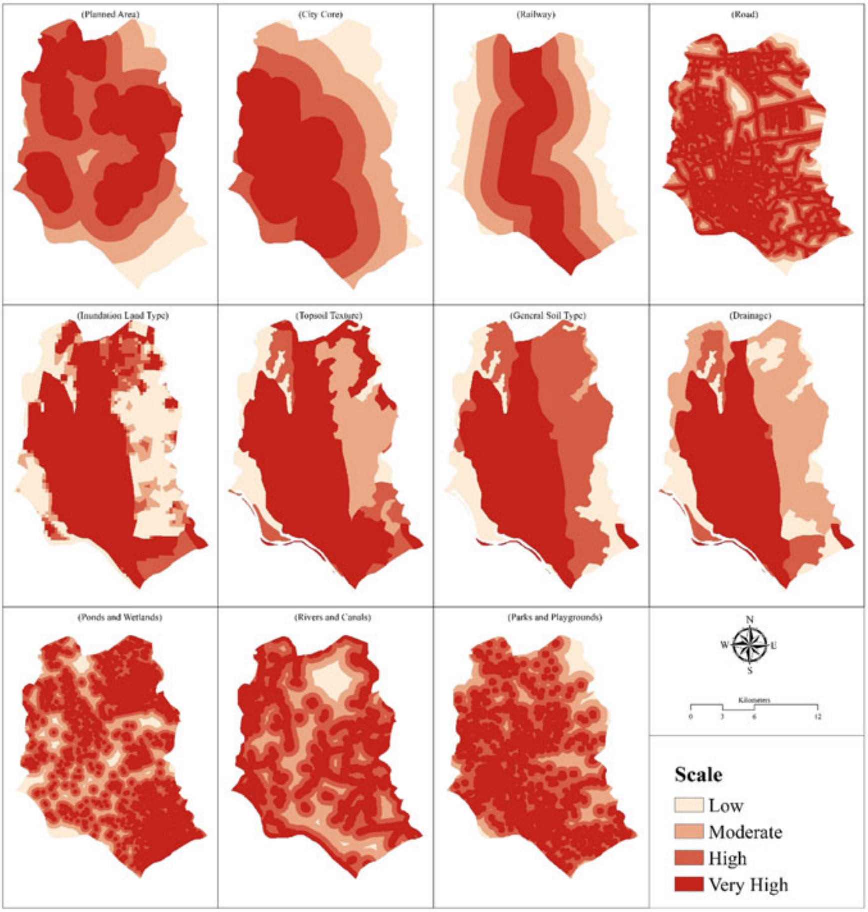


Fig. 17.2 Spatial data layers considered as potential factor of urban growth

parameters (Arai 2020; Paola and Schowengerdt 1995). These parameters are then used to classify pixels. The basic theory, however, assumes that the input data is normally distributed. This method tends to over-classify when dealing with large value signatures (Rawat and Kumar 2015). Several unsupervised classifiers, such as the Iterative Self-Organising Data Analysis Technique (ISODATA) and *K*-means clustering, are widely used for remote sensing data classifications (Karthik and Shivakumar 2021; Naikoo et al. 2020). For unsupervised classification, the *K*-means clustering technique has been adopted in the study. It is a partitional clustering method to classify data into non-overlapping categories (N'Cir et al. 2015). This technique divides n observations integrated with m-dimensional space into k clusters using the Euclidean mean value and helps handle numerical data (Karthik and Shivakumar 2021; Naikoo et al. 2020). Both the classified layers were combined to prepare the final LULC. The mapping accuracy was evaluated using the error matrix and the Kappa methods (Rwanga and Ndambuki 2017). In the study area, four types of land use/cover have been identified: green space, urban area, water bodies and open space (Table 17.2).

Spatial factor analysis

Factors of the spatial distribution of LULC were analysed using the geodetector package in R. It is a tool for detecting heterogeneity of spatial layers and identifying influential factors (Wang et al. 2016). After processing dependent layers, the urban LULC (independent layer) classes of 2020 were graded hierarchically based on their utilisation (Cui et al. 2022; Liu et al. 2020). Grade values were assigned to four classes according to Table 17.3.

Table 17.2 LULC classification scheme used in the study

Class	Description
Green space	This category includes green surfaces with dense vegetation, such as natural or semi-natural tree covers, grassland, low lands with seasonal vegetations
Urban area	This category includes all forms of artificial surfaces such as residential, commercial, and industrial spaces, roadways and railways
Water bodies	This category includes open water bodies such as lakes, rivers, canals, ponds and marshes
Open space	This class includes bare surfaces, landfill sites for development, and fellow land with no vegetative cover

Table 17.3 Hierarchical grading of LULC classes in the study area

Land types	Uncultivated land	Ecological land	Agricultural land	Construction land
LULC classes	Open space	Water bodies	Green space	Urban area
Index values	1	2	3	4

Spatial stratified heterogeneity (SSH) helps us understand the diverse mechanisms of natural and social processes and their interdependence (Wang et al. 2016). Geodetector tool provides q-statistic, which measures the degree of SSH among spatial layers. This tool has four detecting functions: factor detector, interaction detector, risk detector and ecological detector. The factor detector function was used in this study to detect the influence of different factors on urban LULC. The explanatory power (q-statistic) of the influencing factors on the spatially heterogeneous characteristics of LULC can be measured by the following equation (Cui et al. 2022).

$$q = \frac{\sum_{h=1}^{L} N_h \sigma_h^2}{N\sigma^2} \tag{17.1}$$

where q is the determinant power of influential factors and the degree of stratified heterogeneity of LULC; N_h denotes the number of pixels in the subregions h; N denotes the total number of pixels in the study area; σ and σ_h denote the total variance, and variance in the pixels in subregion h, respectively. The value of q ranges between 0 and 1; $q = 0$ indicates no association between influential variables and heterogeneity of LULC, whereas $q = 1$ indicates that LULC is entirely determined by those variables (Wang et al. 2016).

Rank weight analysis

Influential factors in the view of city dwellers were collected from a questionnaire survey. Overall rank weight for each variable was measured based on the rank provided by the respondents. Rank gradings of the respondents were given weights ranging between 0 and 1, where 1 is assigned to the first attribute and 0 to the sixth attribute (Hemphill et al. 2002). The percentage of each variable was calculated for each assigned grade by respondents. Finally, the weighted sum for all the variables was measured using Eq. 17.2 (Aydi et al. 2013).

$$S = \sum_{i=1}^{n} W_i * X_i \tag{17.2}$$

where S is the weighted sum for effective measures of variables, W_i and X_i represent the weight and percentage of the ith variable.

Results and Discussion

Spatio-temporal Patterns of Urbanisation in Dhaka City

The city of Dhaka is rapidly growing in terms of both population and area. To meet the growing needs of the urban population, the urban areas, including human settlements, institutions, hospitals, industries, roads and railways are increasing quickly.

Population growth in developing cities has led to rapid changes in LULC and further environmental degradation (Holdgate 1993). To find the rate of city expansion and the patterns of land use change in Dhaka city, hybrid classification was used for the years 1990, 2000, 2010 and 2020. The results found from the analysis of multi-temporal satellite imageries, four different LULC types, i.e. green space, urban area, water bodies and open space have been identified in Dhaka city.

A comprehensive visualisation of the spatial pattern of urban growth has been shown in Fig. 17.3. According to Table 17.4, it has been found that the city has been witnessing significant urban growth since 1990. The urban areas were 6144.8 ha, 10,522.5 ha, 15,574.5 ha and 18,053.2, respectively, in the years 1990, 2000, 2010 and 2020, consisting of 20.4%, 35%, 51.7% and 60% of the total city areas (Table 17.4). So, the city followed an increase of 40% from 1990 to 2020. According to the historical statistics, the massive infrastructural development within the city resulted in an increasing pattern of urban development areas and the construction of a bridge over the Buriganga River accelerated the urban sprawl to the south and northwest. After 1990, Dhaka expanded further to the Buriganga River and the Turag River to the north and south, separately (Roy et al. 2019). Figure 17.4 shows a comparative exploration of LULC from 1990 to 2020, presenting the spatial encroachment of its urban areas.

On the contrary, Dhaka city experienced the most dramatic change in the green space category during this period. In 2020, it was only 32%, whereas it covered almost 73% of land in 1990. The green space areas, including forests, shrubs, artificial forests, home gardens and farming land, covered about 21,983.6 ha, 18,206.2 ha, 12,581.8 ha and 9704.3 ha in 1990, 2000, 2010 and 2020 consisting of 73.0%, 60.5%, 41.8% and 32.2% of the city area (Table 17.4). From 1990 to 2020, the amount of green space has significantly decreased and been replaced by urban areas. It has been found that around 12,279.24 ha of green spaces disappeared between 1990 and 2020 because of changes in the natural landscape in urban areas. The north and north-western parts of the city lost green space at a higher rate compared to the other parts of the city. A substantial decrease in green space areas occurred from 2000 to 2010.

Open spaces (fellow land, bare land and landfill areas) contained 418.3 ha, 482.0 ha, 921.9 ha and 891.5 ha in 1990, 2000, 2010 and 2020, consisting of 1.4%, 1.6%, 3.1% and 3.0% of the city area (Table 17.4). The amount of open spaces was higher in recent decades than in the previous by getting almost double. The increasing open spaces considered in this study were mostly landfill sites prepared for residential projects which were constantly converting into urban areas (Figure). Consequently, water bodies (rivers, canals, ponds and artificial lakes) comprised about 1550.1 ha, 886.1 ha, 1018.6 ha and 1447.8 ha in the years 1990, 2000, 2010 and 2020 consisting of 5.2%, 2.9%, 3.4%, and 4.8% of the city area (Table 17.4). This has revealed a moderate dropping in water bodies from the year 1990 to 2000. As land became scarce for urban growth, wetlands (water bodies, ponds and canals) turn into the target of urban expansion at this time. During this period, water bodies primarily transformed into urban built-up and green space resulting in 663.93 ha loss. This decrease compared to the 1990s total water bodies was the highest (2.3%) among the studied year. After 2000 the pattern had changed upward with an increase up to

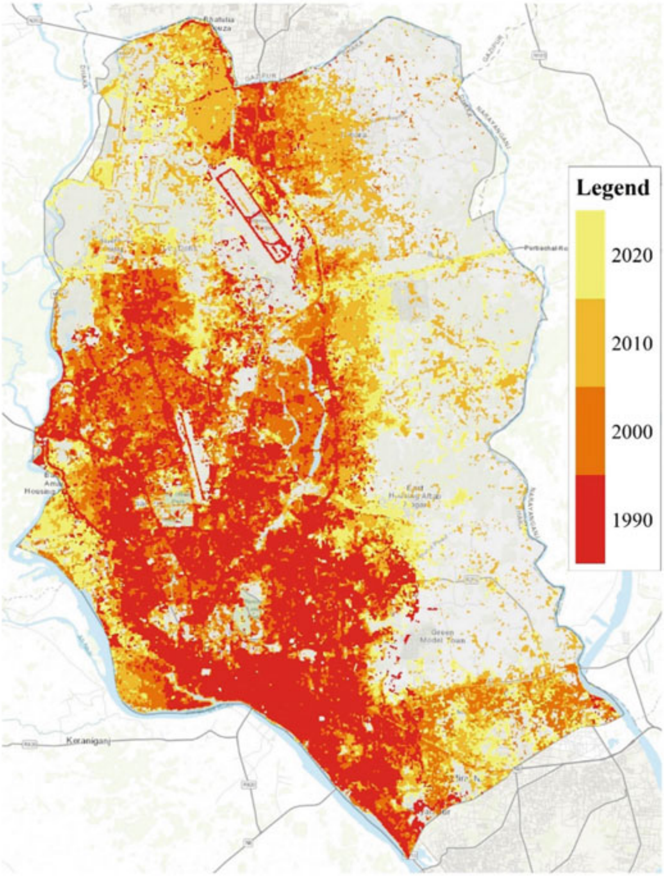


Fig. 17.3 Urban growth pattern from 1990 to 2020 prepared using urban land cover class extracted in Dhaka city

Table 17.4 Attribution of LULC classes retrieved in the study

	1990		2000		2010		2020	
Class	Area (ha)	Area (%)	Area (ha)	Area (%)	Area (ha)	Area (%)	Area (ha)	Area (%)
Green space	21,983.6	73.0	18,206.2	60.5	12,581.8	41.8	9704.3	32.2
Urban area	6144.8	20.4	10,522.5	35.0	15,574.5	51.7	18,053.2	60.0
Water bodies	1550.1	5.2	886.1	2.9	1018.6	3.4	1447.8	4.8
Open space	418.3	1.4	482.0	1.6	921.9	3.1	891.5	3.0

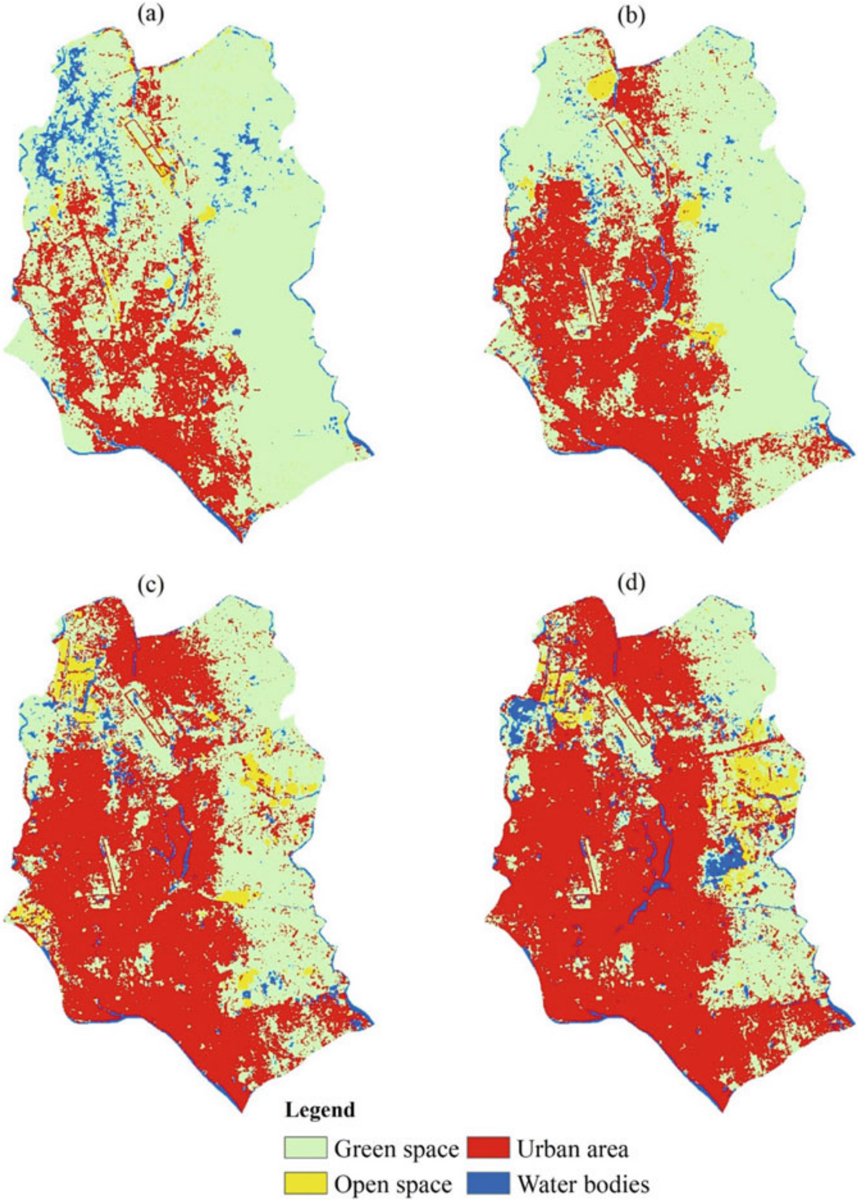


Fig. 17.4 LULC classifications of the study area where **a**, **b**, **c** and **d** represent 1990, 2000, 2010 and 2020, respectively

561.7 ha. The increase in water bodies has been largely attributed to the dredging of Hatirjheel Lake and the increase in fish farming on the outskirts of Dhaka (Islam et al. 2004).

From the analysis, urban area and green space showed an inverse proportional trend throughout the period (Fig. 17.5). Another noticeable fact is that an observable portion of 2.3% of water bodies decreased because of the encroachments of urban areas in the long run following a common convergence pattern (water bodies > green space > open space > urban area). Green space was the main land use type in 1990, followed by urban area, water bodies and open space, and the course of urban growth was northward. Land use patterns have changed exaggeratedly from 1990, when urban space replaced the majority of the green space, open space and water bodies. The earlier development projects had been undertaken informally by the public sector, and the areas had been used for the former development mainly free from inundation and previously used for agriculture; Gulshan, Banani, Dhanmondi and Uttara Model Town are examples of these development projects (Chowdhury 2003). Historic maps and literature suggest that after the independence the depressions and water bodies within the city had been lost quickly and the urban growth was largely attributed to housing, commercial, educational and business purposes (Siddiqui et al. 2000). Urban development has surely increased in greater Dhaka, especially through the process of suburban development, resulting in a reduction in green space and water bodies. Between 1990 and 2000, the city had been extended further to the north, northwest and west. The patterns of LULC change revealed that Dhaka started to expand in all directions, mainly at the expense of green space and water bodies (Fig. 17.4). After the provision of a new master plan in 1995 and the development of infrastructure, the rate of urban invasion of other land uses increased significantly (Siddiqui et al. 2000). During the studied period, the city became a business hub for the real-estate companies to build new apartments for the growing middle-income and upper-income population. Urban development was mostly observed along the existing main roads, in the north and northwest directions (Fig. 17.3). There were new settlements on the urban peripheries in wetlands and floodplains following the accelerated growth since 2005 (Ahmed et al. 2012).

Driving Forces Urbanisation in the City

The factors that cause urban growth are significant for the analysis of urbanisation. It is also necessary to understand the consequences or the impacts of urban growth for achieving sustainable urban development. To identify the major factors that influence urban growth scenarios in Dhaka city factor analysis (geodetector) and questionnaire survey have been done.

The main factors that influence the spatial locations of the study area are divided into two categories: natural and anthropogenic (Fig. 17.6). According to Table 17.5, drainage system, inundation land type and soil type were found to be highly influential natural factors. Anthropogenic factors such as distance from core areas and railways

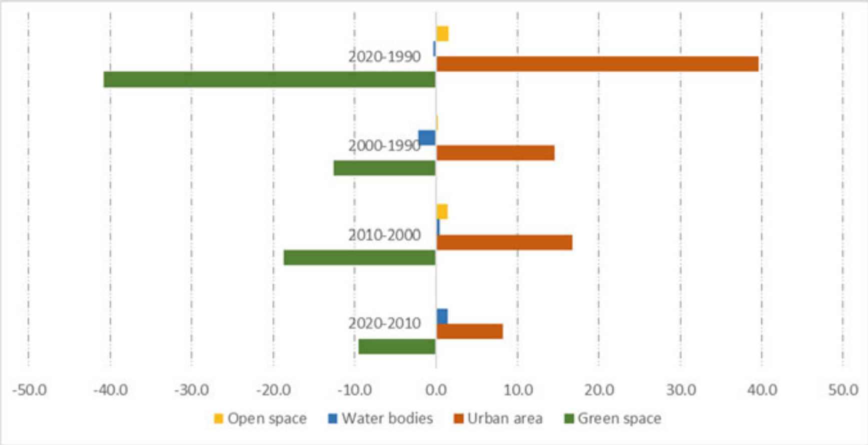


Fig. 17.5 Temporal change percentages of LULC classes

also worked as major determinants of spatial urban growth (Table 17.5). Primarily, new developments occur close to core areas considering drainage and inundation scenarios. Afterwards, low lands get converted into landfill sites for further urban development.

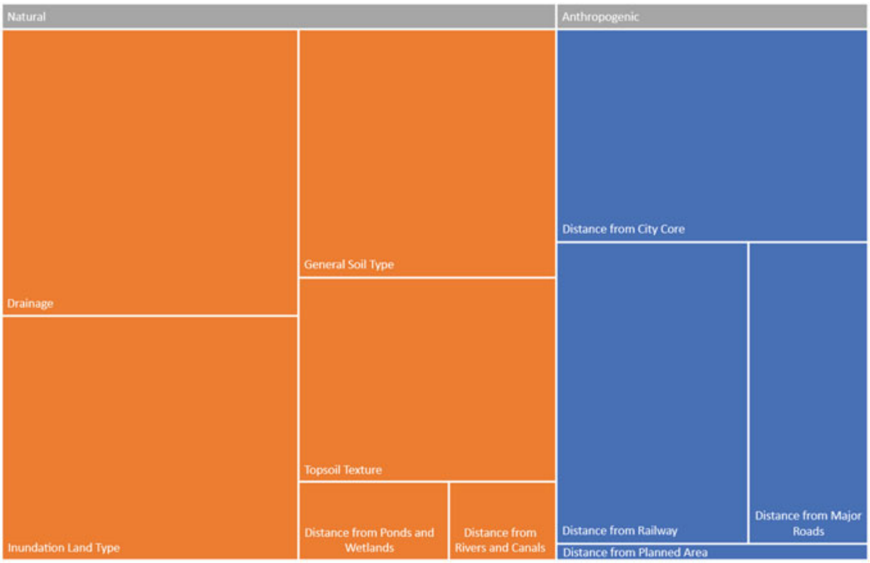


Fig. 17.6 Spatial determinants of urban growth in the area

Table 17.5 *q*-statistic results of spatial factor analysis

Groups	Variables	*q*-statistic	*p*-value
Anthropogenic	Distance from planned area	0.01	< 0.001
	Distance from city core	0.16	< 0.001
	Distance from railway	0.14	< 0.001
	Distance from major roads	0.09	< 0.001
Natural	Inundation land type	0.18	< 0.001
	Topsoil texture	0.13	< 0.001
	General soil type	0.15	< 0.001
	Drainage	0.21	< 0.001
	Distance from ponds and wetlands	0.03	< 0.001
	Distance from rivers and canals	0.02	< 0.001

Several driving forces have been identified in the study that promotes urban growth such as economic opportunities, increasing population, transportation facilities, factories and industries and educational and health institutions (Fig. 17.7). Consequently, the increasing trend of urban population from both migration and internal birth causes uncontrolled urban growth that strains the city's capacity to offer better services such as transportation, sanitation, energy, educational, medical services and physical security. More and more people come to the city from the rural areas for economic opportunities and better living, but unfortunately, the city has already been overpopulated and has crossed its carrying capacity, which has led to the development of unplanned suburbs, especially the slums has increased since 1990. By the year 2016, the city had grown to cover a total area of 304.17 km^2, and its population had reached 8,749,468 (RAJUK 2016). Dhaka is undergoing a chaotic and unplanned transformation, which is being driven by the influx of people from surrounding areas, as shown by the city's pattern of spatial expansion (Islam et al. 2010). These informal communities are located close to embankments, open drains and sewer lines, dumping sites for solid garbage and railway tracks, all of which contribute to an exceedingly unhygienic environment (Islam 1999). The rapid urban expansion in Dhaka has led to widespread environmental degradation. Natural vegetation and biodiversity have been demonstrated to suffer as a result of urban expansion made possible by landfill disposal (Alphan 2003; Dewidar 2002). Since the majority of recent construction in Dhaka has occurred on landfill sites, the city's exposure to earthquake-related risks has also increased (Maksud Kamal and Midorikawa 2004). Moreover, most of the rural people pushed to migrate in Dhaka city because their life and livelihood severely affected by both anthropogenic, e.g. unemployment, political persecution, social conflicts and natural disasters, e.g. cyclone, drought, floods, salinity, etc.

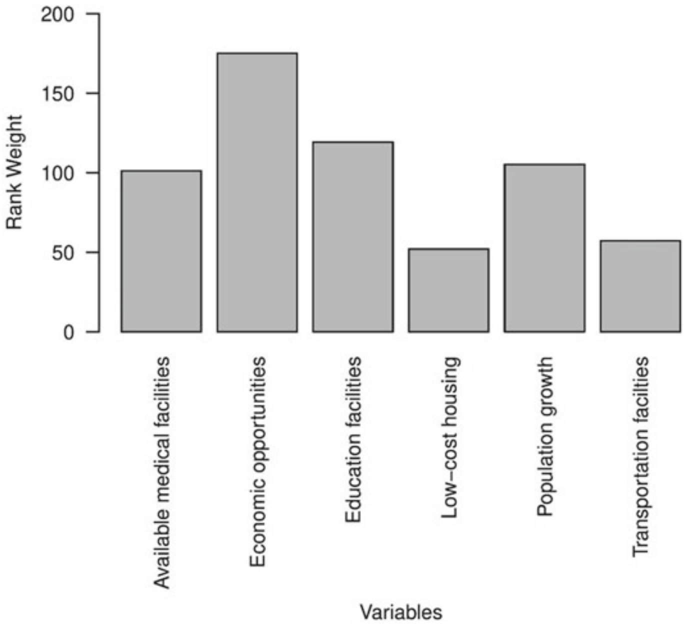


Fig. 17.7 Rank of different driving factors of urban growth according to people's perception

Impact on the Environment and Health

The impact of urban growth can have both positive and negative consequences. Economic benefits and better living conditions could be the positive impacts of urban growth. However, in Dhaka city, the negative impacts override the positive impacts because urban development in Dhaka is often uncontrolled or uncoordinated. Rapid and unplanned urbanisation is frequently associated with the degradation of the environment, infrastructure and human health. Due to uncontrolled urbanisation, environmental degradation has been appearing very unexpectedly and causing many problems, including deteriorating water quality (Srinivasan et al. 2013), excessive air pollution (Mahmood 2011), noise and waste disposal (Hokao et al. 2012), negative effects on human health (Moore et al. 2003b; Vlahov and Galea 2002; Zhu et al. 2011), traffic congestion (Rahman et al. 2020) and hazard risk (Rahman et al. 2015).

There are four impacts of urbanisation that were most pronounced by the respondents in this study, such as air pollution, hazard risk, traffic congestion and water pollution, where each respondent could answer more than one (Table 17.6).

The frequency was then computed based on the total answers given by the respondents. It was determined that one of the major impacts was air pollution, followed by hazard risk (fire hazard/road accidents), traffic congestion and water pollution. Air pollution due to the high degree of vehicle concentration, waste burning, indoor fuel burns and industrial fumes get more severe in the city (Mahmood 2011). Increasing

Table 17.6 Negative consequences of urban growth from people's perceptions

Impacts	Responses
Traffic congestion	153
Hazard risk	154
Air pollution	163
Water pollution	151

vehicles, such as private cars, bikes and public buses to meet the demand for transportation in the city also causes traffic congestion. Generally, private cars carry fewer people considering the spaces they occupy and public transport (bus, human holler) increases without following urban transport policies such as proper fitness of vehicles, education and medical fitness of the drivers and traffic lane disciplines (DTCA 2015; Rahman et al. 2020). These situations make the road unsafe and increase the rate of accidents. Fire incidents have also been considered under the hazard risks which is a concerning issue in densely urbanised residential areas with narrow roads (Rahman et al. 2015). Another major threat to the lives of city inhabitants is water pollution by the rapid spreading of water-borne diseases, amplifying contagion into an epidemic (Bashar and Fung 2020). Given the increasing extent and severity of urbanisation, the urban environment and health impacts depicted in the figure require significant attention.

Conclusion

From the above discussion, it is evident that Dhaka city has been witnessing rapid urban expansion. Four major land covers have been analysed to extract changing spatial patterns from 1990 to 2020. There has been substantial urban occupancy of other land cover classes, particularly in the periphery. Most of the green spaces have been converted to urban areas throughout the study period, following waterbodies and open spaces. Several reasons factored for these conversions of land. Major driving forces are anthropogenic, such as economic opportunities, education and medical facilities, which worked as pull factors for rural–urban migration, resulting in urban population growth. To meet the demands of the growing population, the city expanded its periphery. This spatial expansion also depends on several determining factors for urban built-up preferences. Natural determinants, such as drainage systems, inundated lands, suitable soil types and textures for building infrastructures; artificial determinants, such as distance from the city core, roads and railways worked together in shaping the spatial locations of the city expansion. All major determinants of urban growth trends and patterns along with the increasing need for infrastructural facilities such as residences, schools and medical centres lead to an uncontrolled expansion of the city. Therefore, the city is experiencing degradation in environmental quality as well as increasing health issues among its dwellers. To transform Dhaka into a sustainable city, these determinants should be regulated or controlled. During this investigation, there were some limitations faced by the authors such as partially available data layers compiled from multiple sources, which caused uncertainty and small sample data acquired in the questionnaire due to the lack of resources. Apart from the limitations, this chapter tried to establish a perspective for developing controlled and smart cities by focusing on their spatio-temporal drivers. It will help policymakers to focus on the most influential causes behind new developments and plan sustainably.

Acknowledgements Authors would like to thank the Center for Environmental and Geographic Information Services (CEGIS) for continuous support throughout the project completion period. We are also thankful to all the data sources.

References

Afrose S, Riyadh AM, Haque A (2019) Cores of Dhaka city: area delimitation and comparison of their characteristics. Asia-Pac J Reg Sci 3(2):521–560. https://doi.org/10.1007/s41685-019-00112-z

Aguilar AG, Ward P, Smith C (2003) Globalization, regional development, and mega-city expansion in Latin America: analyzing Mexico City's peri-urban hinterland. https://doi.org/10.1016/S0264-2751(02)00092-6

Ahmed F, Bibi MH, Monsur MH, Ishiga H (2005) Present environment and historic changes from the record of lake sediments, Dhaka City, Bangladesh. Environ Geol 48(1):25–36

Ahmed SJ, Bramley G, Dewan AM (2012) Exploratory growth analysis of a megacity through different spatial metrics: a case study on Dhaka, Bangladesh (1960–2005). J Urban Reg Inf Syst Assoc 24(1)

Ahmed B, Kamruzzaman M, Zhu X, Rahman MS, Choi K (2013) Simulating land cover changes and their impacts on land surface temperature in Dhaka, Bangladesh. Remote Sens 5(11):5969–5998

Ahmed SJ, Bramley G, Verburg PH (2014) Key driving factors influencing urban growth: spatial-statistical modelling with CLUE-s. In: Dewan A, Corner R (eds) Dhaka megacity: geospatial perspectives on urbanisation, environment and health. Springer, Dordrecht, pp 123–145. https://doi.org/10.1007/978-94-007-6735-5_7

Alphan H (2003) Land-use change and urbanization of Adana, Turkey. Land Degrad Dev 14(6):575–586. https://doi.org/10.1002/ldr.581

Angel S, Parent J, Civco DL, Blei A, Potere D (2011) The dimensions of global urban expansion: estimates and projections for all countries, 2000–2050. Prog Plan 75(2):53–107

Arai K (2020) Maximum likelihood classification based on classified result of boundary mixed pixels for high spatial resolution of satellite images. Int J Adv Comput Sci Appl 11(9). https://doi.org/10.14569/IJACSA.2020.0110904

Asgarian A, Amiri BJ, Sakieh Y (2015) Assessing the effect of green cover spatial patterns on urban land surface temperature using landscape metrics approach. Urban Ecosyst 18(1):209–222

Aydi A, Zairi M, Dhia HB (2013) Minimization of environmental risk of landfill site using fuzzy logic, analytical hierarchy process, and weighted linear combination methodology in a geographic information system environment. Environ Earth Sci 68(5):1375–1389. https://doi.org/10.1007/s12665-012-1836-3

Barnsley MJ, Barr SL (1996) Inferring urban land use from satellite sensor images using kernel-based spatial reclassification. Photogramm Eng Remote Sens 62(8):949–958

Bashar T, Fung IWH (2020) Water pollution in a densely populated megapolis, Dhaka. Water 12(8):2124. https://doi.org/10.3390/w12082124

BBS (2015) Changing patterns of urbanization in Bangladesh: an analysis of census data. Bangladesh Bureau of Statistics (BBS), Statistics and Informatics Division (SID), Ministry of Planning, Government of The People's Republic of Bangladesh, p 85

Bhatta B (2010) Remote sensing, GIS, and urban analysis. In: Analysis of urban growth and sprawl from remote sensing data. Springer, Berlin, pp 49–63

Black D, Henderson V (1999) A theory of urban growth. J Polit Econ 107(2):252–284

Brown S, Versace VL, Laurenson L, Ierodiaconou D, Fawcett J, Salzman S (2012) Assessment of spatiotemporal varying relationships between rainfall, land cover and surface water area using geographically weighted regression. Environ Model Assess 17(3):241–254

Byomkesh T, Nakagoshi N, Dewan AM (2012) Urbanization and green space dynamics in Greater Dhaka, Bangladesh. Landscape Ecol Eng 8(1):45–58

Ceccarelli T, Bajocco S, Perini L, Salvati L (2013) Urbanisation and land take of high quality agricultural soils—exploring long-term land use changes and land capability in Northern Italy. Int J Environ Res 8:181–192

Chakraborty T, Lee X (2019) A simplified urban-extent algorithm to characterize surface urban heat islands on a global scale and examine vegetation control on their spatiotemporal variability. Int J Appl Earth Obs Geoinf 74:269–280. https://doi.org/10.1016/j.jag.2018.09.015

Chavez PS Jr (1989). Radiometric calibration of Landsat thematic mapper multispectral images. ISPRS J Photogramm Remote Sens 55:1285–1294

Chen X, Bai J, Li X, Luo G, Li J, Li BL (2013) Changes in land use/land cover and ecosystem services in Central Asia during 1990–2009. Curr Opin Environ Sustain 5(1):116–127

Chen M, Zhang H, Liu W, Zhang W (2014) The global pattern of urbanization and economic growth: evidence from the last three decades. PLoS ONE 9(8):e103799

Chowdhury I (2003) The role of RAJUK in planned urban development. World Habitat Day, pp 88–91

Cui J, Zhu M, Liang Y, Qin G, Li J, Liu Y (2022) Land use/land cover change and their driving factors in the Yellow River basin of Shandong province based on Google Earth Engine from 2000 to 2020. ISPRS Int J Geo Inf 11(3):163. https://doi.org/10.3390/ijgi11030163

Deng JS, Wang K, Hong Y, Qi JG (2009) Spatio-temporal dynamics and evolution of land use change and landscape pattern in response to rapid urbanization. Landsc Urban Plan 92(3–4):187–198

Dewan AM, Yamaguchi Y (2009) Land use and land cover change in Greater Dhaka, Bangladesh: using remote sensing to promote sustainable urbanization. Appl Geogr 29(3):390–401

Dewan AM, Kabir MH, Nahar K, Rahman MZ (2012) Urbanisation and environmental degradation in Dhaka Metropolitan Area of Bangladesh. Int J Environ Sustain Dev 11(2):118–147

Dewidar KhM (2002) Landfill detection in Hurghada, North Red Sea, Egypt, using thematic mapper images. Int J Remote Sens 23(5):939–948. https://doi.org/10.1080/01431160110070645

DTCA (2015) The project on the revision and updating of the strategic transport plan for Dhaka (RSTP) urban transport policy

Fang S, Gertner GZ, Sun Z, Anderson AA (2005) The impact of interactions in spatial simulation of the dynamics of urban sprawl. Landsc Urban Plan 73(4):294–306

Florczyk A, Melchiorri M, Corbane C, Schiavina M, Maffenini M, Pesaresi M et al (2019) Description of the GHS urban centre database 2015. Public Release 1:1–75

Fu B-J, Zhang Q-J, Chen L-D, Zhao W-W, Gulinck H, Liu G-B et al (2006) Temporal change in land use and its relationship to slope degree and soil type in a small catchment on the Loess Plateau of China. CATENA 65(1):41–48

Gong P, Liang S, Carlton EJ, Jiang Q, Wu J, Wang L, Remais JV (2012) Urbanisation and health in China. Lancet 379(9818):843–852

Grimm NB, Faeth SH, Golubiewski NE, Redman CL, Wu J, Bai X, Briggs JM (2008) Global change and the ecology of cities. Science 319(5864):756–760

Gurjar BR, Lelieveld J (2005) New directions: megacities and global change. Atmos Environ 39(2):391–393

Hassan M, Southworth J (2017) Analyzing land cover change and urban growth trajectories of the mega-urban region of Dhaka using remotely sensed data and an ensemble classifier. Sustainability 10(2):10. https://doi.org/10.3390/su10010010

Helal uz Zaman AKM, Tariqul Alam KMd, Islam J (2010) Urbanization in Bangladesh: present status and policy implications. ASA Univ Rev 4

Hemphill L, McGreal S, Berry J (2002) An aggregated weighting system for evaluating sustainable urban regeneration. J Prop Res 19(4):353–373. https://doi.org/10.1080/09599910210155491

Hokao K, Phonekeo V, Srivanit M (2012) Assessing the impact of urbanization on urban thermal environment: a case study of Bangkok Metropolitan. Int J Appl 2(7)

Holdgate MW (1993) The sustainable use of tropical coastal resources—a key conservation issue. Ambio 22(7):481–482

Ishtiaque A, Mahmud MS, Rafi MH (2014) Encroachment of canals of Dhaka city, Bangladesh: an investigative approach. GeoScape 8(2):48–64. https://doi.org/10.2478/geosc-2014-0006

Islam N (1999) Urbanisation, migration and development in Bangladesh: recent trends and emerging issues

Islam N (2013) Overview of urbanization in Bangladesh. Urban dialogue, habitat for humanity Bangladesh, Dhaka, 1

Islam MS, Chowdhury MTH, Rahman MM et al (2004) Urban and peri-urban aquaculture as an immediate source of food fish: Perspectives of Dhaka City, Bangladesh. Urban Ecosyst 7, 341–359. https://doi.org/10.1007/s11252-005-6834-8

Islam MS, Rahman MR, Shahabuddin A, Ahmed R (2010) Changes in wetlands in Dhaka city: trends and physico-environmental consequences. J Life Earth Sci 5:37–42. https://doi.org/10.3329/jles.v5i0.7348

Jat MK, Garg PK, Khare D (2008) Monitoring and modelling of urban sprawl using remote sensing and GIS techniques. Int J Appl Earth Obs Geoinf 10(1):26–43

Jensen JR, Im J (2007) Remote sensing change detection in urban environments. In: Geo-spatial technologies in urban environments. Springer, Berlin, pp 7–31

Karthik, Shivakumar BR (2021) Land cover mapping capability of chaincluster, K-means, and ISODATA techniques—a case study. In: Kalya S, Kulkarni M, Shivaprakasha KS (eds) Advances in VLSI, signal processing, power electronics, IoT, communication and embedded systems, vol 752. Springer, Singapore, pp 273–288. https://doi.org/10.1007/978-981-16-0443-0_23

Khatun MA, Rashid MB, Hygen HO (2016) Climate of Bangladesh (No. 08/2016). Bangladesh Meteorological Department, Bangladesh

Kim Y, Newman G, Güneralp B (2020) A review of driving factors, scenarios, and topics in urban land change models. Land 9(8):246. https://doi.org/10.3390/land9080246

Kraas F (2003) Megacities as global risk areas. Petermanns Geogr Mitt 147(4):6–15

Lambin EF, Meyfroidt P (2011) Global land use change, economic globalization, and the looming land scarcity. Proc Natl Acad Sci 108(9):3465–3472

Liu Y, Phinn SR (2003) Modelling urban development with cellular automata incorporating fuzzy-set approaches. Comput Environ Urban Syst 27(6):637–658

Liu Y, Yue W, Fan P (2011) Spatial determinants of urban land conversion in large Chinese cities: a case of Hangzhou. Environ Plann B Plann Des 38(4):706–725

Liu C, Li W, Zhu G, Zhou H, Yan H, Xue P (2020) Land use/land cover changes and their driving factors in the Northeastern Tibetan plateau based on geographical detectors and Google Earth Engine: a case study in Gannan prefecture. Remote Sens 12(19):3139. https://doi.org/10.3390/rs12193139

Lutz W, Sanderson W, Scherbov S (2001) The end of world population growth. Nature 412(6846):543–545

Mahmood S (2011) Air pollution kills 15,000 Bangladeshis each year: the role of public administration and governments integrity. J Public Adm Policy Res 3:129–140

Maksud Kamal ASM, Midorikawa S (2004) GIS-based geomorphological mapping using remote sensing data and supplementary geoinformation. Int J Appl Earth Obs Geoinf 6(2):111–125. https://doi.org/10.1016/j.jag.2004.08.003

Mandal RB (2000) Urban geography: a textbook. Concept Publishing Co., New Delhi
Moore M, Gould P, Keary BS (2003a) Global urbanization and impact on health. Int J Hyg Environ Health 206(4–5):269–278
Moore M, Gould P, Keary BS (2003b) Global urbanization and impact on health. Int J Hyg Environ Health 206(4):269–278. https://doi.org/10.1078/1438-4639-00223
Murtaza MG (2012) A glossary of terms of urban, rural and regional planning. Centre for Urban Studies
Mushore TD, Odindi J, Dube T, Matongera TN, Mutanga O (2017) Remote sensing applications in monitoring urban growth impacts on in-and-out door thermal conditions: a review. Remote Sens Appl Soc Environ 8:83–93. https://doi.org/10.1016/j.rsase.2017.08.001
Naikoo MW, Rihan M, Ishtiaque M, Shahfahad (2020) Analyses of land use land cover (LULC) change and built-up expansion in the suburb of a metropolitan city: spatio-temporal analysis of Delhi NCR using Landsat datasets. J Urban Manag 9(3):347–359. https://doi.org/10.1016/j.jum.2020.05.004
N'Cir C-EB, Cleuziou G, Essoussi N (2015) Overview of overlapping partitional clustering methods. In: Celebi ME (ed) Partitional clustering algorithms. Springer International Publishing, Cham, pp 245–275. https://doi.org/10.1007/978-3-319-09259-1_8
Opršal Z, Kladivo P, Machar I (2016) The role of selected biophysical factors in long-term land-use change of cultural landscape. Appl Ecol Environ Res 14(2):23–40
Panday PK (2017) Scale and magnitude of urbanization in Bangladesh. In: Reforming urban governance in Bangladesh. Springer International Publishing, Cham, pp 23–37. https://doi.org/10.1007/978-3-319-49598-9_3
Paola JD, Schowengerdt RA (1995) A detailed comparison of backpropagation neural network and maximum-likelihood classifiers for urban land use classification. IEEE Trans Geosci Remote Sens 33(4):981–996. https://doi.org/10.1109/36.406684
Pax-Lenney M, Woodcock CE, Macomber SA, Gopal S, Song C (2001) Forest mapping with a generalized classifier and Landsat TM data. Remote Sens Environ 77(3):241–250. https://doi.org/10.1016/S0034-4257(01)00208-5
Rahman N, Ansary MA, Islam I (2015) GIS based mapping of vulnerability to earthquake and fire hazard in Dhaka city, Bangladesh. Int J Disaster Risk Reduction 13:291–300. https://doi.org/10.1016/j.ijdrr.2015.07.003
Rahman MA, Yunsheng L, Sultana N (2017) Analysis and prediction of rainfall trends over Bangladesh using Mann-Kendall, Spearman's rho tests and ARIMA model. Meteorol Atmos Phys 129(4):409–424. https://doi.org/10.1007/s00703-016-0479-4
Rahman MM, Jahan J, Zhou Y (2020) Alleviating traffic congestion by the strategy of modal shift from private cars to public transports: a case of Dhaka city, Bangladesh. In: Carmichael T, Yang Z (eds) Proceedings of the 2018 conference of the Computational Social Science Society of the Americas. Springer International Publishing, Cham, pp 101–115. https://doi.org/10.1007/978-3-030-35902-7_7
RAJUK (2016) Dhaka structure plan report 2016–2035. https://www.academia.edu/31508051/_Draft_Dhaka_Structure_Plan_Report_2016_2035_Full_Volume_. Accessed 1 July 2022
Ramachandra T, Aithal BH, Sanna DD (2012) Insights to urban dynamics through landscape spatial pattern analysis. Int J Appl Earth Obs Geoinf 18:329–343
Ramachandra TV, Bharath AH, Sowmyashree MV (2015) Monitoring urbanization and its implications in a mega city from space: spatiotemporal patterns and its indicators. J Environ Manage 148:67–81. https://doi.org/10.1016/j.jenvman.2014.02.015
Rana M, Parves M (2011) Urbanization and sustainability: challenges and strategies for sustainable urban development in Bangladesh. Environ Dev Sustain 13(1):237–256
Rawat JS, Kumar M (2015) Monitoring land use/cover change using remote sensing and GIS techniques: a case study of Hawalbagh block, district Almora, Uttarakhand, India. Egypt J Remote Sens Space Sci 18(1):77–84. https://doi.org/10.1016/j.ejrs.2015.02.002
Rimal B, Zhang L, Stork N, Sloan S, Rijal S (2018) Urban expansion occurred at the expense of agricultural lands in the Tarai region of Nepal from 1989 to 2016. Sustainability 10(5):1341

Roy S, Sowgat T, Mondal J (2019) City profile: Dhaka, Bangladesh. Environ Urban ASIA 10(2):216–232. https://doi.org/10.1177/0975425319859126
Roy S, Sowgat T, Islam SMT, Anjum N (2021) Sustainability challenges for sprawling Dhaka. Environ Urbanization ASIA 12(1_suppl):S59–S84. https://doi.org/10.1177/0975425321997995
Rwanga SS, Ndambuki JM (2017) Accuracy assessment of land use/land cover classification using remote sensing and GIS. Int J Geosci 08(04):611–622. https://doi.org/10.4236/ijg.2017.84033
Salvati L, Morelli VG, Rontos K, Sabbi A (2013) Latent exurban development: city expansion along the rural-to-urban gradient in growing and declining regions of Southern Europe. Urban Geogr 34(3):376–394. https://doi.org/10.1080/02723638.2013.778675
Schneider A, Woodcock CE (2008) Compact, dispersed, fragmented, extensive? A comparison of urban growth in twenty-five global cities using remotely sensed data, pattern metrics and census information. Urban Stud 45(3):659–692. https://doi.org/10.1177/0042098007087340
Schneider A, Friedl MA, Potere D (2009) A new map of global urban extent from MODIS satellite data. Environ Res Lett 4(4):044003
Schneider A, Mertes CM, Tatem A, Tan B, Sulla-Menashe D, Graves S et al (2015) A new urban landscape in East–Southeast Asia, 2000–2010. Environ Res Lett 10(3):034002
Serneels S, Linderman M, Lambin E (2007) A multilevel analysis of the impact of land use on interannual land-cover change in East Africa. Ecosystems 10(3):402–418
Serra P, Pons X, Saurí D (2008) Land-cover and land-use change in a Mediterranean landscape: a spatial analysis of driving forces integrating biophysical and human factors. Appl Geogr 28(3):189–209
Seto KC, Fragkias M, Güneralp B, Reilly MK (2011) A meta-analysis of global urban land expansion. PLoS ONE 6(8):e23777
Seto KC, Güneralp B, Hutyra LR (2012) Global forecasts of urban expansion to 2030 and direct impacts on biodiversity and carbon pools. Proc Natl Acad Sci 109(40):16083–16088
Siddiqui K, Ahmed J, Awal A, Ahmed MdS (2000) Overcoming the governance crisis in Dhaka city, 1st edn. The University Press Limited (UPL)
Srinivasan V, Seto KC, Emerson R, Gorelick SM (2013) The impact of urbanization on water vulnerability: a coupled human–environment system approach for Chennai, India. Global Environ Change 23(1):229–239. https://doi.org/10.1016/j.gloenvcha.2012.10.002
Sun Y, Zhao S, Qu W (2015) Quantifying spatiotemporal patterns of urban expansion in three capital cities in Northeast China over the past three decades using satellite data sets. Environ Earth Sci 73(11):7221–7235. https://doi.org/10.1007/s12665-014-3901-6
Sun Z, Yu S, Guo H, Wang C, Zhang Z, Xu R (2021) Assessing 40 years of spatial dynamics and patterns in megacities along the Belt and Road region using satellite imagery. Int J Digit Earth 14(1):71–87. https://doi.org/10.1080/17538947.2020.1747560
Tan KC, Lim HS, MatJafri MZ, Abdullah K (2010) Landsat data to evaluate urban expansion and determine land use/land cover changes in Penang Island, Malaysia. Environ Earth Sci 60(7):1509–1521. https://doi.org/10.1007/s12665-009-0286-z
Thapa RB, Murayama Y (2010) Drivers of urban growth in the Kathmandu valley, Nepal: examining the efficacy of the analytic hierarchy process. Appl Geogr 30(1):70–83
Trotter L, Dewan A, Robinson T, Trotter L, Dewan A, Robinson T (2017) Effects of rapid urbanisation on the urban thermal environment between 1990 and 2011 in Dhaka Megacity, Bangladesh. AIMS Environ Sci 4(1):145–167. https://doi.org/10.3934/environsci.2017.1.145
UN-Habitat (2021) Global environment for cities-GEO for cities: towards green and just cities
United Nations (2012) World urbanization prospects, the 2011 revision (report). United Nations, New York. https://www.un.org/en/development/desa/publications/world-urbanization-prospects-the-2011-revision.html. Accessed 26 June 2022
United Nations (2018a) The sustainable development goals report 2018. United Nations, New York. https://www.un.org/sustainabledevelopment/progress-report. Accessed 30 June 2022
United Nations (2018b) The world's cities in 2018: data booklet. UN. https://digitallibrary.un.org/record/3799524. Accessed 26 May 2022
United Nations (2019) World urbanization prospects 2018: highlights

United Nations (2021) Global population growth and sustainable development. United Nations, New York. Accessed 30 June 2022

Vlahov D, Galea S (2002) Urbanization, urbanicity, and health. J Urban Health 79(1):S1–S12. https://doi.org/10.1093/jurban/79.suppl_1.S1

Wang J-F, Zhang T-L, Fu B-J (2016) A measure of spatial stratified heterogeneity. Ecol Ind 67:250–256. https://doi.org/10.1016/j.ecolind.2016.02.052

Weber H, Sciubba JD (2019) The effect of population growth on the environment: evidence from European regions. Eur J Popul 35(2):379–402. https://doi.org/10.1007/s10680-018-9486-0

Weiss J, Khan HA (eds) (2008) Poverty strategies in Asia: a growth plus approach. Dev Econ 46(1):103–105. https://doi.org/10.1111/j.1746-1049.2007.057_2.x

Weng Y-C (2007) Spatiotemporal changes of landscape pattern in response to urbanization. Landsc Urban Plan 81(4):341–353

Wolvers A, Tappe O, Salverda T, Schwarz T (2015) Introduction. In: Concepts of the global south-voices from around the world, p 23)

Xiao J, Shen Y, Ge J, Tateishi R, Tang C, Liang Y, Huang Z (2006) Evaluating urban expansion and land use change in Shijiazhuang, China, by using GIS and remote sensing. Landsc Urban Plan 75(1–2):69–80

Yadav V, Ghosh SK (2021) Assessment and prediction of urban growth for a mega-city using CA-Markov model. Geocarto Int 36(17):1960–1992. https://doi.org/10.1080/10106049.2019.1690054

Yang Q, Li X, Shi X (2008) Cellular automata for simulating land use changes based on support vector machines. Comput Geosci 34(6):592–602

Yao X, Wang Z, Wang H (2015) Impact of urbanization and land-use change on surface climate in middle and lower reaches of the Yangtze River, 1988–2008. Adv Meteorol

Yin J, Yin Z, Zhong H, Xu S, Hu X, Wang J, Wu J (2011) Monitoring urban expansion and land use/land cover changes of Shanghai metropolitan area during the transitional economy (1979–2009) in China. Environ Monit Assess 177(1):609–621. https://doi.org/10.1007/s10661-010-1660-8

Zhang Q, Seto KC (2011) Mapping urbanization dynamics at regional and global scales using multi-temporal DMSP/OLS nighttime light data. Remote Sens Environ 115(9):2320–2329. https://doi.org/10.1016/j.rse.2011.04.032

Zhu Y-G, Ioannidis JP, Li H, Jones KC, Martin FL (2011) Understanding and harnessing the health effects of rapid urbanization in China

Zitti M, Ferrara C, Perini L, Carlucci M, Salvati L (2015) Long-term urban growth and land use efficiency in Southern Europe: implications for sustainable land management. Sustainability 7(3):3359–3385

Part III
Climate Crisis, Urban Health and Waste Management

Chapter 18
Impacts of Climate Change on Precipitation and Temperature Climatology in Türkiye from Present to Future Perspective

Beyza Ustaoğlu, Katibe Aslı Tunçat, and Derya Evrim Koç

Abstract Türkiye is located in the Mediterranean Basin, one of the hotspot areas most affected by climate change. Extreme events in weather conditions in the last 10 years are one of the most obvious reflections of global warming. Variations in temperature and precipitation regimes directly affect agriculture, water resources, biodiversity, etc. Climate change is a serious threat, especially in countries such as Türkiye, with a dominant agricultural economy. For this purpose, in this study, (a) examples of extreme events in Türkiye will be given; (b) Türkiye's temperature and precipitation conditions in the period 1929–2020 will be determined by analysing 217 meteorological observation data; (c) areas in Türkiye where the Mediterranean climate is dominant or not, according to the Emberger Bioclimate Classification; (d) future temperature and precipitation conditions will be determined based on 19 bioclimate variables obtained from the WorldClim database for the future 2061-2080 CMIP 5 model and RCP 4.5 and 8.5 scenarios. The results obtained will be shared with public and non-governmental organizations in order to develop adaptation strategies at national, regional and local levels to prevent the serious damage of climate change to humans and the environment and ensure sustainable development in changing climate conditions.

Keywords Climate change · Precipitation · Temperature · Drought · Türkiye

B. Ustaoğlu (✉) · K. A. Tunçat · D. E. Koç
Sakarya University, Faculty of Humanities and Social Sciences, Department of Geography, 54050 Esentepe, Sakarya, Türkiye
e-mail: bustaoglu@sakarya.edu.tr

K. A. Tunçat
e-mail: aslituncatt@gmail.com

D. E. Koç
e-mail: dkilic@sakarya.edu.tr

U. Chatterjee et al. (eds.), *Urban Commons, Future Smart Cities and Sustainability*, Springer Geography, https://doi.org/10.1007/978-3-031-24767-5_18

Introduction

The 6th IPCC report clearly statesd that climate change today is mainly caused by human-induced factors as well as the natural variability of the climate. It is indicated that global warming caused by human activities increased by more than 1 °C between 2010 and 2019 compared to the 1850–1900 period. If we continue to produce fossil-based energy, climate projections indicate that we are rapidly moving towards a hotter and drier future worldwide, where there could be an increase of 4 °C (IPCC 2021).

Fossil fuel use, deforestation, changes in land use and the accumulation of greenhouse gases released into the atmosphere have been increased rapidly since the industrial revolution. This situation has caused the strengthening of the natural greenhouse effect, and an increase in the world's surface temperatures with the impact of urbanization. The severity and intensity of extreme events will determine the future impact and damage of the climate conditions. It is thought that the frequency of extreme events especially will cause severe damage. In this context, climate change is one of the biggest natural environmental problems of today. In the statistical studies on the climate, it has been determined that since the 1990s, there has been a tendency in Türkiye, increase of the daily minimum and maximum temperatures, decrease of snowy and frosty days and increase of the number of hot days and nights in some extreme values (Erlat and Türkeş 2012, 2013).

Model studies on climate change also predict that the global climate will likely change in many parts of the world. According to the statement made by the World Meteorological Organisation (WMO), 2016 was determined as the year with the highest global average temperatures (1880–2020). According to the increase rates in temperatures, 2016 is followed by 2019 and 2020, respectively (WMO 2020). The increase in the variability in the climate shows that, especially in the Mediterranean Basin and most of Türkiye, heavy precipitation, storms, severe floods, floods, mass movements, severe heat waves, droughts and forest fires will be encountered. This situation raises the possibility of a climate in Türkiye and its region in the future where the climate will be stronger, which tends to deviate more frequently from the long-term averages. According to our study to determine the areas where the Mediterranean climate is observed depending on the distribution of annual average temperature and total precipitation amounts for long years 1975–2020 in Türkiye, it is seen that the Mediterranean climate is effective in the regions outside the temperate, semi-terrestrial and terrestrial areas in the north and northeast of Türkiye (Baylan and Ustaoğlu 2020). This change, which has been experienced in the climate for many years, has also shown itself with extreme weather events and effects in recent years. 1024 extreme meteorological events occurred in Türkiye in 2021 (Turkish State Meteorological Service 2021) (Fig. 18.1).

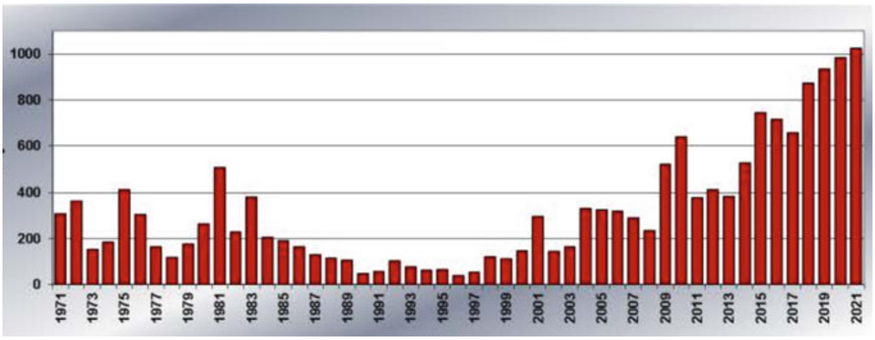


Fig. 18.1 Extreme meteorological events such as heavy rain, storm, tornados event, flood, floods and landslides, heat waves, drought and forest fire are experienced in Türkiye (1971–2021) (Turkish State Meteorological Service 2021)

Study Area

The Mediterranean Basin, including Türkiye, is among the regions most affected by climate change and its global effects (Baltaci and Arslan 2022) (Fig. 18.2).

We have with many natural environmental problems such as crop yield, food supply, food safety, forest fires and changes in land cover, especially the problem to be experienced in accessing clean water resources (Gorji et al. 2017). The most populated region in Türkiye in terms of population density is the Marmara Region, and the most populated province is Kocaeli (İzmit), which ranks second after İstanbul. One of the most critical needs of the population is the need for drinking and utility water. With the start of the water year in October 2020, drought continued until November, December and January and threat to the water requirement of 2021. It has been determined by a drone that the water level in the Yuvacık dam has decreased significantly in recent years and especially in 2020 (June and November) (Fig. 18.3).

According to our study to determine the effects of the change in climatic conditions in the Salda Lake Basin, which is considered an important biodiversity area in Türkiye and has a sensitive ecosystem, it has been determined that there has been a change in the lake surface area and lake water level in the last 48 years. It has been determined that there is a statistically increasing trend in annual average temperatures in the study area. The most critical factor in this change is the degradation of the lake's natural structure due to both the change in climatic conditions and the effect of anthropogenic processes. The lake surface, which had an area of 45.43 km^2 in 1972, decreased to 42.58 km^2 in 2019 (Fig. 18.4). Since Salda Lake is a closed basin, the lake's feeding sources are streams and underground water that show continuous and seasonal flow. According to the findings from field studies, dams and ponds have been built on the main streams feeding the lake in recent years. In addition, groundwater feeding the was used in agricultural activities. In Salda Lake, one of the sensitive lakes with national and international ecological value, located in the Mediterranean Basin, the effects of climate change have been observed in the last 20 years (Fig. 18.5).

Fig. 18.2 Location map of Türkiye

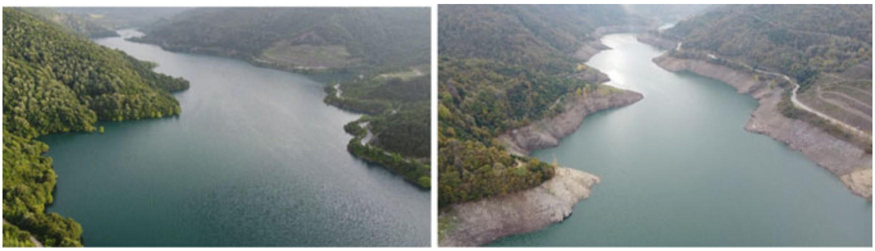


Fig. 18.3 Drone images of Yuvacık Dam in June and November 2020

For sustainable wetland management, adaptation process to climate change should be initiated by the decision-makers in Salda Lake.

With the effect of the global temperature increase, the temperature differences between rural and urban areas have increased due to industrialisation in many cities in Türkiye today (Aykır 2017). In the Marmara Region, where the population density is high in Türkiye, especially in İstanbul, Kocaeli and Sakarya, located on the Çatalca-Kocaeli Peninsula, the effect of the urban heat island has been determined statistically.

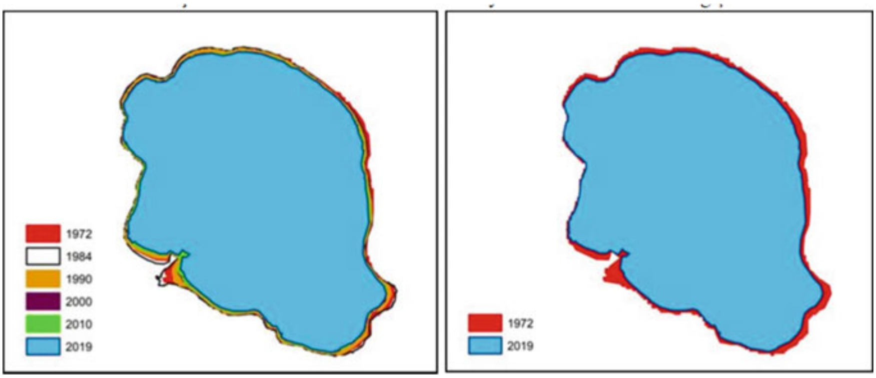


Fig. 18.4 Spatio-temporal change of Salda Lake between 1972 and 2019 (Arıtürk and Ustaoğlu 2020)

Fig. 18.5 Terraces of the Old Lake level containing huntite mineral located on Beyaz Adalar Beach in Salda Lake

Daily minimum temperatures have increased in cities. Especially in Sakarya, where agricultural production is intense, daily minimum temperatures tend to increase (Fig. 18.6) (Ustaoğlu 2018). This situation also affects the phenological periods and yield of crops with high economic value, such as quince, cherries, and grapes.

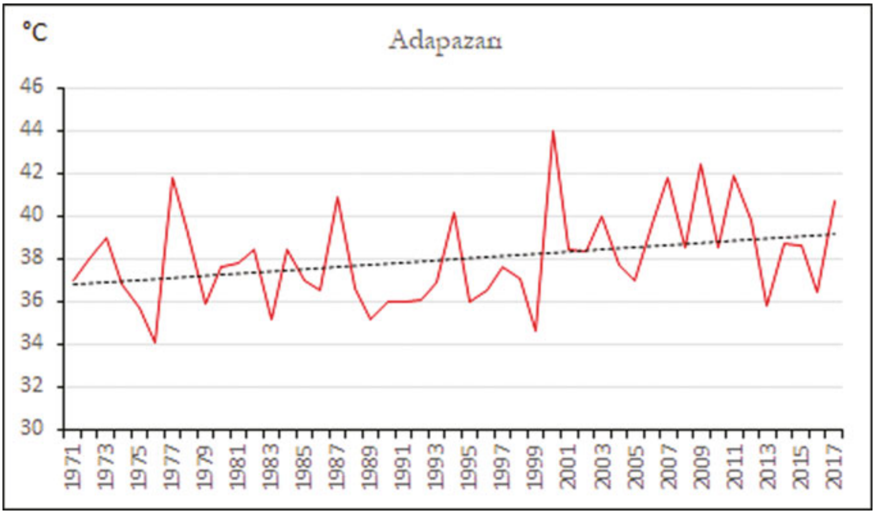


Fig. 18.6 Linear trend of the highest maximum temperatures in Adapazarı

Hazelnut (*Corylus avellena*), which has an important value in exports in Türkiye and ranks first in the world with a yield of 610,200 tons in the last 5 years average Turkish Statistical Institute data, is grown in optimum climatic conditions in the Black Sea Region. However, depending on the changing climatic conditions, there are fluctuations in its yield over the years, and this situation concerns many groups from production to the market, especially many producers who make their living from hazelnut farming. For this purpose temperature increases of up to 6 °C are predicted in the next 80 years depending on the climate projections according to the worst scenario, and it is predicted that the change in temperature conditions may cause the hazelnut planting areas to change horizontally and vertically. Depending on the rising temperature values, it may adversely affect hazelnut cultivation in the coastal zone between 0-250 meters. On the other hand, the cultivated areas will also change in the vertical direction and the areas above 1500 m, will become suitable lands (Ustaoğlu and Karaca 2014). The fact that the olive, which is a bioindicator species in the Mediterranean Region, could not fulfil its chilling requirement in the phenological period, especially due to increasing temperatures (Fig. 18.7), has caused a decrease in its yield recent years (Uzun and Ustaoğlu 2021).

Changes in climatic conditions from year to year in arid and semi-arid regions of developing countries greatly affect the yield and cause financial losses in societies whose economy is based on agriculture. When evaluating the impact of extreme climatic conditions on agricultural activities, it should not be perceived as only a decrease in yield. Because this situation brings together socio-economic phenomena such as economic crisis, food insecurity, hunger, and migration. According to the map in which the distribution of hunger is determined by the World Food Program

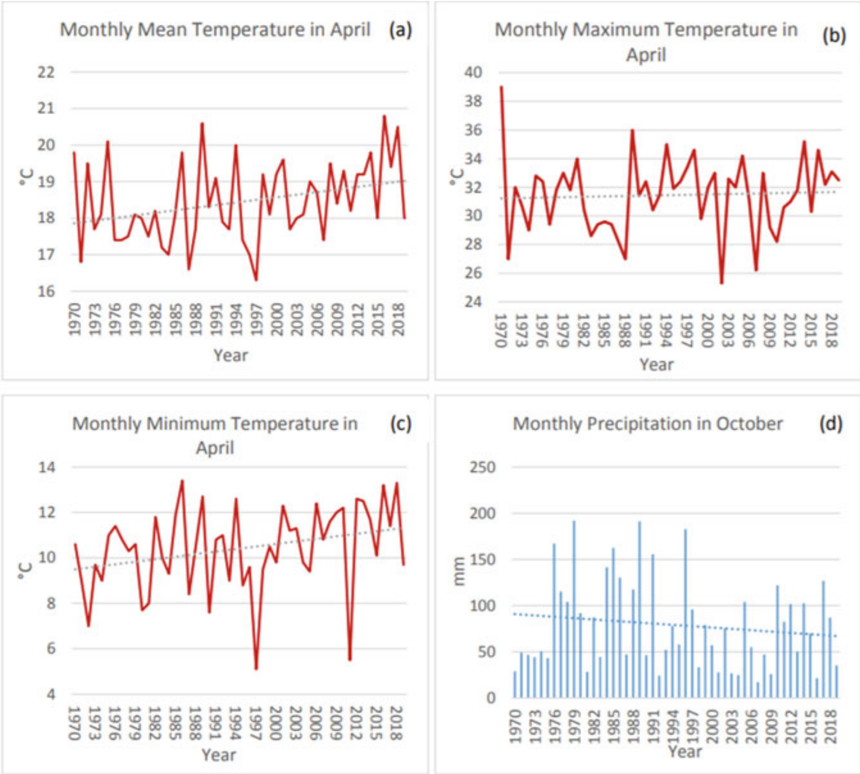


Fig. 18.7 Distribution of average, maximum and minimum temperatures and precipitation during the flowering period of olive in Hatay

(WFP), it is predicted that by 2030, 840 million people will face hunger due to climate change and the negative impact of the COVID-19 epidemic.

On the other hand, heat waves caused by climate change have been effective in Türkiye, especially in the countries located in the Mediterranean Basin in recent years, and have caused the loss of biodiversity (Ustaoğlu 2022) (Fig. 18.8).

Rationale of the Study

The purpose of this study is (a) to determine the present temperature and precipitation conditions in Türkiye (1929–2018), (b) to identify the stations that are arid and non-arid in Türkiye, (c) to predict of the temperature and precipitation conditions depending on the future climate scenarios within the scope of climate change (2061–2080), (d) to determine the arid areas that will be effective in Türkiye in the future.

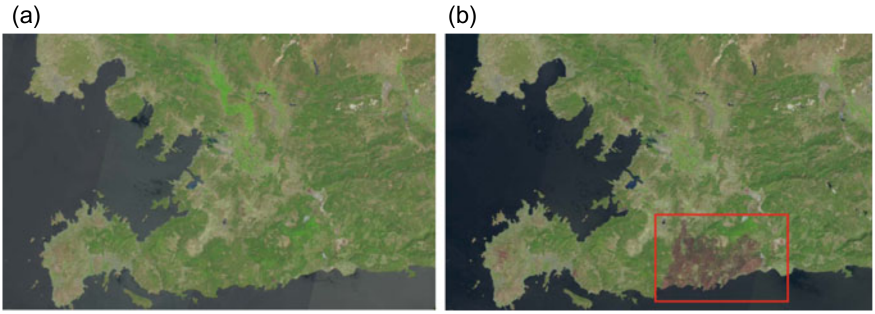


Fig. 18.8 **a** Landsat 8 OLI image of Bodrum and its surroundings in 26 July 2021. **b** Landsat 8 OLI image of Bodrum and its surroundings in 30 July 2021

Materials and Methods

In the study, firstly, Emberger Bioclimate Classification was applied to determine the climatic conditions of Türkiye. The areas where the Mediterranean climate is effective in Türkiye have been selected. Accordingly, humid, arid, continental and semi-continental areas in Türkiye were determined with equations. Especially in Türkiye, the stations with summer drought were determined with ombrothermic diagrams. Afterwards, the temperature and precipitation values of 217 meteorological stations in Türkiye were analysed, temperature and precipitation distribution maps were obtained. To determine the temperature, precipitation and drought condition of Türkiye in the future, climate projection maps created according to the CMIP5 model, WorldClim data, and RCP 4.5 and 8.5 scenarios were applied.

Determining I*, the Mediterranean Climatic Border*

Emberger developed the following equation for the purpose of determining the boundaries of the Mediterranean climate (Akman 2011).

$$I = 2P/(M + m)(M - m) \tag{18.1}$$

where

P the amount of precipitation on rainy days within a year
M The maximum average temperature of the hottest month
m The minimum average temperature of the coldest month.

As a result of the equation, a station that calculates $I < 10$ is understood to be within the boundaries of Mediterranean climate, and the monthly aridity index is understood to be between 1 and 10.

Determination of Seasonal Precipitation Regimes and Determination of Areas with Summer Precipitation > 200 mm and < 200 mm

Türkiye is located in the Mediterranean climate area, but regional and local climate characteristics occur as a result of dynamic and thermal modifications that occur depending on geographical factors (elevation, orography, continentality, etc.). The most distinctive feature of the Mediterranean climate is that the summer precipitation is below 200 mm and there is a distinct summer drought (Akman 2011). The average seasonal precipitation regimes of the 217 meteorological stations that make up the database for many years were checked, and the oceanic, continental or semi-continental conditions of the stations outside the summer season of the driest season were examined.

*Determining Continentality (*C*)*

The seasonal precipitations from the meteorological stations have been calculated in the scope of the study. According to this, in areas where the value of $S < 5$ and the lowest season for precipitation is not summer, Coutagne's precipitation equation is used. The precipitation is calculated according to the value obtained as a result of the total precipitation from the hottest 6 months of the year (April, May, June, July, August, September) being divided into the total rainfall from the coldest 6 months (October, November, December, January, February, March) of the year. As a result of the equation, the following values emerge (Daget 1977):

- $C > 1.75$ shows continental climate
- $1 \leq C \leq 1.75$ shows semi-continental climate
- $C < 1$ shows non-continental climate.

*Determining Aridity (*S*)*

In the Mediterranean climate, the summers are dry and hot, and the winters are warm and rainy. The most effective factor in determining the Mediterranean climate is the determination of summer drought (Kaymaz and İkiel 2007; Atalay 2013; Kurt 2014). Many criteria have been developed for the determination of the dry period. According to this, the hottest three months of the year are the driest. According to the researchers, the driest 3 months are June, July, August in the interior of the countries located in the Northern Hemisphere, and July, August and September for the countries located in the coastal regions in the Mediterranean climate. Emberger developed the following equation to detect the dry season in the Mediterranean climate (Akman 2011; Daget 1977).

Equation for determining the Emberger Aridity Index (Daget 1977):

$$S = \mathrm{PE}/M \tag{18.2}$$

where

S Aridity
PE Total precipitation for June–July–August (September) months
M Average maximum temperature for the hottest month.

According to the results of the equation, the S:

- $S < 5 =$ Mediterranean
- $S = 5 - 7 =$ Sub-Mediterranean
- $S > 7 =$ Non-Mediterranean.

Gaussen Method (Ombrothermic Diagram)

After dealing with climate problems for many years, Gaussen developed a new classification in 1955 to specify the distribution of vegetation units that he used to name biological climates. According to Gaussen, when the precipitation (P) in any month is equal to or less than twice the temperature in that month, that month is considered a dry month.

The dry season is formed by the succession of dry months. There are two curves in the ombrothermic (precipitation–temperature) diagram. One of these curves shows monthly average temperatures (°C), and the other shows monthly precipitation averages (mm). The precipitation curve begins with January in the Northern Hemisphere. In these graphs, the dry period starts where the precipitation curve cuts the temperature curve and passes under it and ends where the two curves intersect for the second time. Thus, the dry period and the duration of the dry period can be easily read on the graph very clearly (Akman 2011; Pina et al. 2016; Pesce et al. 2020; Loucif et al. 2020).

Spatial Analysis with Kriging Interpolation Method in Geographic Information Systems

Kriging is one of the statistical interpolation methods that is used more than other estimation methods and gives extremely accurate results, as well as allowing the calculation of the standard deviation of the estimation and minimum variance (Johnston et al. 2004; Yaprak and Arslan 2008; Ustaoğlu 2012; Kahraman and Ünsal 2014). The data network is quite large in the study area, the distance between this data is calculated with mathematical functions, and a continuous surface is created. The maps were analysed in ArcGIS 10.5 software; Annual Average Temperature Distribution Map in Türkiye (Fig. 18.9), Annual Average Precipitation Distribution Map in Türkiye (Fig. 18.10), Distribution of Areas with Summer Precipitation > 200 mm and < 200 mm (Fig. 18.11), Distribution of Continental and Semi-Continental Areas (Fig. 18.13), Distribution of Summer Drought and Continental-Semi-Continental Areas in Türkiye (Fig. 18.15).

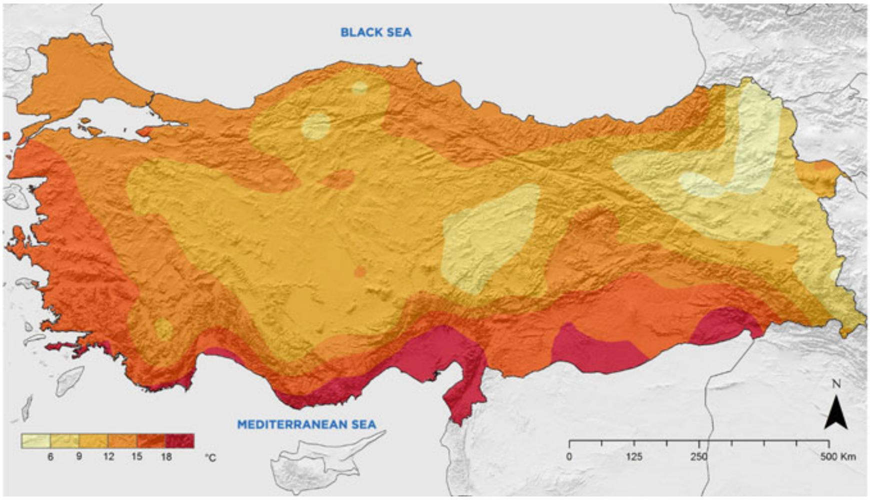


Fig. 18.9 Annual average temperature distribution map in Türkiye (1929–2018)

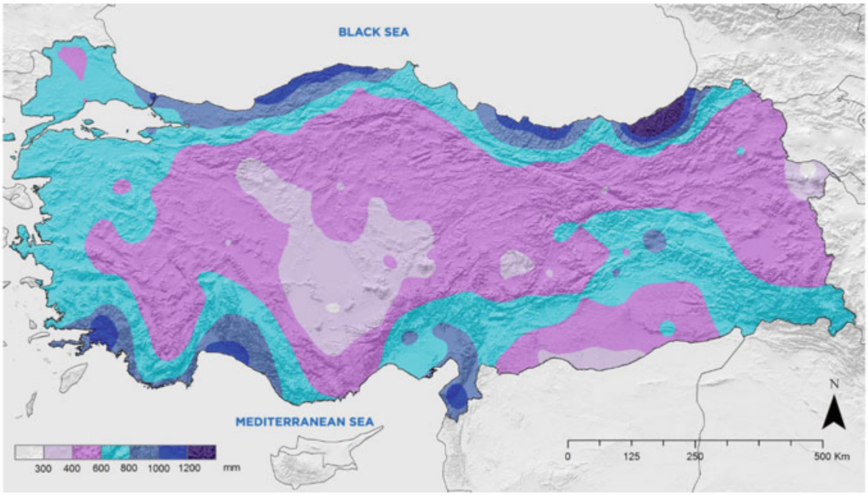


Fig. 18.10 Annual total precipitation distribution map in Türkiye (1929–2018)

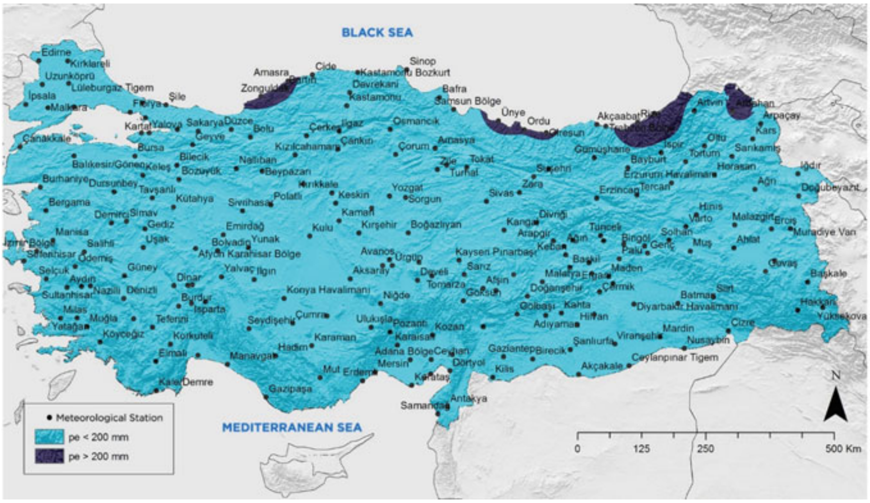


Fig. 18.11 Distribution of Summer Precipitation (June-July-August) with > 200 mm and < 200 mm in Türkiye

Results and Discussion

Temperature and Precipitation Conditions of Türkiye

Annual average temperature values in Türkiye decrease from south to north and from west to east, depending on altitude, geographical latitude and distance from the sea (Koçman 1993). When the annual average temperature values of the 217 meteorology stations used in the study are examined, it is seen that there are significant differences (Fig. 18.9). Temperature values are higher in all coastal regions of the country than inland areas surrounded by high mountain ranges.

Distribution of Precipitation in Türkiye

The most important factor in the distribution of precipitation in Türkiye is geographical factors. In particular, the extent of the mountains, the position of the slopes (aspect effect) against the frontal activities and the effect of the pressure regimes that change according to the seasons are among the most important geographical factors. When the annual average precipitation distribution map (Fig. 18.10) is examined, it is seen that the highest precipitation falls on the seafaced slopes of the mountain ranges in our northern and southern regions and on the coastal zone in front of these mountain. Decrease in temperature is also seen in precipitation towards the inner parts. This is due to the sea effect in the north, south and west of the country. At the same time, the humidity air masses affecting the coastal regions rise on the outer slopes of the Taurus Mountains and the North Anatolian mountains, causing a lot of precipitation to fall between the coastal belt and these mountains. As these air masses, which cause a lot of precipitation in the coastal zone, move inland, they contain less humidity, as they leave most of the humidity they carry in the coastal areas and are heated adiabatically as they cross the mountains. For this reason, precipitation in the interior regions is less than in the coastal regions (İkiel 2005).

Distribution of Areas with Summer Precipitation > 200 mm and < 200 mm

In the Mediterranean climate, summers are hot and dry, and winters are warm and rainy. The most effective factor in determining the Mediterranean climate is the determination of summer drought. For this reason, in addition to the calculation of the drought index (S), the seasonal distribution of precipitation during the year was examined and the areas with the least precipitation in summer were accepted as Mediterranean climate. Another criteria, summer precipitation not exceeding 200 mm, was also mapped (Fig. 18.11). Areas with a drought index of $S > 7$, the lowest precipitation seasonally in spring, and the summer precipitation totals above 200 mm were considered oceanic. As it can be understood from the ombrothermic diagrams, in the stations characterising the oceanic climate, it is rainy all year and there is no dry period. The most precipitation falls in these areas in the autumn season and the least in the spring season (Fig. 18.12).

*Distribution of Continentality (*C*)*

According to the result of the precipitation continentality equation, three stations were determined as continental and 13 stations as semi-continental out of 217 stations. In regions where continentality is evident, summer precipitation is generally higher than winter precipitation. These regions are located in the northeast of Türkiye. Semi-continental zones are located around the continental zone. In areas with continental climate, the total annual precipitation is between 500 and 561 mm, M value; 26.7–24.7, m value; It varies between − 16.5 and − 14.1 (Fig. 18.13). When the precipitation temperature diagram of some stations representing the continental climate is examined, it is seen that the precipitation is extremely low in the winter season, the precipitation increases especially in the spring and summer months, and the temperatures reach the highest level while the precipitation decreases again in September at the end of the summer season at the beginning of the autumn season drought is observed. In the areas with semi-continental climate, the annual precipitation total is 634–262 mm. When the precipitation-temperature

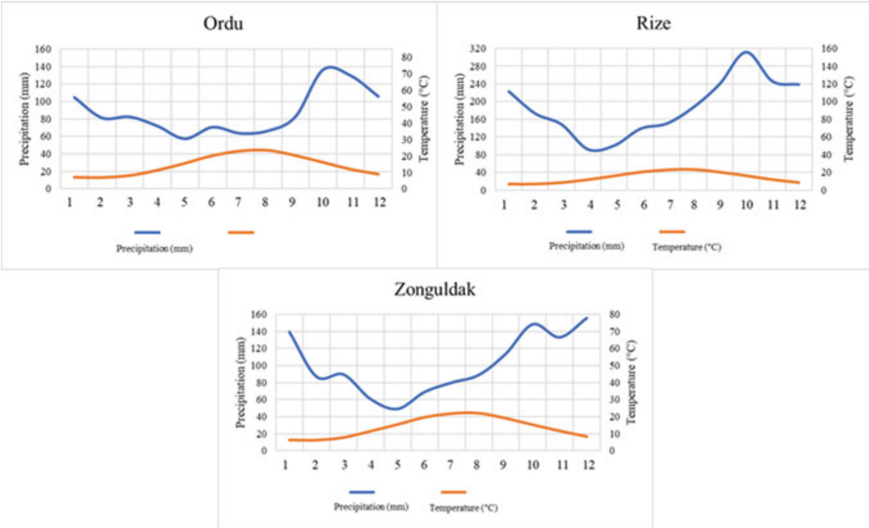


Fig. 18.12 Ombrothermic diagram of oceanic stations in Türkiye

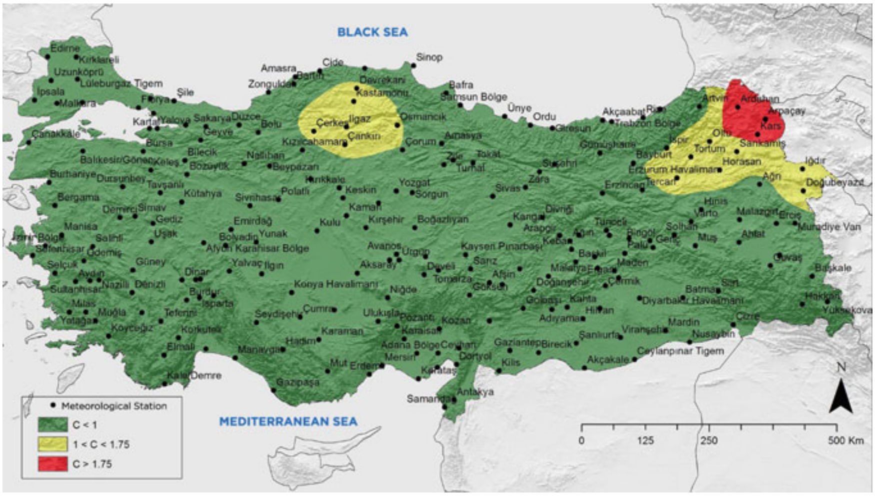


Fig. 18.13 Distribution of continental and semi-continental areas in Türkiye

diagram of some stations representing the semi-continental climate is examined, it is understood that it shows similarities with the stations representing the continental climate, but the dry period observed in the continental stations in September, including the end of August at the semi-continental stations, continues throughout September (Fig. 18.14). An insignificant summer drought is observed in these areas.

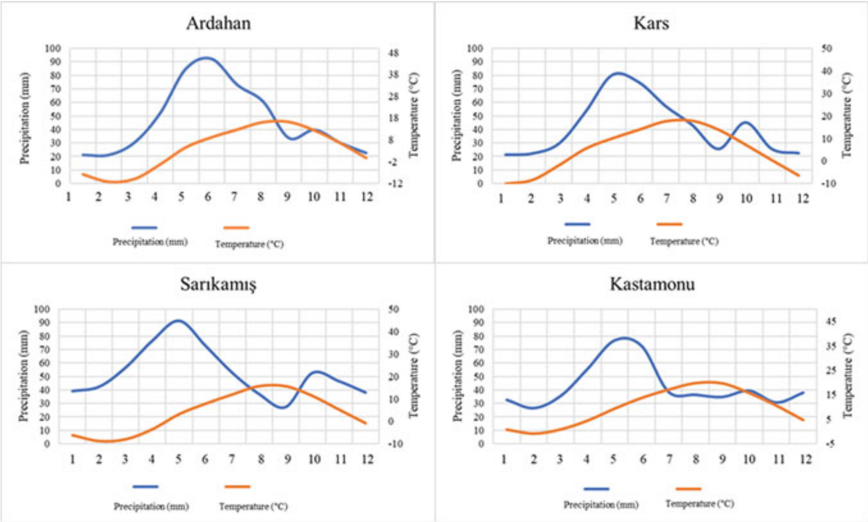


Fig. 18.14 Ombrothermic (precipitation–temperature) diagram of continental and semi-continental stations in Türkiye

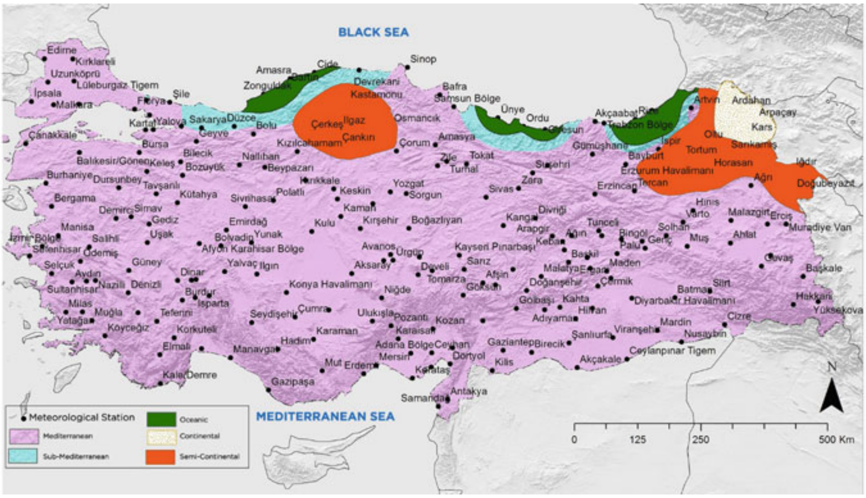


Fig. 18.15 Distribution of summer drought and continental/semi-continental areas in Türkiye according to the Emberger bioclimate classification

*Distribution of Drought Conditions of Selected Cities (*S*)*

Drought, which is the most important factor in determining the Mediterranean climate, was determined using Emberger's (S = PE/M) equation. As a result of the equation, the S value of three stations determined as continental from 217 meteorology stations is greater than 7, and the S value of 10 of 13 stations determined as semi-continental is less than 5, but these 16 stations do not have Mediterranean climate characteristics. Except for continental and semi-continental stations, the S value of 187 of 201 meteorology stations was less than 5, the S value of 5 stations was between 5 and 7, and the other 9 stations were greater than 7 (Fig. 18.15). According to the result of the equation, 187 stations with an S value less than 5 are Mediterranean (Fig. 18.17), 5 stations with an S value between 5 and 7 are Sub-Mediterranean, and 9 stations with an S value greater than 7 are not Mediterranean (Oceanic). Stations with an S value greater than 7 are located on the Black Sea coastline in northern Türkiye, these regions are characterised by not having a dry season and summer precipitation was above 200 mm (Fig. 18.16). In the eastern part of this region, tea plants are grown in places where humid and mild climate conditions are suitable. Hazelnut (*Corylus avellana*) (Ustaoğlu and Karaca 2010, 2014), chestnut (*Castanea sativa*) and spruce (*Picea*) are common in the Black Sea region (Atalay 2015). In addition to the Oceanic climate, it is seen that the rainy Mediterranean climate is also effective on the Black Sea coastline.

Projected Changes in Temperature and Precipitation Climatology in Türkiye

The CMIP 5 model with RCP 4.5 and RCP 8.5 emission scenario outputs is used for future (2061–2080) in order to possible changes in temperature and precipitation climatology, and drought conditions. According to model results of future projections, there will be an increase in average temperature (BIO1) and a decrease in total precipitation (BIO 12) over almost all parts of Türkiye (Fig. 18.18). More arid conditions are likely to occur in most of Türkiye (Figs. 18.19, 18.20 and 18.21).

According to the obtained results, an increase in the annual average temperatures (BIO1) is predicted in the Black Sea coasts where the oceanic climate is observed in Türkiye. A decrease is predicted in the annual total precipitation (BIO 12) (Fig. 18.18) and precipitation of the driest three months (BIO 17) (Fig. 18.23). This situation shows that partially dry conditions can be observed in the areas where oceanic climate prevails on the northern coasts of Türkiye, particularly in summer (Figs. 18.18, 18.19, 18.23 and 18.24). According to the change detection map, in the areas of Türkiye defined as Central and Eastern Anatolia, projected changes in minimum temperature of coldest months (Fig. 18.22) and projected changes in maximum temperature of warmest months (Fig. 18.24) are increase, and annual total precipitation (Fig. 18.18) is projected to decrease according to the both RCP scenarios. Anomaly values are

Fig. 18.16 Ombrothermic (precipitation–temperature) diagram of Sub-Mediterranean stations in Türkiye

about 6–7 °C in RCP 4.5 and 8–9 °C in RCP 8.5 scenario. This situation shows that the existing drought in terrestrial and semi-continental areas will become more severe.

Türkiye is in the impact area of the Mediterranean Climate. Sub-Mediterranean climate is seen in the transition from Mediterranean climate to continental, semi-continental and oceanic climate regions. It is seen that the different temperature and precipitation characteristics (BIO1-BIO5-BIO6-BIO12-BIO17) included in the bioclimatic variables of the areas dominated by the Mediterranean climate will

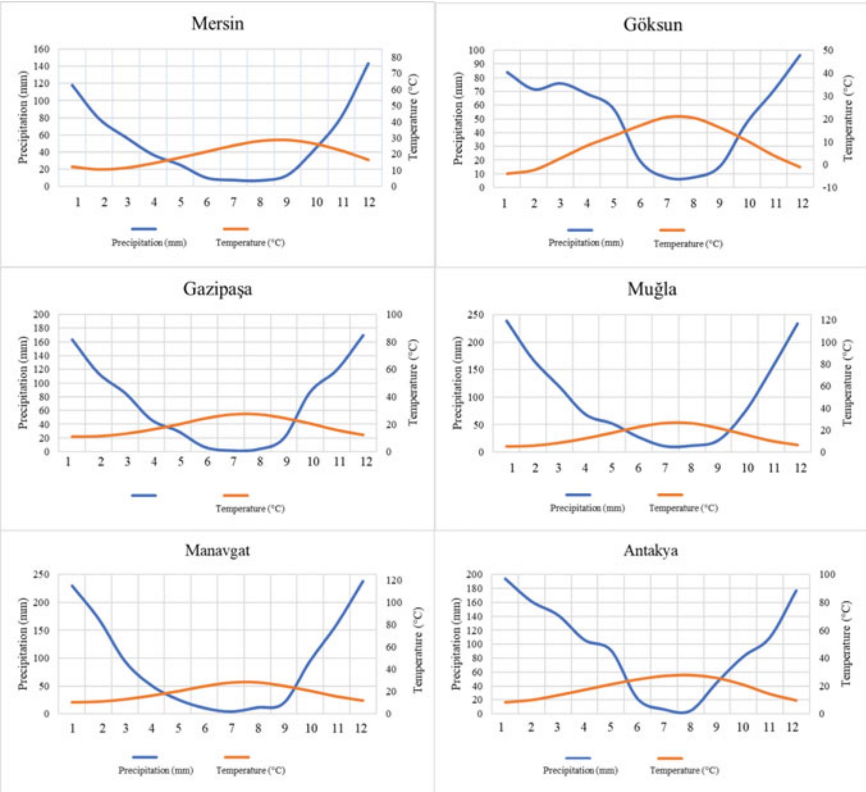


Fig. 18.17 Ombrothermic (precipitation–temperature) diagram of Mediterranean stations in Türkiye

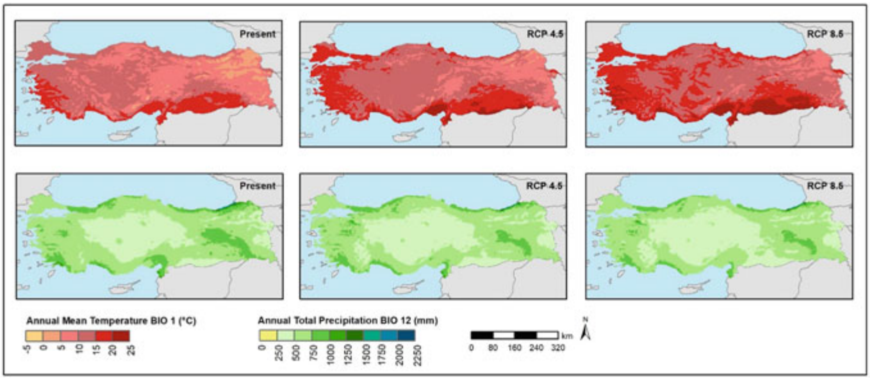


Fig. 18.18 Annual average temperature (°C) and annual total precipitation (mm) distribution for the period of present (1960–1990) and future (2061–2080) according to RCP 4.5 and RCP 8.5 in Türkiye

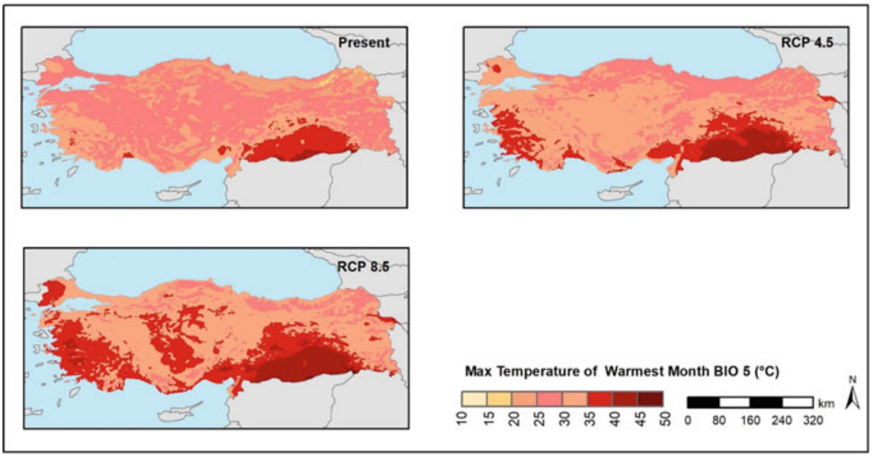


Fig. 18.19 Maximum temperature of warmest months distribution for the period of present (1960–1990) and future (2061–2080) according to RCP 4.5 and RCP 8.5 in Türkiye

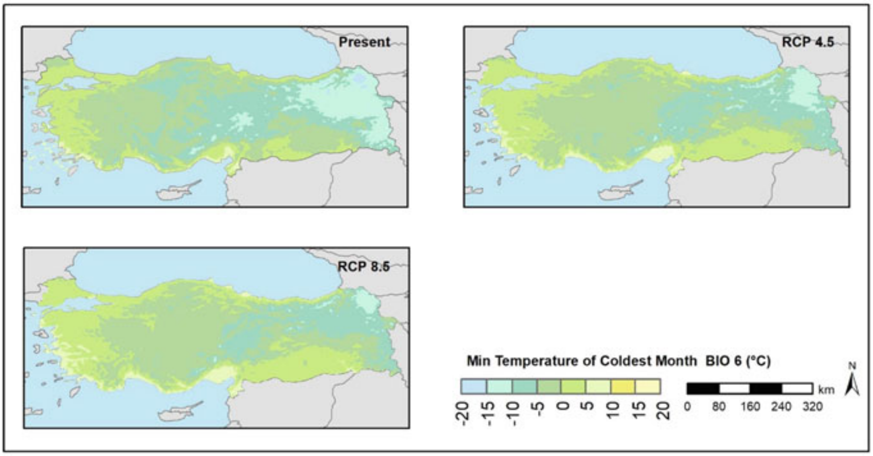


Fig. 18.20 Minimum temperature of coldest months distribution for the period of present (1960–1990) and future (2061–2080) according to RCP 4.5 and RCP 8.5 in Türkiye

change in the future. In general, increases in temperatures and decreases in precipitation will trigger drought and affect the duration and severity of drought (Figs. 18.18, 18.19, 18.20, 18.21, 18.22, 18.23 and 18.24). When other studies related to the study area were discussed, it was observed that similar results were obtained in different time and space scales in the Mediterranean Basin (Dabanlı et al. 2017; Demircan et al. 2017; Türkeş et al. 2020; Bağçacı et al. 2021). According to the results of the study examining possible future changes in mean air temperature, precipitation climatology and inter-year variability over the Mediterranean, the frequency and

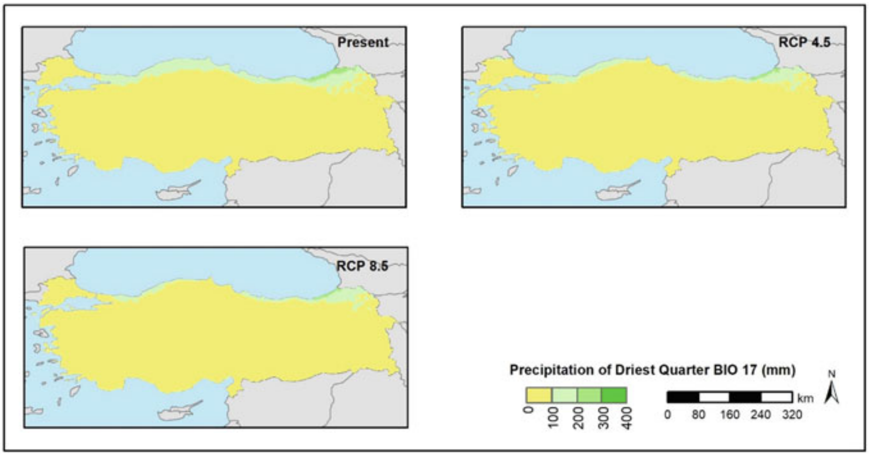


Fig. 18.21 Precipitation of the driest quarter distribution for the period of present (1960–1990) and future (2061–2080) according to RCP 4.5 and RCP 8.5 in Türkiye

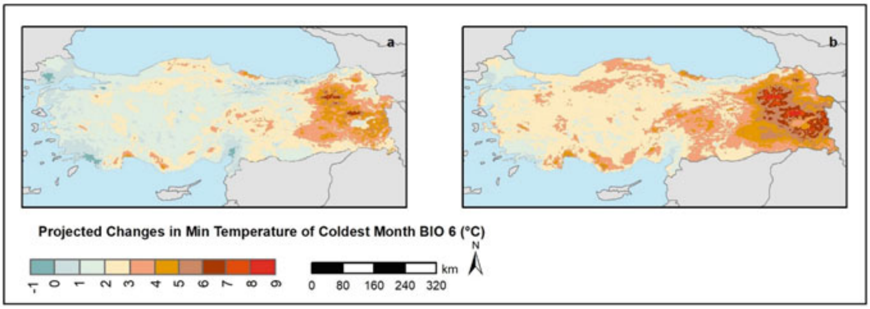


Fig. 18.22 Projected change detection map in minimum temperature of coldest month distribution for the period of present (1960–1990) and future (2061–2080) according to **a** RCP 4.5 and **b** RCP 8.5 in Türkiye

intensity of high temperatures and extreme precipitation events will likely increase in the future (Öztürk et al. 2015). Giorgi and Lionello (2008) examined climate change projections over the Mediterranean region, based on comprehensive global and regional climate change simulations. The results suggest that the Mediterranean may be a particularly vulnerable region to global change. Görgüner et al. (2017) examined temperature and precipitation changes in the Gediz Basin according to the RCP4.5 and RCP 8.5 scenarios. According to the trend analyses obtained, a decrease in annual average precipitation and an increase in annual temperatures are predicted. On the other hand, the changes in seasonal precipitation climatology, extreme weather conditions and drought conditions in Türkiye for the 2021–2050 period are evaluated according to the 1971–2000 reference period using regional climate model simulations. According to the results obtained, drier conditions are expected in Türkiye

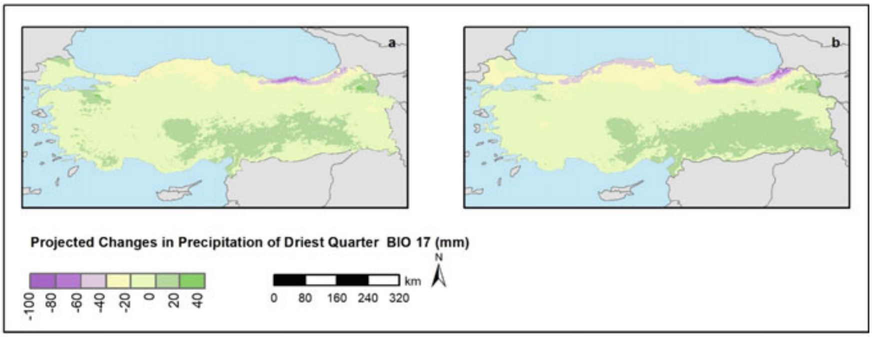


Fig. 18.23 Projected change detection map in precipitation of the driest quarter distribution for the period of present (1960–1990) and future (2061–2080) according to **a** RCP 4.5 and **b** RCP 8.5 in Türkiye

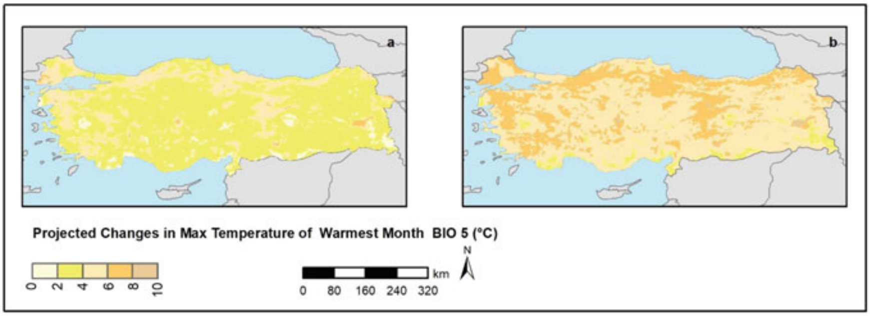


Fig. 18.24 Projected change detection map in maximum temperature of warmest months distribution for the period of present (1960–1990) and future (2061–2080) according to **a** RCP 4.5 and **b** RCP 8.5 in Türkiye

in the near future (Türkeş et al. 2020). Lionello and Scarascia (2018) analysed the recent (twentieth century) and future (twentieth century) climate in the Mediterranean region in relation to the annual average global surface temperature change. According to the results obtained, as the average global temperature increases in the twenty-first century, precipitation will decrease in the Mediterranean region, and warming will be more especially in summer. The decrease in precipitation will affect all seasons in the central and southern Mediterranean regions, and the maximum decrease in winter precipitation will be seen. For areas along the northern border of the Mediterranean region, the decrease will be greatest during the summer months, with no significant precipitation decrease during the winter months. Bucchignani et al. (2018) investigated the predicted changes in future climatic conditions for the Middle East-North Africa region in the twenty-first century. Climate projections have shown a significant warming of the entire area under consideration by the end of the twenty-first century, as well as a reduction in precipitation, which is particularly evident in the western part of the region. Zittis et al. (2022) conducted a study based on a revised analysis of recent observations and projections and a comprehensive review of the latest scientific literature on the causes and effects of regional climate change. Cos et al. (2022) compared CMIP5 and CMIP6 and projections of historical and future scenario simulations to measure the effects of changing climate in the Mediterranean region. The results showed strong and significant warming in the Mediterranean region during all seasons, populations and experiments in the twenty-first century.

Conclusion

Human-induced climate change has had significant impacts on the environment, human health and various segments of society, and these impacts are expected to continue. For this reason, in addition to taking measures, the society needs to be prepared for and adapt to some inevitable consequences of climate change. Adaptation strategies at national, regional and local levels are required in order to prevent the serious damage of climate change to humans and the environment and to ensure sustainable development in changing climatic conditions. Early warning systems are useful in informing long-time-scale forecasts in climate change impact assessment. The catastrophic effect of climate change can be eliminated by irrigation and determining appropriate planting dates. In order to adapt to climate change, product types that are resistant to very high and very low temperatures and drought should be developed or existing species can be improved. In order to reduce and prevent the effects of climate change, we must first reduce the use of fossil fuels. We should implement the principles of energy saving and energy efficiency in all sectors (agriculture, transportation, housing, industry) and turn to the use of renewable energy sources.

In conclusion, considering the future 2061–2080 projections, drought conditions are very likely to affect Türkiye, making it extremely vulnerable to climate change.

Acknowledgements This research has been supported by TUBITAK (The Scientific and Technological Research Council of Türkiye) 119Y041. We also thank the editor and reviewers for their valuable contributions.

References

Akman Y (2011) İklim ve Biyoiklim. Palme Yayıncılık, Ankara

Arıtürk SK, Ustaoğlu B (2020) Salda Gölü Havzası'nda İklim Koşullarındaki Değişikliğin Etkilerinin Belirlenmesi. Anadolu Kültürel Araştırmalar Dergisi 4(3):233–249

Atalay İ (2015) Türkiye vejetasyon coğrafyası. META Basım Matbaacılık, İzmir

Aykır D (2017) Türkiye'de Ekstrem Sıcaklık İndislerinin Eğilimlerinde Şehirleşmenin Etkisi. Türk Coğrafya Dergisi 35–45

Atalay İ (2013) Uygulamalı Klimatoloji. META Basım Matbaacılık Hizmetleri, İzmir

Baltaci H, Arslan H (2022) Seasonal and regional variability of wet and dry spell characteristics over Turkey. Atmos Res 270:106083. ISSN 0169-8095. https://doi.org/10.1016/j.atmosres.2022.106083

Baylan K, Ustaoğlu B (2020) Emberger Biyoiklim Sınıflandırmasına Göre Türkiye'de Akdeniz Biyoiklim Katlarının ve Alt Tiplerinin Dagılısı. Ulusal Çevre Bilimleri Arastırma Dergisi 3(3):158–174

Bağçacı SÇ, Yucel I, Duzenli E, Yilmaz MT (2021) Intercomparison of the expected change in the temperature and the precipitation retrieved from CMIP6 and CMIP5 climate projections: a Mediterranean hot spot case, Turkey. Atmos Res 256, Article 105576. https://doi.org/10.1016/j.atmosres.2021.105576

Bucchignani E, Mercogliano P, Panitz HJ, Montesarchio M (2018) Climate change projections for the Middle East-North Africa domain with COSMO-CLM at different spatial resolutions. Adv Clim Chang Res 9(1):66–80

Cos J, Doblas-Reyes F, Jury M, Marcos R, Bretonnière PA, Samsó M (2022) The Mediterranean climate change hotspot in the CMIP5 and CMIP6 projections. Earth Syst Dyn 13(1):321–340

Dabanlı İ, Mishra AK, Şen Z (2017) Long-term spatio-temporal drought variability in Turkey. J Hydrol 552:779–792. ISSN 0022-1694. https://doi.org/10.1016/j.jhydrol.2017.07.038

Daget P (1977) Le Bioclimat Mediterraneen: Caracteres Generaux. Modes De Caracterisation Vegetatio 34(1):1–20

Demircan M, Gürkan H, Eskioğlu O, Arabacı H, Coşkun M (2017) Climate change projections for Turkey: three models and two scenarios. Turk J Water Sci Manag 1(1):22–43. https://doi.org/10.31807/tjwsm.297183

Erlat E, Türkeş M (2012) Analysis of observed variability and trends in numbers of frost days in Turkey for the period 1950–2010. Int J Climatol 32:1889–1898

Erlat E, Türkeş M (2013) Observed changes and trends in numbers of summer and tropical days, and the 2010 hot summer in Turkey. Int J Climatol. https://doi.org/10.1002/joc.3556

Giorgi F, Lionello P (2008) Climate change projections for the Mediterranean region. Global Planet Change 63(2–3):90–104

Gorji T, Sertel E, Tanik A (2017) Monitoring soil salinity via remote sensing technology under data scarce conditions: a case study from Turkey. Ecol Indic 74:384–391. ISSN 1470-160X. https://doi.org/10.1016/j.ecolind.2016.11.043

Görgüner M, Ishida K, Kavvas ML (2017) Dynamically downscaled CMIP5 climate projections over a Mediterranean-climate watershed in western Turkey. In: World environmental and water resources congress 2017, pp 588–594

IPCC (2021). https://www.ipcc.ch/report/ar6/wg1/#outreach

İkiel C (2005) Rainfall regime regions in Turkey (a statistical climate study). In: International conference on forest ımpact on hydrological processes and soil erosion, Yundola

Johnston K, Ver Hoef JM, Krivoruchko K, Lucas N (2004) Using ArcGIS geostatistical analyst. ESRI Press, New York

Kahraman S, Ünsal Ö (2014) ArcGIS for Destop Spatial Analiz. Esri Bilgi Sistemleri Mühendislik ve Eğitim Ltd. Şti, Ankara

Kaymaz B, İkiel C (2007) Geyve'nin İklimi ve İklim Koşullarının Tarımsal Faaliyetlere Etkisi. Akademik İncelemeler Dergisi 2(2):209–229

Koçman A (1993) Türkiye İklimi. Ege Üniversitesi Yayınları (No 72)

Kurt L (2014) Resimli Türkiye Florası. Bölüm: Türkiye Biyoiklimi. In: Ekim T, Güner A (eds) Resimli Türkiye Florası. Cilt:1. Türkiye İş Bankası Yayınları

Lionello P, Scarascia L (2018) The relation between climate change in the Mediterranean region and global warming. Reg Environ Change 18(5):1481–1493

Loucif K, Neffar S, Menasria T, Maazi MC, Houhamdi M, Chenchouni H (2020) Physico-chemical and bacteriological quality assessment of surface water at Lake Tonga in Algeria. Environ Nanotechnol Monit Manag 13. https://doi.org/10.1016/j.enmm.2020.100284

Öztürk T, Ceber ZP, Türkeş M, Kurnaz ML (2015) Projections of climate change in the Mediterranean Basin by using downscaled global climate model outputs. Int J Climatol 35(14):4276–4292

Pesce GR, Fernandes MC, Mauromicale G (2020) Globe artichoke crop residues and their potential for bioethanol production by dilute acid hydrolysis. Biomass Bioenergy 134. https://doi.org/10.1016/j.biombioe.2020.105471

Pina JJP, Sisó S, Knapik DS, Espejo AD, Flexas J, Galmés J, Pelegrín EG (2016) Leaf morphological and physiological adaptations of a deciduous oak (*Quercus faginea* Lam.) to the Mediterranean climate: a comparison with a closely related temperate species (*Quercus robur* L.). Tree Physiol 36(3):287–299. https://doi.org/10.1093/treephys/tpv107

Türkeş M, Turp MT, An N, Ozturk T, Kurnaz ML (2020) Impacts of climate change on precipitation climatology and variability in Turkey. In: Water resources of Turkey. Springer, Cham, pp 467–491

Turkish State Meteorological Service (2021). https://mgm.gov.tr/iklim/iklim-raporlari.aspx

Ustaoğlu B (2012) Matlab Yazılımında Üretilen Grid Verilere Göre Kuzeydoğu Andadolu'da Yıllık Yağışın Mekansal Dağılışı. In: Sevindi C, Birinci S, Erhan K, Zaman M, Aykaç içinde A (eds) Atatürk Üniversitesi Edebiyat Fakültesi Coğrfaya Bölümü 1. Ulusal Coğrafya Sempozymu. Erzurum, s. 645–651

Ustaoğlu B (2018) Sakaryanın Fiziki, Beseri ve Iktisadi Cografya Özellikleri, Bölüm adı: (Sakarya'nın İklim Özellikleri). SAÜ yayın no: 190, Editör:Cercis Ikiel, Basım sayısı:1

Ustaoğlu B (2022) Land cover change analysis between 1990 and 2021 using Landsat images and object-based classification: a case study in Bodrum peninsula, Aegean region, Turkey. Ege Coğrafya Dergisi 31(1):101–119. https://doi.org/10.51800/ecd.1087278

Ustaoglu B, Karaca M (2010) The possible effects of temperature conditions on hazelnut farming in Turkey. İTÜ Dergisi/d 9(3):153–161

Ustaoğlu B, Karaca M (2014) The effects of climate change on spatiotemporal changes of hazelnut *Corylus avellana* cultivation areas in the Black Sea region Turkey. Appl Ecol Environ Res (AEER) 12(2):309–324

Uzun A, Ustaoğlu B (2021) The effects of atmospheric oscillations on crop (olive, grape and cotton) yield in the eastern part of the Mediterranean region, Turkey. Int J Environ Geoinf (IJEGEO) 9(1):147–161. https://doi.org/10.30897/ijegeo.1010181

WMO (2020) https://public.wmo.int/en/media/press-release/2020-was-one-of-three-warmest-years-record

Yaprak S, Arslan E (2008) Kriging yöntemi ve geoit yüksekliklerinin enterpolasyonu. Jeodezi, Jeoinformasyon ve Arazi Yönetimi Dergisi 98:36–42

Zittis G, Almazroui M, Alpert P, Ciais P, Cramer W, Dahdal Y et al (2022) Climate change and weather extremes in the Eastern Mediterranean and Middle East. Rev Geophys e2021RG000762

Chapter 19
An Assessment About the Quality of Life: Case Study of Asansol

Sudarshana Sinha and Anindya Basu

Abstract The ways in which the built environment can impact the quality of life (QoL) tend to vary spatio-temporally. The entire debate revolving around the ability or inability of material assets and physical infrastructure to improve QoL has been gaining ground. A thorough review of the literature reveals that not only assets but the availability of select resources are equally important to improve QoL. However, such an assessment is lacking in the context of Asansol, the second largest urban agglomeration of West Bengal. This paper aims to analyse this theme in the context of Asansol Municipal Corporation by incorporating a ward-wise analysis based on material wellbeing and the availability of select resources such as green spaces and blue spaces. The data presented has been obtained from secondary sources such as census records and Landsat imageries. A set of 23 indicators have been used following which various statistical analyses such as the calculation of Housing Index, Sanitation and Basic Amenities Index, Asset Index, Material Wellbeing Index, Correlation and principal component analysis have been carried out alongside NDBI, NDVI, ARVI, MNDWI. It can be observed that a disparity exists within the wards and in general the QoL of the entire region is not very high. The results of this chapter might help the planners and policymakers devise or implement strategies that aim to resolve micro-level disparities and could help the residents lead a better QoL.

Keywords Wellbeing · Housing · Sanitation · Assets · Resource · Built environment

S. Sinha
Department of Humanities and Social Sciences, Indian Institute of Technology Kharagpur, Kharagpur, West Bengal, India

A. Basu (✉)
Department of Geography, Diamond Harbour Women's University, Sarisha, West Bengal, India
e-mail: basu_anindya2004@yahoo.com

U. Chatterjee et al. (eds.), *Urban Commons, Future Smart Cities and Sustainability*, Springer Geography, https://doi.org/10.1007/978-3-031-24767-5_19

Introduction

Owing to the process of urbanisation, an unprecedented escalation in the urban population has become an evident phenomenon where a large section of people tends to migrate to cities and urban areas in search of more profitable employment opportunities, a higher standard of education and a good quality of life (QoL). However, Basu and Das (2023) stated that how the built environment can impact the QoL tends to vary spatio-temporally. There is an ongoing debate among academicians about the various positive and negative impacts of the cities on the QoL of the residents. Mouratidis (2019) had quite rightly pointed out that on one hand people living in cities tend to possess several material assets that help them to lead a better lifestyle but on the other owing to the rapid grey infrastructure in the cities rapid land conversion of blue and green spaces can be observed which has not only deteriorated the quality of the various ecosystem services that were available to the residents but have also negatively impacted QoL.

Bhagvandas (2021) describes QoL as the extent of the wellbeing of a person's life. The understanding and the perception enshrouding QoL vary according to an individual's socio-economic conditions, current scenario and past experiences (Chaturvedi and Muliyala 2016). An individual's personality, values and perception of life are thus dependent upon various subjective and objective factors (Jokela et al. 2015; Morrison and Weckroth 2017; Tonne et al. 2021). Kyte et al. (2016) stated that QoL in addition to the various internal components is also dependent upon the environs surrounding an individual and the relationship shared between them. Rather than being restricted to a singular domain, analysis regarding QoL is much more appropriate to be analysed as a composite component where an individual's take on both subjective and objective factors are equally important (Bandura 2006).

Previous studies about the assessment of the QoL in urban areas have mostly restricted to the evaluation of subjective wellbeing (see Ettema and Schekkerman 2016; Feng et al. 2017; Hajrasouliha et al. 2018; Kyttä et al. 2016; Morrison and Weckroth 2017; Okulicz-Kozaryn and Mazelis 2018). However, for a much more comprehensive analysis evaluation of not only subjective factors but also the availability and affordability of the urban people to access and procure various amenities, assets and services are equally important. Scant literature exists where both material wellbeing and the availability of select resources that are essential to lead a good QoL have been talked about. Hence, the main aim of this paper is to assess the QoL of the people staying in the different parts of Asansol Municipal Corporation (M. Corp.) from the perspective of material wellbeing and by analysing the nature of select open resources that are available to the residents of that area.

Theoretical Orientation

As stated by Mouratidis (2021), a deeper knowledge between the built environment and QoL, especially in cities, can play an important role in bringing forth more sustainable development in future. Won et al. (2018) stated that a strong and harmonious correlation between the neighbourhood environs and the lifestyle of the people is a significant way to assess their QoL. The availability and accessibility of material assets in a built environment can also lead to life satisfaction that can positively impact the QoL (Mouratidis 2021). Even within densely compacted built environments, the availability of open spaces (Anderson et al. 2017) and green spaces (Ugolini et al. 2020; Xie et al. 2020) tends to positively impact the QoL by providing the residents with a space to unwind carry out various physical activities engage in social cohesion and release their daily stress. Even within the built environment, the places where positive social relationships can be spotted those regions tend to offer a better QoL (Diener et al. 2018a, b; Small and Adler 2019). Scholars have stated that the presence of aesthetically pleasing open spaces that can either be a part of blue or green infrastructures has positive effects on human life owing to the various health benefits and cooling effects (Tang and Long 2019; Markevych et al. 2017).

Studies have pointed out that residential characteristics such as housing satisfaction (Clapham et al. 2018), the morphology of the houses and the households such as availability of adequate interior space (Foye 2017), construction quality, ownership, design (Mouratidis 2018a, b), price (Nguyen et al. 2018), location (Wang and Wang 2019) also play a significant role in improving the QoL of the residents. The availability and accessibility of local amenities near households positively impact the QoL of the residents (Zhang et al. 2017). However, various scholars have pointed out that since the city comprises clustering of various heterogeneous neighbourhoods, the availability of resources might not be evenly spread out all over the region, thus leading to the creation of differentials in the QoL. Studies have put forth that there is a tendency of clustering of various amenities and services mostly at the core of the city centre; hence, the people residing in these areas tend to enjoy a greater life satisfaction and has a high chance of leading a better QoL (MacKerron and Mourato 2009; Arifwidodo and Perera 2011). However, other scholars have argued that owing to this characteristic, the city centre or the core area tends to be extremely populated and there is a substantial lack of open spaces and green patches; hence, there is always a possibility of a deterioration of QoL in these regions (White et al. 2013; Ambrey and Fleming 2014).

QoL is a composite indicator which is dependent upon several other subdomains. It is stated that QoL and wellbeing are positively interconnected, and a greater level of safety (Boessen et al. 2018), identity, social ties (Miao et al. 2019) and community engagement (Mouratidis and Poortinga 2020) leads to upgradation of the QoL. Various factors like neighbourhood satisfaction (Mouratidis 2020), leisure activity satisfaction (Clark et al. 2019; de Vos 2019), perceived noise levels (Cao et al. 2018) and low crime rate (Lee et al. 2017) tend to positively impact the QoL. Attainment of good health tends to have a positive impact on the QoL of the people

(Kent and Thompson 2014). Discussions revolving around the QoL and the development of indices have been undertaken by various scholars and institutes where income, human development, happiness, wealth, subjective wellbeing, material wellbeing and emotional wellbeing have been much talked about (Barcaccia et al. 2013; Greyling and Tregenna 2017; Jana and Ghosh 2015; Sinha and Basu 2022). However, since a person's needs and wants tend to vary from region to region, arriving at one standardised index might not be the solution.

Marans and Stimson (2011) provided a technique to measure and analyse urban environments and their impact on QoL. Kent and Thompson (2014) discussed the potential of exercise, social cohesion and equitable access to healthy food and its impact on QoL. Pfeiffer and Cloutier (2016) studied the relationship between greenspaces, neighbourhoods and their impact on QoL. Wang and Wang (2016) added to the theoretical stand of QoL by studying the impact of geographical locations on subjective wellbeing.

Objectives

The major objective of this paper is to assess the quality of life of the people staying in the different parts of Asansol M. Corp. It aims to bring out the quality of housing, sanitation and basic amenities, asset; along with the availability of select open resources which influences the wellbeing of the residents. This study in addition to filling up the research gap, the findings can also assist the planners and policymakers to pinpoint the exact areas where a more amenity-specific improvement or an upgradation in their existing quality is required.

Materials and Methods

The methodology that has been adopted is diagrammatically presented in Fig. 19.1.

Data Sources

The data presented in this paper has been obtained from secondary sources that have been obtained from satellite imageries (Table 19.1) and census records (Census of India 2011).

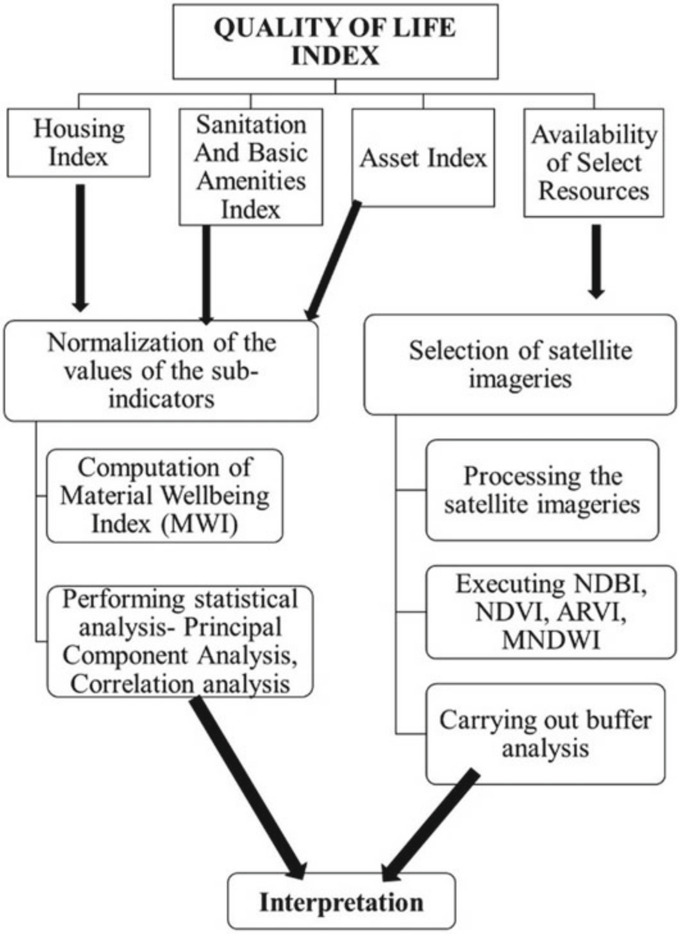


Fig. 19.1 Methodological framework of the study to ascertain quality of life in Asansol Municipal Corporation Area, West Bengal

Statistical Analysis

A set of 23 subindicators has been selected for assessing the QoL (Table 19.2). These were clubbed under four subheads, namely Housing Index (HI), Sanitation and Basic Amenities Index (SBAI), Asset Index (AI) and availability of select resources (Fig. 19.2). The descriptive details about these have been stated in case of the HI, SBAI and AI initially the values were normalised using the formula

$$\text{Sub-component score} = \frac{(\text{Observed Value} - \text{Minimum Value})}{(\text{Maximum Value} - \text{Minimum Value})}$$

Table 19.1 Satellite imagery details for the study region, i.e. Asansol Municipal Corporation Area, West Bengal

Study area	Satellite	Sensor	Path	Row	Date of acquisition
Asansol	Landsat 8	Operational land imager	139	044	1711/2021
Landsat 8 Operational Landsat Imagers (OLI)					
Band	Band name	Wavelength (μm)			Resolution (m)
1	Ultra blue	0.435–0.451			30
2	Blue	0.452–0.512			30
3	Green	0.533–0.590			30
4	Red	0.636–0.673			30
5	NIR	0.851–0.879			30
6	SWIR 1	1.566–1.651			30
7	SWIR 2	2.107–2.294			30
8	Panchromatic	0.503–0.676			15
9	Cirrus	1.363–1.384			30
10	TIRS 1	10.60–11.19			100 * (30)
11	TIRS 2	11.50–12.51			100 * (30)

Source USGS Earth Explorer, 2022

In this case, the scores range from 0 to 1, where 0 indicates the lowest score and 1 indicates the highest value. Equal weightage has been given to each subindicator as each one of them is an equally important determinant of the QoL. Following this, a composite score or the Material Wellbeing Index (MWI) was composed. These were calculated using

$$\mathrm{HI} = \frac{\left(X_a + X_b + X_c + X_d + X_e + X_f\right)}{N_{\text{Sub-indicators}}}$$

$$\mathrm{SBAI} = \frac{\left(X_g + X_h + X_i + X_j + X_k + X_l + X_m + X_n\right)}{N_{\text{Sub-indicators}}}$$

$$\mathrm{AI} = \frac{\left(X_o + X_p + X_q + X_r + X_s\right)}{N_{\text{Sub-indicators}}}$$

$$\mathrm{MWI} = \frac{(\mathrm{HI} + \mathrm{SBAI} + \mathrm{AI})}{N_{\text{Sub-indicators}}}$$

Table 19.2 Details about the subindicators used for constructing quality of life for Asansol Municipal Corporation Area, West Bengal

Broad domains	Subindicators details	Subindicator ID	Description of the subindicators	References
HI	Condition of houses	X_a	Only the house that has been classified as good by the census were selected owing to the quality check	Das et al. (2022a, b)
	Material of roof	X_b	Houses having cemented roofs were selected as it is considered more durable and weather resistant	
	Material of wall	X_c	Houses having cemented walls were selected as more durable and weather resistant	
	Material of floor	X_d	Houses having concrete roofs were selected as more durable and weather resistant	
	Ownership	X_e	Houses that were classified under owned were selected as it signifies the economic status of a household	
	Structure of houses	X_f	Only the house that has been classified as permanent by the Census was selected as it signifies the economic status of a household	

(continued)

Table 19.2 (continued)

Broad domains	Subindicators details	Subindicator ID	Description of the subindicators	References
SBAI	Quality of drinking water	X_g	Only treated tap water was selected as it is considered to be safe and hygenic	Bohnke (2008), Kingdon and Knight (2006), Li et al. (2010), Muhammad and Sabo (2017), Das and Mistri (2013), Sinha and Basu (2022)
	Availability of water within premises	X_h	In this case, households having the availability of treated tap water were selected owing to the safety, convenience and hygiene reasons	
	Source of lighting	X_i	Those households using electricity as a source of lighting were selected as it signifies a good quality of life as well as the affordability of the people	
	Latrine facility within premises	X_j	Households that have latrine facilities within the premises were selected owing to the safety, convenience and hygiene reasons	
	Bathroom with a roof within premises	X_k	Households that have bathroom facilities with a roof on top of it were selected owing to the safety, convenience and hygiene reasons	

(continued)

Table 19.2 (continued)

Broad domains	Subindicators details	Subindicator ID	Description of the subindicators	References
	Water outlet connected to closed drainage facilities	X_l	Households having closed drainage facilities were selected as it is considered more hygienic and there are lesser chances of diseases to spread	
	Fuel used	X_m	Only LPG/PNG was used as it is more hygienic and tends to eliminate smoke which is more prevalent in the case of firewood	
	Availability of kitchen within the house	X_n	As it eliminates smoke and ensures better living conditions in households	
AI	Availability of banking facility	X_o	As it ensures the availability of essential services	Bhagat (2011), Haq et al. (2010), Haq and Zia (2008), Haque (2016), Vijaya and Krishnan (2014)
	Television facility	X_p	It provides entertainment and its ownership enhances one's QoL	
	Availability of computer or laptop with internet facility	X_q	It is considered an essential good in the current scenario owing to its multi-purpose use in education, work, procuring various amenities and services	

(continued)

Table 19.2 (continued)

Broad domains	Subindicators details	Subindicator ID	Description of the subindicators	References
	Availability of mobile facility	X_r	It is considered an important means of communication	
	Availability of scooter or moped or motorcycle	X_s	It is considered important for transportation purposes	
Availability of select resources	Normalised difference built-up index	NDBI	This analysis would help to analyse the areas that have been converted to grey infrastructure. A higher concentration of such spaces may on one hand lead to an increase in the functionality and the economic value of the region but on the other hand might lead to the deterioration in the ecosystem services of that areas	Mouratidis (2021)
	Normalised difference vegetation index	NDVI	This analysis would help to understand the presence of green vegetation in an area. A greater percentage share of green spaces tends to increase the quality of life of the people, owing to the various cultural ecosystem services that these places have to offer	Nguyen et al. (2021), Wang et al. (2021)

(continued)

Table 19.2 (continued)

Broad domains	Subindicators details	Subindicator ID	Description of the subindicators	References
	Atmospherically resistant vegetation index	ARVI	This analysis would help to understand the quality of green spaces that are available in the area. A better quality of greenspaces tends to offer better quality of ecosystem services thus increasing the QoL	Abutaleb et al. (2021), Giannico et al. (2021)
	Modified normalised difference water index	MNDWI	This analysis would help to understand the presence of waterbodies in an area. A greater percentage share of blue spaces tends to increase the quality of life of the people, owing to the various ecosystem services that these places have to offer	White et al. (2020), Wu et al. (2021)

Source Computed by the authors based on Census of India (2011)

However, to analyse the quality of life not only possession of material tangible assets is important, but availability and quality of open resources such as quality of vegetation, quality of water bodies and analysis of the pattern of the built-up areas are also important. Hence, three buffer zones that are 4, 8 and 12 km buffers were constructed encircling the focal point of the Asansol M. Corp. for this analysis.

Figure 19.2 briefly states the four broad domains and the 23 subindicators that have been used to calculate the QoL. Under the Housng Index, condition of houses, material of roof, material of wall, material of floor, ownership status and structure of the houses were considered. Under Sanitation And Basic Amenities Index, quality of drinking water, availability of latrine within premises, presence of bathroom with the premises with roof, availability of water outlet and closed drainage facilities, types of fuel used, availability of kitchen within house were considered. Under Asset Index, Availability of Banking Index, television facility, mobile facility and

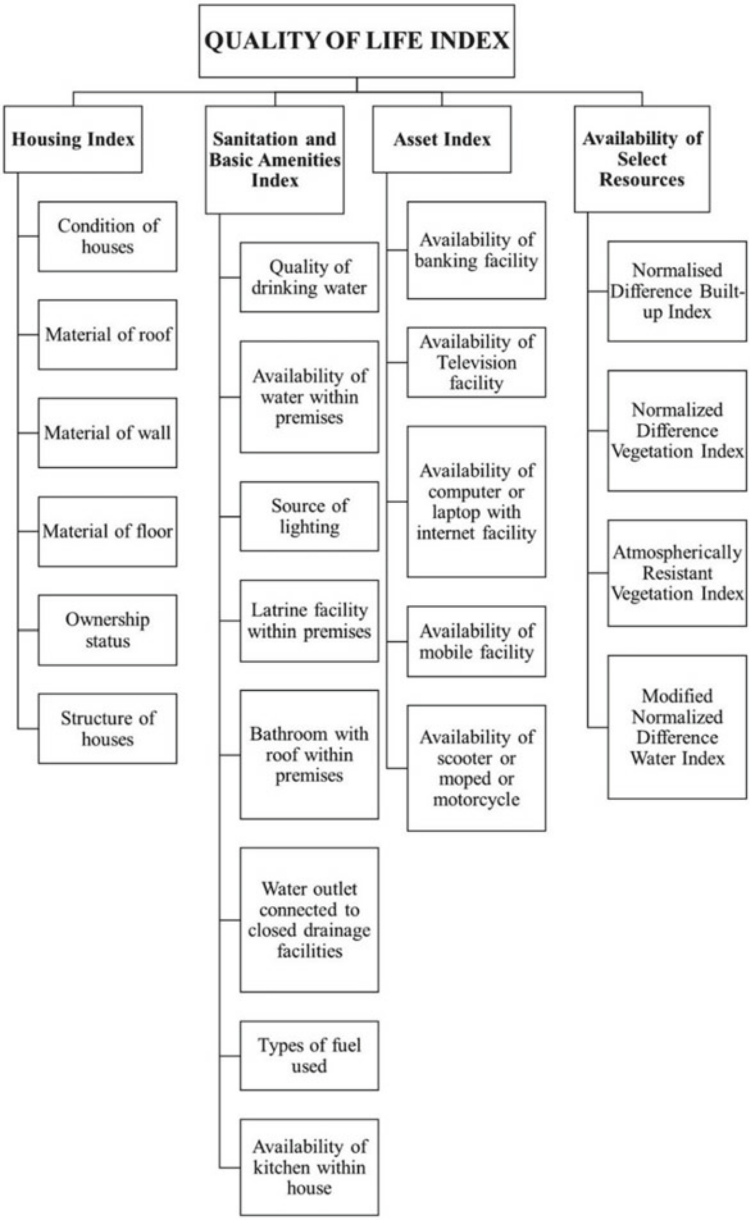


Fig. 19.2 Construction of Quality of Life Index for Asansol Municipal Corporation Area, West Bengal

scooter/moped/motorcycle were considered. Under Availability of Select Resources, Normalised Difference Built-up Index, Normalised Difference Vegetation Index, Atmospherically Resistant Vegetation Index and Modified Normalised Difference Water Index were considered.

NDBI Analysis

Normalised Difference Built-up Index (NDBI) is used to calculate the built-up area; it can be calculated using

$$\mathrm{NDBI} = \frac{(\mathrm{SWIR1} - \mathrm{NIR})}{(\mathrm{SWIR1} + \mathrm{NIR})}$$

The value tends to range between 1 and -1, where 1 tends to signify a highly built-up area and -1 tends to signify a very low density of the built-up area.

NDVI Analysis

Normalised Difference Vegetation Index (NDVI) is also used to estimate the relative biomass of vegetation; it can be calculated using

$$\mathrm{NDVI} = \left[\frac{(\mathrm{NIR} - \mathrm{RED})}{(\mathrm{NIR} + \mathrm{RED})}\right]$$

The value tends to range between 1 and -1, where 1 tends to signify a dense vegetation area and -1 tends to signify a sparse vegetation.

ARVI Analysis

Atmospherically Resistant Vegetation Index (ARVI) is an improved index which is used to correct the influence of the atmosphere. It is most useful in regions with a high content of atmospheric aerosol, including tropical areas polluted with soot. Higher values tend to signify a better quality of vegetation, and lower values tend to signify poorer quality of vegetation. It can be calculated using

$$\mathrm{ARVI} = \left\{\frac{\mathrm{NIR} - [(\mathrm{RED} - 1) * (\mathrm{BLUE} - \mathrm{RED})]}{\mathrm{NIR} + [(\mathrm{RED} - 1) * (\mathrm{BLUE} - \mathrm{RED})}\right\}$$

MNDWI Analysis

Modified Normalised Difference Water Index (MNDWI) is used to study the quality of water bodies. It can enhance the features of open water by effectively either or at times removing built-up land noise, vegetation noise and soil noise.

$$\mathrm{MNDWI} = \frac{(\mathrm{GREEN} - \mathrm{SWIR})}{(\mathrm{GREEN} + \mathrm{SWIR})}$$

The value tends to range between 1 and −1, where 1 tends to signify deep waterbodies.

Correlation Analysis

Pearson's correlation coefficient measures the statistical relationship between two variables. The value ranges between −1 and 1, where 1 indicates a strong positive relationship, whereas −1 indicates a strong negative relationship. It can be calculated by

$$r = \frac{N\sum xy - [\sum(x) * \sum(y)]}{\sqrt{\left\{\left[N\sum x^2 - \left(\sum x\right)^2\right]\left[N\sum y^2 - \left(\sum y\right)^2\right]\right\}}}$$

where r is the Pearsons's correlation coefficient; N is the number of pairs of scores; $\sum xy$ is the sum of the products of paired scores; $\sum x$ is the sum of x scores; $\sum y$ is the sum of y scores; $\sum x^2$ is the sum of squared x scores; $\sum y^2$ is the sum of squared y scores.

Principal Component Analysis

Principal component analysis (PCA) is a variable reduction technique; it aims at reducing a large set of variables into smaller sets by selecting the most important variable which accounts for most of the variance. It takes into its account the variation between the eigenvalues. The PCA was conducted among the subindicators belonging to the three broad domains to bring out the specific subindicator which has brought about the maximum variance within each one of the three broad domains, and hence, this analysis was chosen.

Rationale Behind the Section of the Indicators

To analyse the QoL select indicators of material wellbeing and availability of select open resources have been chosen. An assessment of the amenities is very important as it helps to garner positive feelings about a sense of place and helps people enjoy a better QoL (Howie et al. 2010). In developing countries like India, a significant share of the people often lack access to basic amenities and services that are necessary to lead a decent standard of life (Das et al. 2020a, b). Hence, an assessment in that regard is important. Various scholars have observed that the condition of the houses (Bohnke 2008; Kingdon and Knight 2006; Li et al. 2010), availability of safe drinking water (Muhammad and Sabo 2017) and households having access to electricity (Das and Mistri 2013) have observed that tend to enjoy a better QoL, presence of proper sanitation facilities like latrines, bathrooms and closed drainage facilities within the premises (Sinha and Basu 2022) and presence of various physical infrastructures as well as assets are important to lead a good QoL (Bhagat 2011; Haq et al. 2010;

Haq and Zia 2008; Haque 2016). The ability of the individuals to afford and access these parameters also reflects their economic condition hence facilitating a much more comprehensive analysis of QoL (Vijaya and Krishnan 2014). In addition to the availability of green and blue spaces (Ugolini et al. 2020; Xie et al. 2020), the density of the built-up area (Wang and Wang 2019) has also been considered while conducting the QoL analysis.

Software

Statistical analysis was performed using Statistical Package for Social Science (SPSS v22), and mapping was based on ArcGIS software (v10.5).

Study Area

Asansol is considered the second largest urban agglomeration in West Bengal (Fig. 19.3). It can be observed from the census records that 75.88% of the houses that are situated in the Asansol M.Corp. are used for residential purposes. Other than this, 5.24% is used for non-residential as well as other purposes, 2.29% of the houses are used for residential-cum other purposes, 8.49% are used for shops, 0.65% are used as places of worship, 0.52% are used for factory/workshop/workshed, 0.37% are used for hotels/lodges/guesthouses, 0.33% are used for hospitals/dispensaries, 0.3% are used for schools/college. Asansol M. Corp. has been selected because it is considered the second largest urban agglomeration of West Bengal (Census of India 2011). It is a famous mining area although it is emerging as an important trading hub and various industries are located in close vicinity to this region. Owing to this, people residing in various neighbouring areas tend to migrate to this region in search of better employment, livelihood opportunities and a better quality of life, and hence, this region has been chosen.

The mean size of the households of Asansol M. Corp. is five persons per household. Among these census houses that are either used for residence or residence-cum-other purposes 84% of such structures have been classified as permanent ones. In the case of Asansol M. Corp., it can be observed that out of the three broad indicators (Table 19.3), HI is relatively better than the other two. In the case of SBAI, an overall less availability of treated water within the premises (35.3%) and less affordability among people opting for a closed drainage facility (15.8%) can be observed. The SBAI score is far from desirable. In the case of AI, it can be observed that relatively fewer people possess computers/laptops with internet facilities (5%) and fewer people can afford scooters or other related transportation facilities (30.20%). Through the values of MWI, it can be realised that the overall material wellbeing of the people is very satisfactory.

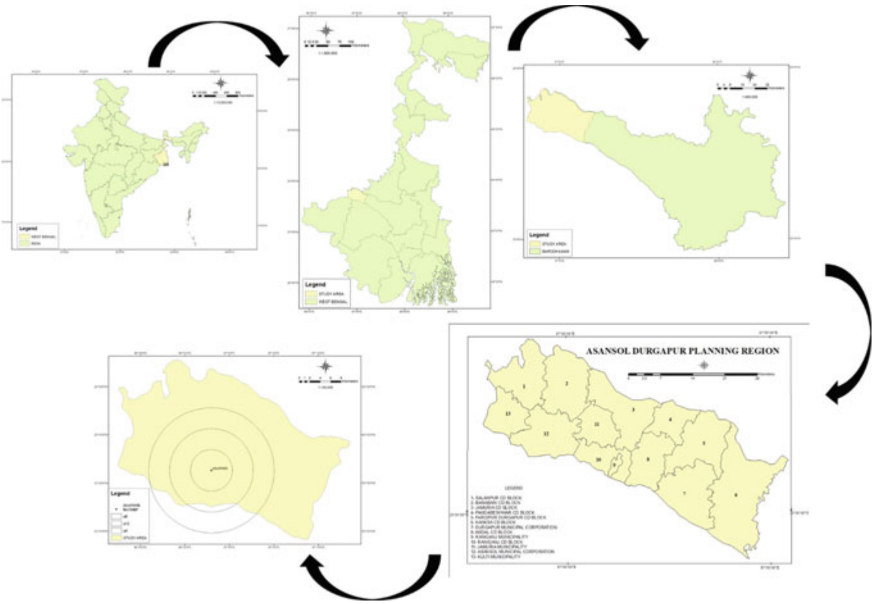


Fig. 19.3 Location map of the study area of Asansol Municipal Corporation Area, West Bengal

Results

The QoL has been performed for 49 wards of the Asansol M. Corp. Table 19.4 shows the descriptive analysis of the subindicators. It can be observed that significant differences exist between the availability of resources within the study region. Some of the subindicators like the availability of bathrooms with roof facilities within the premises, availability of latrine facilities within the premises and availability of treated tap water within premises tend to show a higher range of variance. On the other hand, subindicators like differentials between the wards with regards to the ownership of mobiles, ownership of own houses, and availability of electricity as a source of lighting are seemingly less.

HI

In the case of the HI, widespread discrepancies can be noticed (Tables 19.5 and 19.6). Based on the normalised value that was obtained, the wards were divided into three categories: high, medium and low. Based on the good condition of houses, 8 wards could be classified under low, 19 wards could be classified under medium, and 22 wards could be classified under high category. The average score is 0.6. This shows that a greater section of residential houses is in a good condition. Based on the

Table 19.3 Computation of material wellbeing index for Asansol Municipal Corporation Area, West Bengal

Indicators	Subindicator ID	Subindicator details	Value (%)	In (%)	MWS (%)
HI (housing index)	X_a	Condition of houses (for example 60.10% of the census houses are in a good condition)	60.10	61.97 (represents the value of HI)	55.81
	X_b	Material of roof (for example 62.40% of the houses have concrete roofs)	62.40		
	X_c	Material of wall	12.40		
	X_d	Material of floor	77.10		
	X_e	Ownership	75.80		
	X_f	Structure of houses	84.00		
SBAI (sanitation and basic amenities index)	X_g	Quality of drinking water	84.40	56.35	
	X_h	Availability of water within premises	35.30		
	X_i	Source of lighting	88.00		
	X_j	Latrine facility within premises	64.20		
	X_k	Bathroom with a roof within premises	65.00		
	X_l	Water outlet connected to closed drainage facilities	15.80		
	X_m	Fuel used	39.80		
	X_n	Availability of kitchen within the house	58.30		
AI (asset index)	X_o	Availability of banking facility	67.50	49.12	
	X_p	Television facility	76.30		

(continued)

Table 19.3 (continued)

Indicators	Subindicator ID	Subindicator details	Value (%)	In (%)	MWS (%)
	X_q	Availability of computer or laptop with internet facility	5.00		
	X_r	Availability of mobile facility	66.60		
	X_s	Availability of scooter or moped or motorcycle	30.20		

Source Computed by the authors based on Census of India (2011)

Table 19.4 Descriptive statistical analysis of the subindicators of Material Wellbeing Index for Asansol Municipal Corporation Area, West Bengal

Indicator ID	Subindicator ID	Max	Min	Kurt	Mean	S.D.
HI	X_a	85.5	26.5	– 0.90	61.74	15.14
	X_b	93.9	30.5	– 0.35	64.40	16.16
	X_c	47.8	0.1	0.59	14.03	12.10
	X_d	93.8	44.5	0.45	78.00	11.23
	X_e	96.6	55.9	1.56	76.27	7.50
	X_f	99.6	50.9	0.53	85.13	11.98
SBAI	X_g	98.9	33.9	5.21	85.73	12.66
	X_h	79.4	1.6	– 1.32	38.53	23.73
	X_i	98.4	55.2	2.46	88.61	9.61
	X_j	94.5	11.9	0.08	65.00	20.05
	X_k	92.7	8.2	– 0.42	66.65	21.78
	X_l	55.2	0.7	0.75	17.73	13.65
	X_m	80.6	1.2	– 1.15	40.94	23.39
	X_n	89.3	21.4	– 1.02	60.18	18.88
AI	X_o	92.3	35.6	– 0.94	68.27	16.90
	X_p	93.5	42.3	0.41	77.28	11.79
	X_q	16.7	0.4	0.35	5.304	4.516
	X_r	83.4	46.6	– 0.07	67.39	8.82
	X_s	53.8	7.1	– 0.30	30.73	10.65

Source Computed by the authors based on Census of India (2011)

usage of concrete for the construction of roofs, 10 wards could be classified under low, 25 wards could be classified under medium, and 14 wards could be classified under high category. The average score is 0.53. This shows that a greater number of households have the affordability to opt for concrete for the construction of a roof. Based on the usage of cement for the construction of walls, 32 wards could be classified under low, 13 wards could be classified under medium and wards could be classified under 4 high category. The average score is relatively very low at 0.29. This shows the widespread discrepancy within the wards and among those who can afford cemented walls. Based on the condition of usage of concrete for floors, 4 wards could be classified under low, 17 wards could be classified under medium, and 28 wards could be classified under the high category. The average score is 0.68. This shows that most people can afford a good quality of floors. A greater percentage of people tend to reside in their own homes, and most of these residential houses have been classified under the permanent category by the Census. The average score is 0.78. In the case of HI, 6 wards could be classified under low (0.17–0.40), 33 wards could be classified under medium (0.41–0.63), and 10 wards could be classified under the high (0.64–0.86) category. The average score is 0.56. This shows that although most people have been able to afford their own permanent residential houses, the ability of the people to opt for an improvement in the condition of the houses, roofs, walls and floors would positively impact their QoL.

SBAI

In the case of the SBAI, widespread discrepancies can be noticed (Tables 19.5 and 19.6). Based on the normalised value that was obtained, the wards were divided into three categories: high, medium, and low category. In the case of the availability and ability of people to afford treated tap water as the major source of drinking water, it can be observed that most of the people staying in the wards could afford and access it. The average score is 0.8. However, significant discrepancy lies when one analyses the availability of such facilities within the premises of their houses. People staying in as many as 22 wards could be classified under low, 15 wards could be classified under medium, and only 12 wards could be classified under the high category. The average score is 0.47. It can be observed that most of the people staying in the study region can afford electricity as their major source of light. The average score is 0.77. Most people have the affordability and provision to have latrine facilities and a bathroom with a roof for bathing purposes within their houses which make it safer to access especially post sunset. In the case of the availability of latrine and the bathroom facility, only 8 and 5 wards could be classified under low for the former and the latter categories; and 12 and 14 wards could be classified under medium category. The average scores for the former and latter categories are 0.64 and 0.69, respectively.

However, significant differentials can be noticed among people being able to afford closed drainage facilities for the discharge of wastewater from their households. Under this category, 30 wards could be classified under low, 14 wards could be

Table 19.5 Calculation of the selected subindicators of HI, SBAI, AI and MWI for Asansol Municipal Corporation Area, West Bengal

Ward No.	HI						SBAI								AI				
	X_a	X_b	X_c	X_d	X_e	X_f	X_g	X_h	X_i	X_j	X_k	X_l	X_m	X_n	X_o	X_p	X_q	X_r	X_s
1	73.70	80.20	11.00	68.00	82.80	90.80	89.70	61.70	91.80	77.50	87.70	32.50	74.70	85.10	86.20	89.10	11.90	59.90	52.20
2	65.80	66.10	20.40	55.00	76.60	88.30	93.20	51.50	91.10	48.30	75.30	36.40	57.00	64.70	71.10	83.80	15.60	59.20	38.40
3	79.10	80.60	11.20	74.50	70.40	93.80	94.20	73.70	98.20	76.40	90.50	35.10	80.60	89.30	92.30	93.50	12.60	67.30	43.80
4	65.70	74.80	26.90	88.80	64.30	96.10	92.90	47.10	95.40	83.60	82.80	12.70	55.80	65.30	83.40	83.60	5.50	72.10	34.40
5	82.00	71.60	7.40	74.90	71.70	91.40	89.00	62.70	95.00	66.70	78.60	41.60	65.30	80.10	83.00	89.40	10.30	73.20	41.10
6	85.50	68.70	9.40	67.80	74.30	94.70	86.70	75.70	96.50	58.30	88.00	52.80	71.60	82.70	85.00	91.50	15.10	63.70	46.10
7	68.30	72.40	11.20	81.00	68.90	94.00	94.00	72.30	92.90	76.70	79.30	23.30	61.40	76.50	78.80	82.40	8.40	68.50	37.10
8	63.50	68.10	24.30	88.70	78.30	89.00	94.10	52.50	90.10	75.20	83.60	24.30	36.00	71.60	68.10	79.60	2.10	80.20	25.20
9	75.20	75.60	7.50	79.80	75.70	90.70	81.10	53.50	91.90	86.30	86.50	19.80	66.90	82.80	82.90	87.00	7.40	68.80	46.70
10	57.40	82.90	31.80	87.50	74.40	92.90	94.10	49.90	94.50	87.90	83.30	20.90	51.90	71.50	77.40	87.20	4.70	75.60	33.70
11	78.20	77.60	45.50	93.80	78.50	94.50	96.80	58.80	98.10	94.50	83.70	28.10	56.90	80.30	79.10	86.60	6.60	80.30	31.80
12	76.60	92.20	0.20	89.20	79.70	99.10	91.80	73.60	98.30	70.70	84.20	16.30	69.90	67.70	88.00	88.60	4.90	83.40	32.10
13	81.10	93.90	23.40	87.20	87.20	99.60	95.90	72.30	98.40	91.20	92.70	42.00	74.90	82.90	74.30	86.60	8.40	71.50	32.40
14	62.70	79.80	33.50	67.70	79.10	91.20	97.50	71.10	95.40	67.00	89.20	55.20	58.10	85.00	75.70	88.50	9.90	59.90	42.30
15	76.40	82.60	0.20	89.80	66.80	96.80	83.90	54.20	97.70	81.20	80.30	9.60	42.50	65.60	80.90	85.20	5.50	66.80	24.90
16	68.70	70.00	39.50	78.50	72.00	91.90	92.40	67.10	96.00	84.40	81.00	28.50	53.70	65.00	88.20	89.90	5.60	69.00	36.80
17	50.30	65.80	5.10	81.00	72.90	72.30	92.80	44.10	91.50	73.30	68.50	12.50	33.00	50.00	61.60	76.60	5.20	73.30	26.50
18	67.60	67.80	7.40	84.60	84.60	90.60	90.30	40.80	93.30	82.30	90.90	7.40	60.20	77.70	80.90	88.00	2.80	73.80	36.10
19	75.00	65.60	4.00	76.60	81.90	88.60	87.40	46.20	89.80	77.30	76.70	17.60	46.60	69.10	70.60	77.90	8.40	69.80	31.70
20	57.00	51.20	26.10	85.10	73.70	91.40	85.80	37.80	91.80	64.30	72.40	21.30	41.70	69.60	80.70	80.80	5.10	70.70	31.20

(continued)

Table 19.5 (continued)

Ward No.	HI						SBAI								AI				
	X_a	X_b	X_c	X_d	X_e	X_f	X_g	X_h	X_i	X_j	X_k	X_l	X_m	X_n	X_o	X_p	X_q	X_r	X_s
21	75.20	76.90	20.00	59.10	77.00	93.60	91.80	67.50	94.30	81.80	83.50	26.60	68.90	78.30	88.90	88.10	16.70	67.30	47.50
22	82.30	49.30	47.80	75.60	80.90	81.30	98.60	79.40	85.20	30.10	83.70	48.30	32.50	79.90	38.30	74.60	15.80	53.10	42.60
23	58.10	60.30	0.10	82.20	79.80	78.00	54.40	18.60	85.70	65.00	47.20	9.60	18.20	35.60	48.80	68.90	3.10	67.70	20.80
24	56.50	63.80	6.00	78.70	73.50	79.20	90.70	46.60	87.60	69.10	68.40	12.00	47.00	58.60	69.00	75.70	3.80	66.60	33.30
25	74.90	70.00	12.40	89.00	66.10	93.20	96.80	37.30	94.50	75.70	74.20	10.70	41.80	61.80	71.50	78.50	7.10	77.70	32.10
26	51.00	59.30	19.00	86.00	63.20	89.80	92.40	30.40	90.60	77.40	49.60	6.90	29.20	45.00	65.20	70.10	2.60	74.10	21.90
27	49.20	59.80	4.30	90.60	73.70	95.20	92.90	32.80	95.50	78.00	56.30	5.90	14.00	44.20	43.70	69.40	1.20	64.00	10.90
28	40.40	41.50	8.30	78.50	71.30	67.50	89.00	18.20	89.30	56.20	39.30	7.50	5.80	23.60	35.60	62.40	0.50	57.80	7.10
29	46.30	55.10	7.30	89.30	77.20	94.80	94.00	30.40	96.50	68.50	55.70	10.50	12.50	38.80	37.40	72.80	1.00	69.60	13.50
30	79.70	90.30	2.20	74.90	78.50	94.00	81.10	71.90	92.20	86.80	90.40	20.00	74.70	86.40	90.80	90.40	12.00	72.20	53.80
31	51.20	61.20	21.80	65.70	73.00	72.20	76.70	23.80	74.80	39.90	43.10	12.60	23.40	49.00	54.90	60.70	2.50	55.60	25.50
32	38.50	35.40	12.60	55.60	78.90	62.40	61.40	10.50	69.60	33.50	32.00	4.90	12.10	35.40	46.10	56.20	2.30	54.30	19.50
33	44.00	31.50	5.10	77.40	71.80	74.10	64.40	3.40	82.30	37.80	39.00	2.00	14.40	45.90	50.60	69.40	0.90	71.10	25.20
34	54.20	30.50	15.10	61.30	81.50	57.90	68.50	4.90	75.90	21.90	26.80	6.80	5.20	27.00	51.70	59.40	1.10	51.00	16.60
35	37.90	43.30	1.60	61.10	86.90	64.60	95.80	1.60	72.20	28.00	27.80	0.70	3.00	29.50	39.60	51.80	0.40	47.70	15.70
36	35.40	38.20	9.90	65.40	86.40	59.60	85.30	11.20	65.50	26.40	28.10	9.90	2.70	40.00	39.50	60.50	1.30	50.30	20.80
37	26.50	32.80	0.10	44.50	96.60	50.90	33.90	9.90	55.20	11.90	8.20	0.90	1.20	21.40	40.70	42.30	0.50	46.60	14.70
38	47.70	60.40	2.90	86.60	72.70	88.50	82.90	14.30	91.50	69.60	55.20	5.90	22.50	38.30	44.60	68.60	1.60	70.20	19.10
39	78.60	69.20	5.10	93.10	70.80	96.50	92.30	26.10	96.20	81.10	87.70	14.60	43.70	75.00	79.70	81.70	3.30	70.20	33.60

(continued)

Table 19.5 (continued)

Ward No.	HI						SBAI								AI				
	X_a	X_b	X_c	X_d	X_e	X_f	X_g	X_h	X_i	X_j	X_k	X_l	X_m	X_n	X_o	X_p	X_q	X_r	X_s
40	56.20	53.20	12.90	86.50	55.90	80.90	74.30	15.80	89.60	62.80	60.50	11.90	31.40	45.40	68.80	77.60	2.90	68.00	28.10
41	81.50	90.90	0.10	88.00	72.60	95.90	98.90	34.70	95.50	76.90	84.50	4.40	74.20	80.20	83.20	91.80	4.20	79.20	40.10
42	62.30	77.80	2.50	86.80	75.60	93.10	96.90	24.10	92.20	75.00	80.70	22.50	58.40	69.60	81.90	85.60	4.20	70.80	37.20
43	68.80	72.00	12.60	87.10	79.90	90.80	81.40	16.30	89.40	73.40	79.40	5.10	45.60	58.00	72.70	80.80	2.20	75.60	32.60
44	68.40	71.00	21.70	85.30	82.90	86.40	72.90	11.50	83.80	70.10	72.90	21.20	48.40	58.10	79.20	79.30	3.20	74.60	36.50
45	40.20	47.10	24.60	75.70	73.00	79.80	84.70	12.90	85.00	53.60	39.50	6.00	16.90	39.60	69.40	70.60	1.50	71.60	22.20
46	41.30	58.40	8.20	74.30	74.40	85.80	80.60	14.20	89.50	69.50	49.80	9.90	37.00	49.30	73.50	78.60	2.50	70.90	26.20
47	68.00	60.00	20.30	80.70	73.30	82.80	84.40	8.00	89.80	58.30	57.00	13.80	27.40	54.60	75.20	75.40	1.10	75.00	26.20
48	49.30	56.00	5.90	70.10	96.50	70.30	69.20	21.20	69.10	37.00	39.30	4.10	6.00	48.30	51.00	57.50	0.70	55.40	26.90
49	51.80	52.80	30.90	73.60	79.60	74.40	91.00	23.90	75.60	46.40	50.80	15.40	29.00	49.70	65.70	72.20	3.70	66.90	30.80

Source Computed by the authors based on Census of India (2011)

Table 19.6 Normalised values of the selected subindicators and computation of HI, SBAI, AI and MWI for Asansol Municipal Corporation Area, West Bengal

Ward No.	X_a	X_b	X_c	X_d	X_e	X_f	X_g	X_h	X_i	X_j	X_k	X_l	X_m	X_n	X_o	X_p	X_q	X_r	X_s	HI	SBAI	AI	MWI
1	0.8	0.78	0.23	0.48	0.66	0.91	0.86	0.77	0.85	0.79	0.94	0.58	0.93	0.94	0.89	0.91	0.71	0.36	0.97	0.64	0.83	0.77	***0.75***
2	0.67	0.56	0.43	0.21	0.51	0.86	0.91	0.64	0.83	0.44	0.79	0.66	0.7	0.64	0.63	0.81	0.93	0.34	0.67	0.54	0.7	0.68	***0.64***
3	0.89	0.79	0.23	0.61	0.36	0.98	0.93	0.93	1	0.78	0.97	0.63	1	1	1	1	0.75	0.56	0.79	0.64	0.9	0.82	***0.79***
4	0.66	0.7	0.56	0.9	0.21	1.03	0.91	0.58	0.93	0.87	0.88	0.22	0.69	0.65	0.84	0.81	0.31	0.69	0.58	0.68	0.72	0.65	***0.68***
5	0.94	0.65	0.15	0.62	0.39	0.93	0.85	0.79	0.92	0.66	0.83	0.75	0.81	0.86	0.84	0.92	0.61	0.72	0.73	0.61	0.81	0.76	***0.73***
6	1	0.6	0.19	0.47	0.45	1	0.81	0.95	0.96	0.56	0.94	0.96	0.89	0.9	0.87	0.96	0.9	0.46	0.84	0.62	0.87	0.81	***0.77***
7	0.71	0.66	0.23	0.74	0.32	0.99	0.92	0.91	0.87	0.78	0.84	0.41	0.76	0.81	0.76	0.78	0.49	0.6	0.64	0.61	0.79	0.65	***0.68***
8	0.63	0.59	0.51	0.9	0.55	0.87	0.93	0.65	0.81	0.77	0.89	0.43	0.44	0.74	0.57	0.73	0.1	0.91	0.39	0.67	0.71	0.54	***0.64***
9	0.83	0.71	0.16	0.72	0.49	0.91	0.73	0.67	0.85	0.9	0.93	0.35	0.83	0.9	0.83	0.87	0.43	0.6	0.85	0.63	0.77	0.72	***0.71***
10	0.52	0.83	0.66	0.87	0.45	0.96	0.93	0.62	0.91	0.92	0.89	0.37	0.64	0.74	0.74	0.88	0.26	0.79	0.57	0.72	0.75	0.65	***0.71***
11	0.88	0.74	0.95	1	0.56	1	0.97	0.74	0.99	1	0.89	0.5	0.7	0.87	0.77	0.87	0.38	0.92	0.53	0.85	0.83	0.69	***0.79***
12	0.85	0.97	0	0.91	0.58	1.1	0.89	0.93	1	0.71	0.9	0.29	0.87	0.68	0.92	0.9	0.28	1	0.54	0.74	0.78	0.73	***0.75***
13	0.93	1	0.49	0.87	0.77	1.11	0.95	0.91	1	0.96	1	0.76	0.93	0.91	0.68	0.87	0.49	0.68	0.54	0.86	0.93	0.65	***0.81***
14	0.61	0.78	0.7	0.47	0.57	0.92	0.98	0.89	0.93	0.67	0.96	1	0.72	0.94	0.71	0.9	0.58	0.36	0.75	0.68	0.89	0.66	***0.74***
15	0.85	0.82	0	0.92	0.27	1.05	0.77	0.68	0.98	0.84	0.85	0.16	0.52	0.65	0.8	0.84	0.31	0.55	0.38	0.65	0.68	0.58	***0.64***
16	0.72	0.62	0.83	0.69	0.4	0.94	0.9	0.84	0.94	0.88	0.86	0.51	0.66	0.64	0.93	0.93	0.32	0.61	0.64	0.7	0.78	0.68	***0.72***
17	0.4	0.56	0.1	0.74	0.42	0.49	0.91	0.55	0.84	0.74	0.71	0.22	0.4	0.42	0.46	0.67	0.29	0.73	0.42	0.45	0.6	0.51	***0.52***
18	0.7	0.59	0.15	0.81	0.71	0.91	0.87	0.5	0.88	0.85	0.98	0.12	0.74	0.83	0.8	0.89	0.15	0.74	0.62	0.64	0.72	0.64	***0.67***
19	0.82	0.55	0.08	0.65	0.64	0.86	0.82	0.57	0.8	0.79	0.81	0.31	0.57	0.7	0.62	0.7	0.49	0.63	0.53	0.6	0.67	0.59	***0.62***
20	0.52	0.33	0.55	0.82	0.44	0.93	0.8	0.47	0.85	0.63	0.76	0.38	0.51	0.71	0.8	0.75	0.29	0.65	0.52	0.6	0.64	0.6	***0.61***
21	0.83	0.73	0.42	0.3	0.52	0.98	0.89	0.85	0.91	0.85	0.89	0.48	0.85	0.84	0.94	0.89	1	0.56	0.87	0.63	0.82	0.85	***0.77***

(continued)

Table 19.6 (continued)

Ward No.	X_a	X_b	X_c	X_d	X_e	X_f	X_g	X_h	X_i	X_j	X_k	X_l	X_m	X_n	X_o	X_p	X_q	X_r	X_s	HI	SBAI	AI	MWI
22	0.95	0.3	1	0.63	0.61	0.7	1	1	0.69	0.22	0.89	0.87	0.39	0.86	0.05	0.63	0.94	0.18	0.76	0.7	0.74	0.51	***0.65***
23	0.54	0.47	0	0.76	0.59	0.62	0.32	0.22	0.71	0.64	0.46	0.16	0.21	0.21	0.23	0.52	0.17	0.57	0.29	0.5	0.37	0.36	**0.41**
24	0.51	0.53	0.12	0.69	0.43	0.65	0.87	0.58	0.75	0.69	0.71	0.21	0.58	0.55	0.59	0.65	0.21	0.54	0.56	0.49	0.62	0.51	***0.54***
25	0.82	0.62	0.26	0.9	0.25	0.97	0.97	0.46	0.91	0.77	0.78	0.18	0.51	0.59	0.63	0.71	0.41	0.85	0.54	0.64	0.65	0.63	***0.64***
26	0.42	0.45	0.4	0.84	0.18	0.89	0.9	0.37	0.82	0.79	0.49	0.11	0.35	0.35	0.52	0.54	0.13	0.75	0.32	0.53	0.52	0.45	**0.50**
27	0.38	0.46	0.09	0.94	0.44	1.01	0.91	0.4	0.93	0.8	0.57	0.1	0.16	0.34	0.14	0.53	0.05	0.47	0.08	0.55	0.53	0.26	**0.44**
28	0.24	0.17	0.17	0.69	0.38	0.38	0.85	0.21	0.79	0.54	0.37	0.12	0.06	0.03	0	0.39	0.01	0.3	0	0.34	0.37	0.14	*0.28*
29	0.34	0.39	0.15	0.91	0.52	1	0.92	0.37	0.96	0.69	0.56	0.18	0.14	0.26	0.03	0.6	0.04	0.63	0.14	0.55	0.51	0.29	**0.45**
30	0.9	0.94	0.04	0.62	0.56	0.99	0.73	0.9	0.86	0.91	0.97	0.35	0.93	0.96	0.97	0.94	0.71	0.7	1	0.67	0.83	0.86	***0.79***
31	0.42	0.48	0.45	0.43	0.42	0.49	0.66	0.29	0.45	0.34	0.41	0.22	0.28	0.41	0.34	0.36	0.13	0.24	0.39	0.45	0.38	0.29	**0.37**
32	0.2	0.08	0.26	0.23	0.57	0.26	0.42	0.11	0.33	0.26	0.28	0.08	0.14	0.21	0.19	0.27	0.12	0.21	0.27	0.27	0.23	0.21	*0.23*
33	0.3	0.02	0.1	0.67	0.39	0.53	0.47	0.02	0.63	0.31	0.36	0.02	0.17	0.36	0.26	0.53	0.03	0.67	0.39	0.33	0.29	0.38	**0.33**
34	0.47	0	0.31	0.34	0.63	0.16	0.53	0.04	0.48	0.12	0.22	0.11	0.05	0.08	0.28	0.33	0.04	0.12	0.2	0.32	0.2	0.2	*0.24*
35	0.19	0.2	0.03	0.34	0.76	0.31	0.95	0	0.39	0.19	0.23	0	0.02	0.12	0.07	0.19	0	0.03	0.18	0.31	0.24	0.09	*0.21*
36	0.15	0.12	0.21	0.42	0.75	0.2	0.79	0.12	0.24	0.18	0.24	0.17	0.02	0.27	0.07	0.36	0.06	0.1	0.29	0.31	0.25	0.17	*0.25*
37	0	0.04	0	0	1	0	0	0.11	0	0	0	0	0	0	0.09	0	0.01	0	0.16	0.17	0.01	0.05	*0.08*
38	0.36	0.47	0.06	0.85	0.41	0.86	0.75	0.16	0.84	0.7	0.56	0.1	0.27	0.25	0.16	0.51	0.07	0.64	0.26	0.5	0.45	0.33	**0.43**
39	0.88	0.61	0.1	0.99	0.37	1.04	0.9	0.31	0.95	0.84	0.94	0.26	0.54	0.79	0.78	0.77	0.18	0.64	0.57	0.67	0.69	0.59	***0.65***
40	0.5	0.36	0.27	0.85	0	0.69	0.62	0.18	0.8	0.62	0.62	0.21	0.38	0.35	0.59	0.69	0.15	0.58	0.45	0.44	0.47	0.49	**0.47**
41	0.93	0.95	0	0.88	0.41	1.03	1	0.43	0.93	0.79	0.9	0.07	0.92	0.87	0.84	0.97	0.23	0.89	0.71	0.7	0.74	0.73	***0.72***
42	0.61	0.75	0.05	0.86	0.48	0.97	0.97	0.29	0.86	0.76	0.86	0.4	0.72	0.71	0.82	0.85	0.23	0.66	0.64	0.62	0.7	0.64	***0.65***

(continued)

Table 19.6 (continued)

Ward No.	X_a	X_b	X_c	X_d	X_e	X_f	X_g	X_h	X_i	X_j	X_k	X_l	X_m	X_n	X_o	X_p	X_q	X_r	X_s	HI	SBAI	AI	MWI
43	0.72	0.65	0.26	0.86	0.59	0.91	0.73	0.19	0.79	0.74	0.84	0.08	0.56	0.54	0.65	0.75	0.11	0.79	0.55	0.67	0.56	0.57	***0.60***
44	0.71	0.64	0.45	0.83	0.66	0.81	0.6	0.13	0.66	0.7	0.77	0.38	0.59	0.54	0.77	0.72	0.17	0.76	0.63	0.68	0.55	0.61	***0.61***
45	0.23	0.26	0.51	0.63	0.42	0.66	0.78	0.15	0.69	0.5	0.37	0.1	0.2	0.27	0.6	0.55	0.07	0.68	0.32	0.45	0.38	0.44	**0.43**
46	0.25	0.44	0.17	0.6	0.45	0.8	0.72	0.16	0.79	0.7	0.49	0.17	0.45	0.41	0.67	0.71	0.13	0.66	0.41	0.45	0.49	0.52	**0.49**
47	0.7	0.47	0.42	0.73	0.43	0.73	0.78	0.08	0.8	0.56	0.58	0.24	0.33	0.49	0.7	0.65	0.04	0.77	0.41	0.58	0.48	0.51	**0.53**
48	0.39	0.4	0.12	0.52	1	0.44	0.54	0.25	0.32	0.3	0.37	0.06	0.06	0.4	0.27	0.3	0.02	0.24	0.42	0.48	0.29	0.25	**0.34**
49	0.43	0.35	0.65	0.59	0.58	0.54	0.88	0.29	0.47	0.42	0.5	0.27	0.35	0.42	0.53	0.58	0.2	0.55	0.51	0.52	0.45	0.48	**0.48**

Italic: low (0.08–0.30); Bold: medium (0.31–0.50); Bolditalic: high (0.51–0.85)
Source Computed by the authors based on Census of India (2011)

classified under medium, and only 5 wards could be classified under the high category. The average score is as low as 0.31. Based on the availability of kitchens within the house, 10 wards could be classified under low, 18 wards could be classified under medium, and 21 wards could be classified under high category. The average score is 0.57. Based on the affordability of people to opt for LPG/PNG as a cooking fuel, 15 wards could be classified under low, 17 wards could be classified under medium, and wards could be classified under 17 high category. The average score is 0.5.

In the case of SBAI, 7 wards could be classified under low (0.01–0.32), 19 wards could be classified under medium (0.33–0.62), and 23 wards could be classified under the high (0.63–0.93) category. The average score is 0.6. Although most people can afford treated tap water for drinking purposes, the presence of such facilities within their premises is lacking. It can be observed that most people cannot afford closed drainage facilities for an outlet of wastewater from their households, the absence of such facility might affect the health and hygiene of the residents owing to the stagnation of waters but has a high potential for the spread of various vector-borne diseases. It can be observed that a significant percentage of people can neither afford kitchens nor use LPG/PNG as a source of fuel. The presence of both of these facilities would have improved their lifestyle, and the absence tends to negatively impact the QoL of the people.

AI

In case of the AI, widespread discrepancies can be noticed (Tables 19.5 and 19.6). Based on the normalised value that was obtained, the wards were divided into three categories: high, medium, and low category. Based on the availability of banking facilities 13 wards could be classified under low, wards could be classified under 13 medium, and 23 wards could be classified under the high category. The average score is 0.58. Based on the affordability of the people to afford television, only 5 wards could be classified under low, 15 wards could be classified under medium, and 29 wards could be classified under the high category; the average score is 0.68. Based on the affordability of people to have either computer or laptop with internet facilities, 14 wards could be classified under low, 8 wards could be classified under medium, and 27 wards could be classified under the high category; the average score is as low as 0.30. In the case of affordability of mobiles, 9 wards could be classified under low, 23 wards could be classified under medium, and 17 wards could be classified under the high category; the average score is 0.56. It can be observed that not many people possess scooters/motorcycles/mopeds; 12 wards could be classified under low (0.05–0.32), 27 wards could be classified under medium (0.33–0.59), and 10 wards could be classified under high (0.60–0.86) category. This could be used for their high price. The average score is 0.51. In the case of AI, 11 wards could be classified under low, 26 wards could be classified under medium, and wards could be classified under 12 high category; the average score is 0.53. It can be observed that a very less percentage of households can afford computers/laptops with internet facilities.

Having the affordability of such resources has become more or less a necessity in the present time, and an increase in this category would significantly improve the QoL. An increase in the number of people that can have access to banking facilities, and people having the affordability to procure mobiles could certainly lead to an improvement in the QoL.

MWI

In the case of the MWI, certain differentials can be noticed (Tables 19.5 and 19.6). Based on the normalised value that was obtained, the wards were divided into three categories: high (0.51–0.81), medium (0.31–0.50) and low (0.08–0.30) category. Under this category, only 6 wards could be classified under low, 12 wards could be classified under medium, and 31 wards could be classified under high category. The average score that can be observed under this category is 0.56. The average score that can be observed under this category could be attributed to the bleak performance of the different wards under the three broad domains (AI, SBAI, HI).

Table 19.7 shows the correlation matrix between the various subindicators. A high correlation exists between the condition of the house and the roof condition, availability of treated tap water, bathroom facilities, type of fuel used, availability of kitchen within the house, availability of bathroom with roof facilities and the availability of television. A greater value in either categories would lead to a better QoL.

Table 19.8 shows the PCA of the three broad indicators. It can be observed that in the case of HI, the first component explains 52.1% of the variance, whereas the second component explains 69.76%. In the case of the first component permanent structure of the houses, and in the case of the second component ownership of the houses have created most of the variance. In the case of SBAI, the first component explains 71.83% of the variance, whereas the second component explains 12.69%. In the case of the first component availability of a bathroom with a roof within the premises, availability of a kitchen within the house, and usage of LPG/PNG fuel, and in the case of the second component availability of a latrine facility within the premises has created most of the variance. In the case of AI, the first component explains 69.11% of the variance, whereas the second component explains 22.27% of the variance. In the case of the first component, the availability of television, and banking facilities, and in the case of the second component availability of mobiles has created most of the variance.

Analysis of Select Resources of the Study Region

To study the nature of the select resources that are available to the local people, the study is restricted to the analysis of three main components, namely the built-up

Table 19.7 Correlation matrix of the selected subindicators of HI, SBAI, AI and MWI for Asansol Municipal Corporation Area, West Bengal

	X_a	X_b	X_c	X_d	X_e	X_f	X_g	X_h	X_i	X_j	X_k	X_l	X_m	X_n	X_o	X_p	X_q	X_r	X_s
X_a	1																		
X_b	0.769**	1																	
X_c	0.171	0.041	1																
X_d	360*	0.461**	0.043	1															
X_e	− 0.187	− 0.164	− 0.065	0.466**	1														
X_f	0.741**	0.829**	0.126	0.651**	0.404**	1													
X_g	0.470**	0.531**	0.318*	0.451**	0.331*	0.627**	1												
X_h	0.735**	0.697**	0.295*	0.127	− 0.101	0.637**	0.526**	1											
X_i	0.689**	0.735**	0.116	0.669**	0.553**	0.910**	0.674**	0.616**	1										
X_j	0.602**	0.816**	0.066	0.702**	0.411**	0.863**	0.539**	0.527**	0.861**	1									
X_k	0.878**	0.862**	0.228	0.486**	0.257	0.867**	0.633**	0.794**	0.824**	0.790**	1								
X_l	0.622**	0.455**	0.489**	0.078	− 0.001	0.443**	0.421**	0.773**	0.438**	0.245	0.638**	1							
X_m	0.837**	0.871**	0.119	0.248	− 0.197	0.774**	0.491**	0.780**	0.705**	0.707**	0.903**	0.629**	1						
X_n	0.868**	0.796**	0.260	0.270	− 0.114	0.754**	0.551**	0.823**	0.654**	0.633**	0.927**	0.717**	0.914**	1					
X_o	0.729**	0.776**	0.133	0.278	0.296*	0.709**	0.374**	0.580**	0.634**	0.692**	0.783**	0.438**	0.888**	0.794**	1				
X_p	0.823**	0.838**	0.193	0.458**	0.364*	0.868**	0.599**	0.733**	0.859**	0.795**	0.938**	0.606**	0.922**	0.882**	0.867**	1			
X_q	0.695**	0.494**	0.268	0.203	0.073	0.458**	0.372**	0.809**	0.432**	0.276	0.650**	0.809**	0.710**	0.735**	0.505**	0.624**	1		
X_r	0.475**	0.609**	0.058	0.776**	0.430**	0.718**	0.386**	0.254	0.707**	0.771**	0.590U**	0.038	0.521**	0.440**	0.604**	0.660**	0.023	1	
X_s	0.772**	0.669**	0.211	0.001	0.062	0.553**	0.345*	0.703**	0.440**	0.443**	0.784**	0.666**	0.872**	0.887**	0.781**	0.783**	0.795**	0.277	1

*Correlation is significant at the 0.05 level (2-tailed)
**Correlation is significant at the 0.01 level (2-tailed)
Source Computed by the authors based on Census of India (2011)

Table 19.8 Principal component analysis of the components for HI, SBAI and AI for Asansol Municipal Corporation Area, West Bengal

HI						
Total variance explained						
Component	Initial eigenvalues			Extraction sums of squared loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	3.126	52.102	52.102	3.126	52.102	52.102
2	1.059	17.658	69.759	1.059	17.658	69.759
3	0.992	16.53	86.29			
4	0.486	8.092	94.381			
5	0.219	3.654	98.035			
6	0.118	1.965	100			
Extraction method: principal component analysis						
SBAI						
Total variance explained						
Component	Initial eigenvalues			Extraction sums of squared loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	5.747	71.832	71.832	5.747	71.832	71.832
2	1.016	12.694	84.525	1.016	12.694	84.525
3	0.585	7.314	91.84			
4	0.263	3.29	95.13			
5	0.183	2.292	97.422			
6	0.092	1.146	98.568			
7	0.081	1.015	99.583			
8	0.033	0.417	100			
Extraction method: principal component analysis						
AI						
Total variance explained						
Component	Initial eigenvalues			Extraction sums of squared loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	3.455	69.108	69.108	3.455	69.108	69.108
2	1.114	22.274	91.382	1.114	22.274	91.382
3	0.244	4.878	96.26			
4	0.109	2.173	98.434			
5	0.078	1.566	100			
Extraction method: principal component analysis						

Source Computed by the authors based on Census of India (2011)

spaces, green spaces (vegetation) and blue spaces (water bodies). It can be observed from the satellite imageries that a relatively denser structure of the built-up areas can be observed at the 4 km buffer zone. In the case of Fig. 19.4a, the tendency of the built-up areas to spread centring the major transportation route is evident. This intensity of increase in the built-up spaces tends to thin out towards the peripheral areas. However, in Fig. 19.4c as well as Fig. 19.4b, occasional increase in the intensity of the built-up areas can be noticed in the north north-eastern (NNE) part of the study region. A densely packed up core region thus suggests that this region might be experiencing a crunch in the availability of open spaces, and increased pressure on the existential resources that might have lowered the quality of life of the people staying in these regions.

To study the quality of green spaces two analyses, namely NDVI and ARVI, have been performed (Fig. 19.5). On one hand, when NDVI analysis is much more suitable to garner a rough overview of the nature of the available green patches, ARVI is much more suited to point out the quality of these patches by correcting the atmospheric influence. In the case of NDVI on average, the values tend to range from 0.48 to −0.16; however, minor variations can be noticed within the three buffers. From Fig. 19.5a, it can be observed that within the 4 km buffer, the central or the core region of the study area relatively has a lesser density of green patches as compared to the edge of the periphery. Although a high range can be noticed within the 8 km and the 12 km buffer zones, this range is higher in the case of the latter. The NDVI shows that green spaces are not uniformly distributed throughout the study region and there is a tendency for a gradual reduction of such spaces, especially in the central and the northern part of the study region. This shows that all people might not have access to such resources; hence, it might lead to the gradual deterioration in their quality of life. In the case of the ARVI analysis in Fig. 19.5d, it can be observed that the quality of vegetation is extremely poor within the 4 km buffer zone. In the case of Fig. 19.5e, it can be observed that a slight improvement in the quality of vegetation can be noticed beyond the core areas. However, it can be observed that neither can the quantity nor can the quality of the green patches be considered to be ideal for a good quality of life for the residents.

In the case of MNDWI, the values tend to range on an average from 0.40 to −0.65 (Fig. 19.6). However, within the 4 km and 8 km buffer, the maximum values of blue spaces are restricted to 0.24 and 0.25, respectively. This shows the presence of scant blue spaces within these two buffer regions. This shows that the available blue spaces are not adequately distributed across the study region. It can be observed that select wards of the study region have a higher availability of blue and green spaces; these wards are mostly located towards the periphery of the study region; hence, there is a greater chance that people staying in these wards tend to enjoy a better QoL as compared to the ones staying at the core. On the other hand, existing literature has pointed out that the presence of both blue and green spaces tends to have a positive impact on the quality of life of the people owing to the varied ecosystem services that are provided by these areas. Hence, it shows that the scant availability of blue spaces within the study region might have affected the QoL of the people.

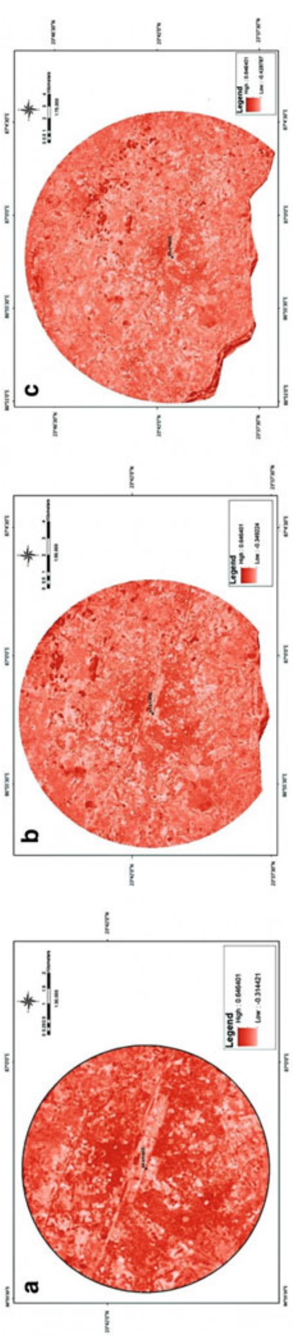


Fig. 19.4 Normalised difference built-up index analysis for Asansol Municipal Corporation Area, West Bengal (**a** for 4 km, **b** for 8 km, **c** for 12 km). *Source* Computed by the authors based on satellite imageries obtained from USGS, 2021

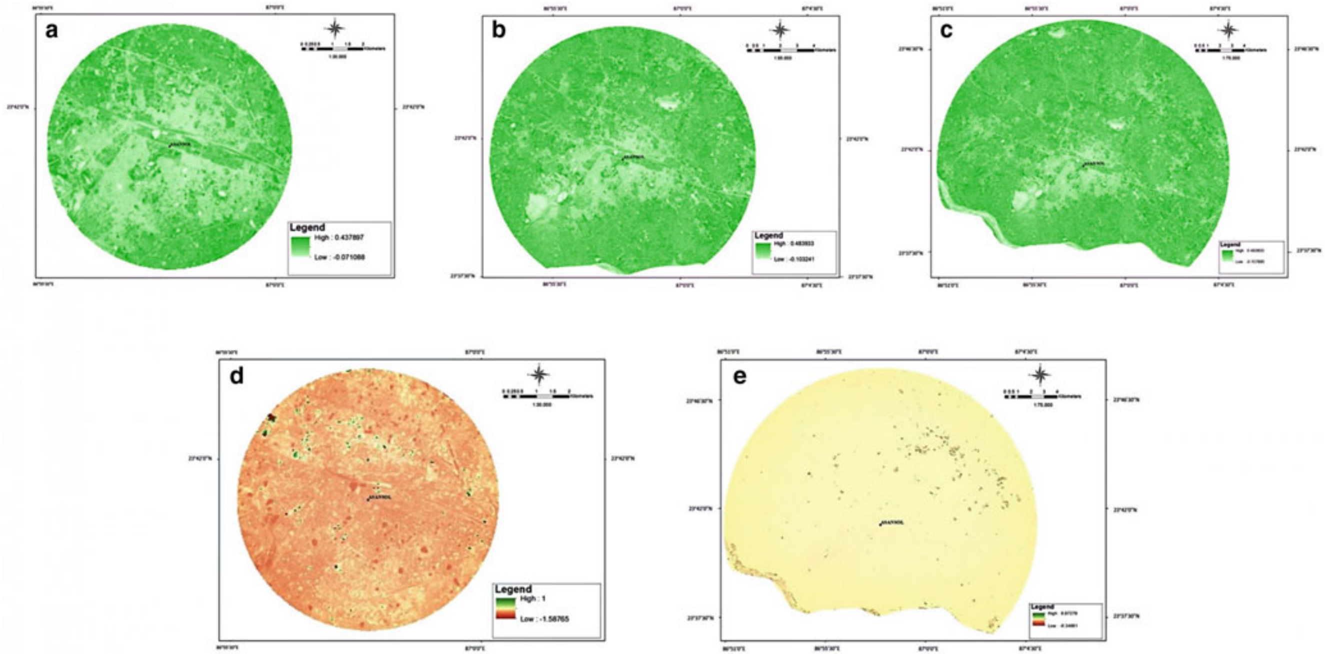


Fig. 19.5 Normalised difference vegetation index analysis for Asansol Municipal Corporation Area, West Bengal (**a** for 4 km, **b** for 8 km, **c** for 12 km) and atmospherically resistant vegetation index analysis (**d** for 4 km and **e** for 12 km). *Source* Computed by the authors based on satellite imageries obtained from USGS, 2021

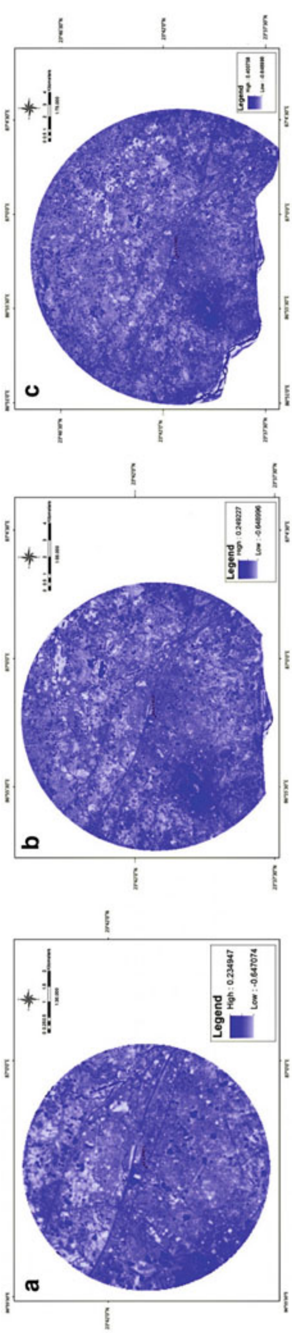


Fig. 19.6 Modified normalised difference water index analysis for Asansol Municipal Corporation Area, West Bengal (**a** for 4 km, **b** for 8 km, **c** for 12 km).*Source* Computed by the authors based on satellite imageries obtained from USGS, 2021

Conclusion

It can be observed that despite being the second largest urban agglomeration of West Bengal, there are certain loopholes in the provisions of urban amenities. The population of Asansol M. Corp. is 563,917 persons, out of which 292,387 are males and 271,530 are females. The literacy rate of Asansol city is 83%; however, a disparity in the male–female literacy rate can be noticed as the former has 88.31% literate, whereas the latter has 77.9% literate (Census of India 2011). The population is not evenly distributed across the different wards, where on one hand, ward 13 shows the lowest share of the population (0.54%, 3026 persons), whereas ward 28 shows the highest share of the population (5.9%, 33,265 persons), with the average population size being around 11,278 persons per ward. It is interesting to note that there is no linear relationship between population concentration and QoL, even the wards with low populations lag in the general wellbeing of the local people. Overall, the HI as well as the AI index is not very high among the different wards. This shows that a substantial section of people staying in this region does not have the affordability and access to procure good housing facilities. Their ability to possess various assets such as laptops/computers with internet facilities, their access to banking facilities and ownership of motorcycles is also pretty restricted. The SBAI index is also not very high. In the case of HI wards 27, 46, 38, 23 and 14 can be classified under the low category; in the case of SBAI wards, 7, 30, 11, 45 and 18 stands in a vulnerable condition and in the case of AI wards 43, 12, 42, 32, 46 are in a vulnerable condition. It shows that the ability of the people to have proper sanitation facilities and access to basic amenities is also limited. An increase in built-up spaces leading to the deterioration in the quality of green spaces and less availability of blue spaces can be observed. Efforts should be made to prevent the unsustainable land conversion of open resources to grey infrastructures or other built forms. This shows that looking at the present scenario, the study region is experiencing a resource crunch where the current infrastructural facilities are not able to handle the pressure of the population. This scenario has affected the QoL of most people, select wards such as wards 13, 11, 3, 30 and 6. In these wards, the intensity of built-up areas is greater, and as a result, these areas tend to have a less quantity of green spaces and blue spaces, and a summation of all these factors tends to affect the QoL. In terms of the combined attributed select 1, 30, 41 wards can be categorised as the best performer, and 36 and 28 wards can be categorised as the worst performer. It can be concluded by saying that the planning and implementation of niche schemes to improve the physical, green and blue infrastructures are much needed. A region-specific approach looking into the micro-level scenario would be ideal because of the high rate of differentials between the wards of the region. In addition to the improvement of the current infrastructure, creation of new infrastructures catering to the ward-specific requirements is needed to improve the QoL of the people.

References

Abutaleb K, Mudede MF, Nkongolo N, Newete SW (2021) Estimating urban greenness index using remote sensing data: a case study of an affluent vs poor suburbs in the city of Johannesburg. Egypt J Remote Sens Space Sci 24:343–351. https://doi.org/10.1016/j.ejrs.2020.07.002

Ambrey C, Fleming C (2014) Public greenspace and life satisfaction in urban Australia. Urban Stud 51:1290–1321

Anderson J, Ruggeri K, Steemers K, Huppert F (2017) Lively social space, wellbeing activity, and urban design: findings from a low-cost community-led public space intervention. Environ Behav 49(6):685–716

Arifwidodo S, Perera R (2011) Quality of life and compact development policies in Bandung, Indonesia. Appl Res Qual Life 6:159–179

Bandura A (2006) Adolescent development from an agentic perspective. Self Efficacy Beliefs Adolesc 5:1–43

Barcaccia B, Esposito G, Matarese M, Bertolaso M, Elvira M, De Marinis MG (2013) Defining quality of life: a wild-goose chase? Europe's J Psychol 9(1):185–203

Basu T, Das A (2023) Urbanization induced degradation of urban green space and its association to the land surface temperature in a medium-class city in India. Sustain Cities Soc 90:104373. Article No S2210670722006783. https://doi.org/10.1016/j.scs.2022.104373

Bhagat RB (2011) Urbanization and access to basic amenities in India. Urban India 31(1):1–14

Bhagvandas M (2021) Development of multifactor index for assessing quality of life of a tribal population of India: multilevel analysis approach. BMC Public Health 21(383):2–14

Boessen A, Hipp JR, Butts CT, Nagle NN, Smith EJ (2018) The built environment, spatial scale, and social networks: do land uses matter for personal network structure? Environ Plann B Urban Analytics City Sci 45(3):400–416

Bohnke P (2008) Does society matter? Life satisfaction in the enlarged Europe. Soc Indic Res 87:189–210

Cao X, Wu X, Yuan Y (2018) Examining built environmental correlates of neighborhood satisfaction: a focus on analysis approaches. J Plan Lit 33(4):419–432

Census (2001) Census tables. Office of the Register General & Census Commissioner, India, Ministry of Home Affairs, Government of India. https://censusindia.gov.in/census.website/data/census-tables

Census (2011) Census tables. Office of the Register General & Census Commissioner, India, Ministry of Home Affairs, Government of India. https://censusindia.gov.in/census.website/data/census-tables

Chaturvedi SK, Muliyala KP (2016) The meaning in quality of life. J Psychosoc Rehabil Ment Health 3:47–49

Clapham D, Foye C, Christian J (2018) The concept of subjective well-being in housing research. Hous Theory Soc 35(3):261–280

Clark B, Chatterjee K, Martin A, Davis A (2019) How commuting affects subjective wellbeing. Transportation 1–10

Das B, Mistri A (2013) Household quality of living in Indian states: analysis of 2011 census. Environ Urbanization Asia 4(1):151–171. https://doi.org/10.1177/0975425313477759

Das M, Das A, Momin S (2022a) Quantifying the cooling effect of urban green space: a case from urban parks in a tropical mega metropolitan area (India). Sustain Cities Soc 87, 104062. Article No S2210670722003808. https://doi.org/10.1016/j.scs.2022.104062

Das M, Das A, Pereira P (2022b) Developing an integrated urban ecological efficiency framework for spatial ecological planning: a case on a tropical mega metropolitan area of the global south. Geosci Front. https://doi.org/10.1016/j.gsf.2022.101489

Das A, Das M, Rejjak A (2020a) Evaluating profile of well-being status (material) of bottom ten backward districts in India: a households level analysis. GeoJournal 1–10

Das M, Das A, Mandal A (2020b) Assessing the level of living condition in Bundelkhand region of Central India: a households level analysis. GeoJournal 1–11

de Vos J (2019) Analysing the effect of trip satisfaction on satisfaction with the leisure activity at the destination of the trip in relationship with life satisfaction. Transportation 46(3):623–645
Diener E, Oishi S, Tay L (2018a) Advances in subjective well-being research. Nat Hum Behav 2(4):253–260
Diener E, Seligman MEP, Choi H, Oishi S (2018b) Happiest people revisited. Perspect Psychol Sci 13(2):176–184
Ettema D, Schekkerman M (2016) How do spatial characteristics influence wellbeing and mental health? Comparing the effect of objective and subjective characteristics at different spatial scales. Travel Behav Soc 5:56–67
Feng J, Tang S, Chuai X (2017) The impact of neighbourhood environments on quality of life of elderly people: evidence from Nanjing, China. Urban Stud
Foye C (2017) The relationship between size of living space and subjective well-being. J Happiness Stud 18(2):427–461. https://doi.org/10.1007/s10902-016-9732-2
Giannico V, Spano G, Elia M, D'Este M, Sanesi G, Lafortezza R (2021) Green spaces, quality of life, and citizen perception in European cities. Environ Res 196:110922. https://doi.org/10.1016/j.envres.2021.110922
Greyling T, Tregenna F (2017) Construction and analysis of a composite quality of life index for a region of South Africa. Soc Indic Res 131:887–930
Hajrasouliha A, del Rio V, Francis J, Edmonson J (2018) Urban form and mental wellbeing: scoping a framework for action. J Urban Des Mental Health 5(10):1–15
Haq R, Zia U (2008) Dimensions of well-being and millennium development goals. Pak Dev Rev 47(4):851–876
Haq R, Ahmed A, Shafque S (2010) Variation in the quality of life within Punjab: evidence from MICS, 2007–2008. Pak Dev Rev 49(4):863–879
Haque I (2016) Infrastructure development and access to basic amenities in class-I cities of West Bengal, India: insights from census data. J Infrastruct Dev 1–10
Howie P, Murphy SM, Wicks J (2010) An application of a stated preference method to value urban amenities. Urban Stud 47(2):235–256
Jana NC, Ghosh PK (2015) Socio-economic conditions and quality of life in the tribal areas of Orissa with special reference to Mayurbhanj district. Space Culture India 3(2):25–41
Jokela M, Bleidorn W, Lamb ME, Gosling SD, Rentfrow PJ (2015) Geographically varying associations between personality and life satisfaction in the London metropolitan area. Proc Natl Acad Sci 112(3):725–730
Kent JL, Thompson S (2014) The three domains of urban planning for health and well-being. J Plan Lit 29(3):239–256
Kingdon GG, Knight J (2006) Subjective well-being poverty vs. income poverty and capabilities poverty? J Dev Stud 42(7):1199–1224
Kyte D, Reeve BB, Efficace F, Haywood K, Mercieca-Bebber R, King MT, Norquist JM, Lenderking WR, Snyder C, Ring L, Velikova G (2016) International society for quality-of-life research commentary on the draft European medicines agency reflection paper on the use of patient-reported outcome (PRO) measures in oncology studies. Qual Life Res 25(2):359–362
Kyttä M, Broberg A, Haybatollahi M, Schmidt-Thomé K (2016) Urban happiness: context-sensitive study of the social sustainability of urban settings. Environ Plann B Plann Des 43(1):34–57
Lee SM, Conway TL, Frank LD, Saelens BE, Cain KL, Sallis JF (2017) The relation of perceived and objective environment attributes to neighborhood satisfaction. Environ Behav 49(2):136–160
Li L, Young D, Wei H, Zhang Y, Zheng Y, Xiao S, Wang X, Chen X (2010) The relationship between objective life status and subjective life satisfaction with quality of life. Behav Med 23(4):149–159
MacKerron G, Mourato S (2009) Life satisfaction and air quality in London. Ecol Econ 68:1441–1453
Markevych I et al (2017) Exploring pathways linking greenspace to health: theoretical and methodological guidance. Environ Res 158:301–317
Miao J, Wu X, Sun X (2019) Neighborhood, social cohesion, and the elderly's depression in Shanghai. Soc Sci Med 229:134–143

Morrison PS, Weckroth M (2017) Human values, subjective well-being and the metropolitan region. Reg Stud 1–13
Mouratidis K (2018a) Rethinking how built environments influence subjective wellbeing: a new conceptual framework. J Urbanism Int Res Placemaking Urban Sustain 11(1):24–40
Mouratidis K (2018b) Is compact city livable? The impact of compact versus sprawled neighbourhoods on neighbourhood satisfaction. Urban Stud 55(11):2408–2430
Mouratidis K (2019) Compact city, urban sprawl, and subjective well-being. Cities 92:261–272
Mouratidis K (2020) Commute satisfaction, neighborhood satisfaction, and housing satisfaction as predictors of subjective well-being and indicators of urban livability. Travel Behav Soc 21:265–278
Mouratidis K (2021) Urban planning and quality of life: a review of pathways linking the built environment to subjective well-being. Cities 115:103229
Mouratidis K, Poortinga W (2020) Built environment, urban vitality and social cohesion: do vibrant neighborhoods foster strong communities? Landsc Urban Plan 204:103951
Muhammad S, Sabo A (2017) The impact of material wellbeing and safe drinking water on quality of life in Africa. Int J Novel Res Mark Manag Econ 4(2):1–7
Nguyen AT, Tran TQ, Vu HV, Luu DQ (2018) Housing satisfaction and its correlates: a quantitative study among residents living in their own affordable apartments in urban Hanoi, Vietnam. Int J Urban Sustain Dev 10(1):79–91
Nguyen P-Y, Astell-Burt T, Rahimi-Ardabili H, Feng X (2021) Green space quality and health: a systematic review. Int J Environ Res Public Health 18:11028. https://doi.org/10.3390/ijerph182111028
Okulicz-Kozaryn A, Mazelis JM (2018) Urbanism and happiness: a test of Wirth's theory of urban Life. Urban Stud 55(2):349–364
Pfeiffer D, Cloutier S (2016) Planning for happy neighborhoods. J Am Plann Assoc 82(3):267–279
Sinha S, Basu A (2022) Changing levels of disparity in material well being: highlighting rural urban differentials in West Bengal, India. GeoJournal 1–19
Small ML, Adler L (2019) The role of space in the formation of social ties. Ann Rev Sociol 45(1):111–132
Tang J, Long Y (2019) Measuring visual quality of street space and its temporal variation: methodology and its application in the Hutong area in Beijing. Landsc Urban Plan 191:103436. https://doi.org/10.1016/j.landurbplan.2018.09.015
Tonne C et al (2021) Defining pathways to healthy sustainable urban development. Environ Int 146:106236
Ugolini F et al (2020) Effects of the COVID-19 pandemic on the use and perceptions of urban green space: an international exploratory study. Urban Forest Urban Greening 56:126888
Vijaya N, Krishnan GSS (2014) Characterization of semi-open subcomplexes in abstract cellular complex. In: C. Intelligence (ed) Cyber security and computational models. Springer, Berlin, pp 275–283
Wang F, Wang D (2016) Place, geographical context and subjective well-being: the state of art and future directions. Mobility, sociability and well-being of urban living. Springer, Berlin, pp 189–230
Wang F, Wang D (2019) Changes in residential satisfaction after home relocation: a longitudinal study in Beijing, China. Urban Stud 1–14
Wang R, Feng Z, Pearce J, Liu Y, Dong G (2021) Are greenspace quantity and quality associated with mental health through different mechanisms in Guangzhou, China: a comparison study using street view data. Environ Pollut 290:117976
White MP, Alcock I, Wheeler BW, Depledge MH (2013) Would you be happier living in a greener urban area? A fixed-effects analysis of panel data. Psychol Sci 24:920–928
White MP, Elliot LR, Gascon M, Roberts B, Flemming LE (2020) Blue space, health and wellbeing: a narrative overview and synthesis of potential benefits. Environ Res 191:110169. https://doi.org/10.1016/j.envres.2020.110169

Won FY, Yang L, Yuen JWM, Chang KKP, Wong FKY (2018) Assessing the quality of life using WHOQOLBREF: a cross-sectional study on the association between quality of life and neighborhood environmental satisfaction, and the mediating effect of health-related behaviors. BMC Public Health 18:1113

Wu Y-T, Claire L, Jones IR, Nelis SM, Quinn C, Martyr A, Victor CR, Lamont RA, Rippon I, Matthews FE (2021) Perceived and objective availability of green and blue spaces and quality of life in people with dementia: results from the IDEAL programme. Soc Psychiatry Psychiatr Epidemiol 56:1601–1610. https://doi.org/10.1007/s00127-021-02030-y

Xie J, Luo S, Furuya K, Sun D (2020) Urban parks as green buffers during the COVID-19 pandemic. Sustainability 12(17):6751

Zhang Y, Van den Berg AE, Van Dijk T, Weitkamp G (2017) Quality over quantity: contribution of urban green space to neighborhood satisfaction. Int J Environ Res Public Health 14(5):1–12

Chapter 20
Analysing Land Use Transformation and Water Security: Evidence from the Global North and the Global South

Arindam Biswas, Vibhu Singh, and Zhu Qian

Abstract The chapter investigates the pattern of land use transformation and water security in cities from the global north and the global south. The study considers Toronto and National Capital Territory Delhi (NCT Delhi) to investigate the approach and pattern of urban water management to meet the water demand with the changing land use transformation and built form intensification. The chapter also recognises the different contexts and challenges experienced by the cities of the two hemispheres. The motivation for the study comes with the global recognition of water as a crucial resource for human sustenance and the opportunity to learn between the global north and south through a case study approach.

Keywords Land use transformation · Spatio-temporal analysis · Water security · Built form intensification · Rapid urbanisation · Groundwater

Introduction

The rate of urbanisation has experienced a rapid increase in the past 50 years across the globe. The United Nations (UN) has estimated that by the year 2050, 68% of the world's population will live in urban areas (Ritchie 2018). This rapid urbanisation results in a rapid transformation of land use affecting the infrastructure demand and consumption patterns. This study considers two regions, i.e. Toronto and National

A. Biswas (✉)
Department of Architecture and Planning, Indian Institute of Technology (IIT) Roorkee, Roorkee, Uttarakhand 247667, India
e-mail: arindam.biswas@ar.iitr.ac.in

V. Singh
School of Planning and Architecture New Delhi, 4-Block-B, Indraprastha Estate, New Delhi 110002, India
e-mail: vibhusingh125@gmail.com

Z. Qian
Faculty of Environment, School of Planning, University of Waterloo, Environment 3 (EV3), Third Floor, Waterloo, Canada
e-mail: z3qian@uwaterloo.ca

U. Chatterjee et al. (eds.), *Urban Commons, Future Smart Cities and Sustainability*, Springer Geography, https://doi.org/10.1007/978-3-031-24767-5_20

Capital Territory Delhi (NCT Delhi), to explore the urban water security and urban water management during land use transformation and built form intensification.

Rapid urbanisation took place at the beginning of the nineteenth century and continued throughout the twentieth century in Canada. Canada's three largest census metropolitan areas (CMAs)—Toronto, Montreal and Vancouver—cover one-third of its population. In 2018, almost 26.5 million people were living in the CMAs (Statistics Canada 2019). In India, steady urbanisation took place with a small growth in the urbanisation trend at the beginning of the twentieth century. The population is increasing in Hyderabad, Bengaluru, Chennai and Delhi and decreasing in Mumbai and Kolkata (Census of India 2011). In 2019, the annual population growth of India and Canada was 1.42% and 1.01%, respectively.

With this pace of urbanisation, the core infrastructure facilities are under continuous stress. Water, one of the most significant resources of the planet, needs to be managed appropriately to ensure a sustainable future for these megacities. The two cities are selected, i.e. Toronto and NCT Delhi, from the global north and the global south, to assess and compare the impact of rapid urbanisation on water security and how the cities address the water security issues. Toronto and Delhi are two important cities in their respective region and faces extreme challenges from rising urbanisation, pollution, land use transformation, and threats of climate change. The local and regional administrations of both cities work hard to achieve water security and meet the desired water quality standard. While Toronto is very particular about maintaining its water adequacy with proper planning and management, NCT Delhi struggles to secure a stable water supply for its citizen. A comparative study from one of the populous cities of the global north will be extremely important for Delhi to comprehend the approach and methods of creating water secured city. This study analyses the water consumption patterns of both cities and the changes in land use dynamics. The research contributes towards a deeper understanding of how the geography and socio-demography of the cities in distinct locations affect water consumption. The objectives of the research are:

i. to study the background and demography of Toronto and NCT Delhi;
ii. to assess the land use land cover change in these cities in the past two decades; and
iii. to analyse the water security and water adequacy.

Section Introduction discusses the background of urbanisation over the past decades and compares the two at the country level. The remaining chapter consists of seven sections. Section Literature Review includes the literature review from the previous research on Toronto and NCT Delhi on spatio-temporal and land use land cover changes. Sections Study Areas and Demographic Profile—A Comparison discuss the two study areas and compare their respective demographic profiles. Section Spatio-Temporal Changes—A Comparison compares the spatio-temporal changes through the mapping of land use and land cover changes over the past two decades. Sections Water Management in Toronto and Water Management in NCT Delhi discuss the water management status in Toronto and NCT Delhi and the conservation measures suggested and implemented by the respective regulating authorities.

Finally, Sect. Discussion and Conclusion the chapter with the final arguments and a summary of the analysis.

Literature Review

The Greater Toronto Area (GTA) comprises the regions like York, Halton, Durham, Peel, Hamilton, and the City of Toronto. Toronto is the biggest metropolitan area of the Greater Toronto Area and experiencing a gradual growth of population compared to other cities. Toronto is the most populous city in the region and achieved a point of population saturation. Therefore, the increase in population is not prominent as compared in other areas.

Wang (2015) mapped the urban growth of Toronto from the year 1974–2014. The imageries from Landsat 1 and 2 (Multi-spectral scanner), Landsat 5 (Thematic mapper), Landsat 7 (Thematic mapper plus) and Landsat 8 (Operational lands imager) were used as the main datasets for the input. The imageries were acquired from the United States Geological Survey's (USGS) Landsat Data Archive (Wang 2015). The city of Toronto consists of various types of land cover such as lakes and rivers, highly dense urban areas, and the rural area along with agricultural land, forests. The multi-spectral change detection for the period 1974–2014 helped to assess the growth and expansion pattern in Toronto.

Figure 20.1 visually analyses the temporal growth of the built-up area of the GTA. The analysis suggests a radiated expansion of built forms from the urban centres, especially in the city of Toronto. The GTA also expanded like a ribbon along Lake Ontario. The increase in population was strongly correlated to the urban expansion of the area.

The most significant expansion was observed between 1984–89 and 1999–2004, with an annual growth rate of 4.3% and 3.6%, respectively. The negative trend in early 1974–79 could be due to the error of poor data acquired by Landsat 1. The expansion in the period 2004–2009 is only recorded to be 0.1%. We argue that the decrease in population growth percentage is due to the population saturation of the GTA. The urban expansion in the subsequent period is delayed by the notable population increase in the previous years as the city prepares for its infrastructure needs (Wang 2015). In the case of Toronto, the city was well urbanised in the late twentieth century. The downtown area of the city of Toronto was the main focal point of urban expansion and influenced the growth in the surrounding regions.

Dutta and Rahman (2017) record the urban growth and the land use and land cover changes in Delhi between 1977–2014 (Dutta and Rahman 2017). The study uses the satellite imageries of Landsat 1 and 2 (Multi-spectral scanner), Landsat 5 (Thematic mapper) and Landsat 8 (Operational lands imager) during the winter season (February–March) to avoid cloud cover in the imageries for better analysis. The pre-processing of Landsat data was done in 1977, 2003 and 2014. The field observation is then accurately assessed and compared with the pre-processing and classification results to obtain urban growth analysis in NCT Delhi.

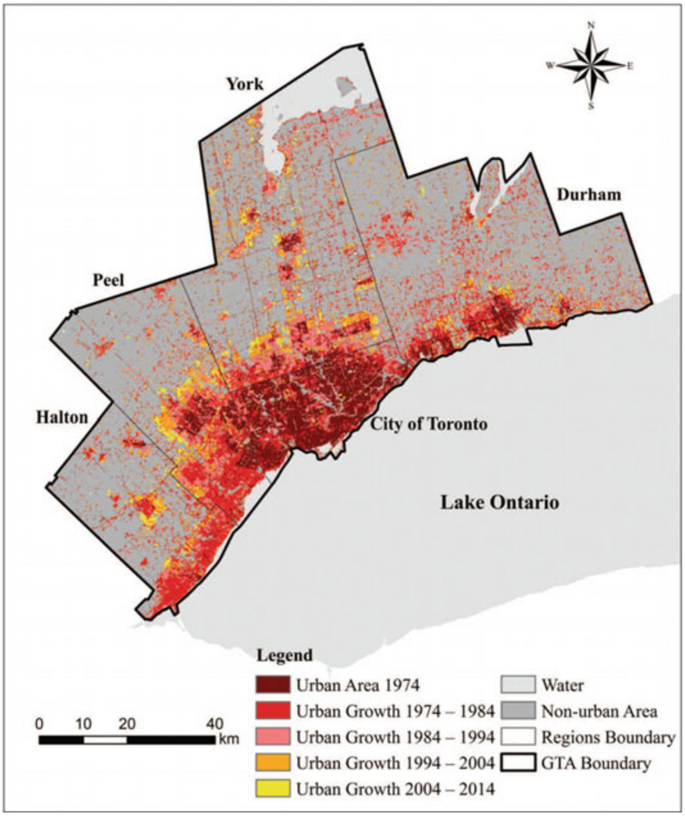


Fig. 20.1 Multi-temporal change detection from 1974 to 2014 (Wang 2015)

In 1977, agricultural land use was predominant, along with the patches of high-density built-up areas and sparse vegetation. High-density built-up areas are mostly observed in Central Delhi and East Delhi along the river Yamuna. In 2003, the built-up areas were densified in the North-West and Southern areas. An increase in sparse vegetation can be observed along with the development of low-density built-up areas in the east. The dense vegetation during 1977–2003 has also decreased subsequently. In 2014, a sharp increase in high-density built-up areas can be observed in the core area and in the Southern areas. The dense vegetation has also increased from the earlier observation period in 2003.

The quantum of land use change can be observed in terms of the percentage change of each class during the two consecutive periods in Table 20.1. In 1977–2003, the change in built-up areas was recorded as 7.16%, and the decrease in sparse vegetation by about 12.2%. The decrease in vegetation is reciprocal for accommodating more built-up areas during this period A sharp increase of almost 20% was observed from 2003 to 2014, accompanying the decrease in sparse vegetation and agricultural land.

Table 20.1 Percentage change in land use of NCT Delhi (1977–2014) (Dutta and Rahman 2017)

LULC classes	Area in percentage (NCT Delhi)			Change (%)	
	1977	2003	2014	1977–2003	2003–2014
High-density built-up	1.62	8.79	28.42	7.16	19.63
Low-density built-up	11.03	25.52	19.01	14.5	−6.51
Dense vegetation	7.61	8.91	10.62	1.31	1.7
Agricultural land	38.23	31.42	26.96	−6.81	−4.46
Sparse vegetation	29.01	16.81	8.41	−12.2	−8.4
Water body	1.98	1.54	1.47	−0.44	−0.07
Wasteland	10.52	7	5.11	−3.52	−1.89
Total	100	100	100		

This study shows that the expansion of built-up areas in NCT Delhi was only about 12.65% of the total area in 1977. The built-up area expanded to approximately 50% of the total area of NCT Delhi by 2014. This expansion was recorded for a period of 37 years. In another study of NCT Delhi, the spatio-temporal transformations were recorded by (Sirkarwar and Chattopadhyay 2015) using the land use and land cover analysis technique for the past three decades following the census years. Delhi was compared with other metropolitan areas of India such as Mumbai, Chennai, Bengaluru, Kolkata and Hyderabad. It was observed that the built-up area in NCT Delhi was 27% in 1991, 42% in 2001 and approximately 65% in 2011. It corroborates with the other study confirming the rapid pace of urbanisation in NCT Delhi. In comparing Toronto with NCT Delhi, it can be observed that the rate of urban expansion in NCT Delhi from 1977–2014 was much more than in Toronto in the period 1974–2014. Since the city of Toronto was already urbanised in 1974, a significant expansion is observed in the case of NCT Delhi.

Study Areas

The research investigates two study areas, each selected from the global north and the global south. The two cities selected for the case study are Toronto and NCT Delhi. The two cities are selected to assess and compare the spatio-temporal transformations and land use changes and their subsequent impacts on the water security of cities and also, to observe the current water conservation practices implemented in the cities by the respective authorities.

Toronto, Canada

Toronto is the most populous city in Canada and the provincial capital of Ontario. It caters to a population of 2,731,571 (Toronto Census 2016). Toronto covers an area of 630.2 km^2. Its borders are formed by Lake Ontario in the South, Steeles Avenue in

Fig. 20.2 Regions of the Greater Toronto Area (University of Toronto 2018)

the North, Scarborough in the east, and the western boundary of Marie Curtis Park. Figure 20.2 shows the nearby regions of Toronto, including the regions of York, Durham, Peel, Halton and the city of Hamilton.

The growth in the GTA is influenced by the growth of Toronto city as it acts as the centre of development of the urban region. The Toronto area comprises 45% of the total population of the GTA (Census Backgrounder Report—2016). This study mainly focuses on understanding the impact of land use dynamics on the water consumption patterns of the city of Toronto. The density of Toronto is 4150 persons per km^2. Which is the largest compared to the rest of the regions of GTA (Table 20.2). Toronto is the most populous city in the GTA, catering to 630 km^2. Toronto has undergone a series of administrative or spatial changes over the past few decades. In 1998, the six lower-tier municipalities York, East York, North York, Etobicoke, Scarborough, and Toronto, amalgamated into the city of Toronto, thus expanding it greatly.

NCT Delhi, India

Delhi, or the National Capital Territory of Delhi (NCT Delhi), is bordered by two states, Haryana on three sides and Uttar Pradesh on the east. NCT Delhi covers an area of 1484 km^2. The city of Delhi caters to a population of eleven million, while NCT Delhi caters to 16.8 million (Census of India 2011). NCT Delhi has five municipal corporations, which are New Delhi Municipal Council (NDMC), East Delhi Municipal Corporation (EDMC), North Delhi Municipal Corporation (NDMC), South Delhi Municipal Corporation (SDMC), and Delhi Cantonment. The SDMC is spread across Southern and Western Delhi comprising Janakpuri, Dwarka, Tilak Nagar, Sadar Bazaar, Chandni Chowk, etc. (Fig. 20.3).

Table 20.2 Comparison of regions of the Greater Toronto Area (Toronto Census 2016)

	Total area (km^2)	Population	Density (persons per km^2)
Durham	2523.15	645,862	241
York	1761.84	1,109,909	586
Peel	1241.99	1,381,739	1040
Halton	967.17	548,435	520
City of Toronto	630	2,731,571	4150
Greater Toronto Area	7124.15	6,417,516	850

Fig. 20.3 Map of NCT Delhi (right) and its location in India (right)

Demographic Profile—A Comparison

Toronto, Canada

Toronto is the most populous city in the country and serves as the centre of the economy for the country. Delhi has been one of the fastest-growing cities in India. A large portion of this population increase has been due to continuous migration. NCT Delhi also attracts the population from nearby cities such as Ghaziabad, Noida, Greater Noida and Gurgaon.

The population of Toronto grew by 3.8% during 1991–1996, 4.8% during 1996–2001, 4% during 2001–2006, 1% during 2006–2011 and 4.5% during 2011–2016 (Fig. 20.4) (Statistics Canada 2016).

While reviewing the population growth rate of Toronto during 2001–2011, an abrupt decrease is observed in the year 2006. Toronto records only a 0.9% population

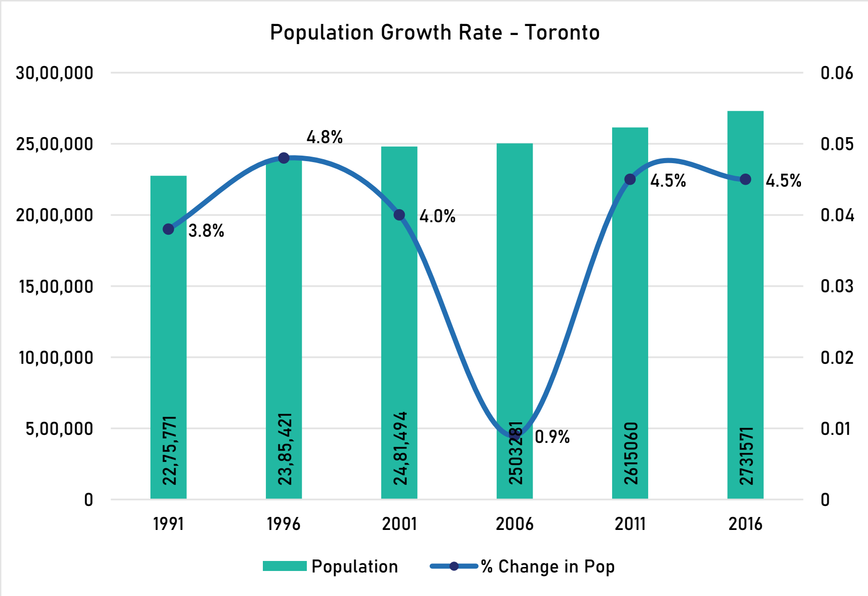


Fig. 20.4 Population growth rate of Toronto over the last two decades. *Source* Census of Population 2016, Statistics Canada

growth rate from 2001 to 2006. This unusual decline in the percentage change in the population reflects the likelihood of the Census missing more people for records than it usually does. The statistical data shows a difference of 61,270 units (5.9% of the total units) between the total dwelling count and the personal dwellings occupied by the residents. The 2001 census report shows only 22,475 such units (2.3% of the total (Toronto Census 2006)).

The choropleth mapping of population density persons per hectare (pph) of Toronto for the years 2011 and 2016 shows the concentration of population and the manner of population densification at particular regions over the years (Fig. 20.5).

In 2011, 60 pph or more population density was observed in Wards 14, 17, 18, 19, 20, 21, 22 and 27, comprising Parkdale, Davenport and Main Toronto Centre. In 2016, population density increased from approximately 55–70 pp ha. in wards 23, 26, 31 and 32, comprising Willowdale, East York and Parkwoods. The areas with the largest population percentage changes, i.e. more than 50% increase, are located in Toronto Waterfront, Mimico area, and King West.

NCT Delhi, India

In the case of NCT Delhi, the aggregate population growth rate for the decade 2001–2011 is 21.21%. The population growth in NCT Delhi is recorded much more than in Toronto during the same period. Table 20.3 shows the summary of the demographic profile of each district of NCT Delhi.

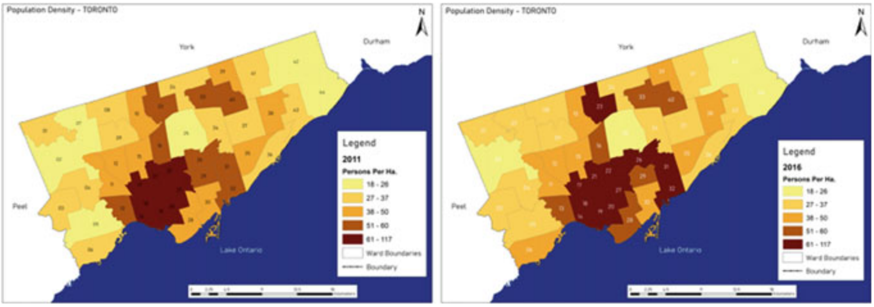


Fig. 20.5 Choropleth map representing population density—Toronto 2011 (left) and 2016 (right). *Source* Authors

Table 20.3 Demographic details of NCT Delhi—District-wise (Census of India 2011; Biswas and Gangwar 2020)

District	Area (in km^2)	Population	Population growth rate 2011	Population growth rate 2001	Density (p.p. km^2)	No. of households
North-West	443	3,656,539	27.81	60.91	8254	732,966
South	247	2,731,929	20.51	50.95	11,060	568,863
West	130	2,543,243	19.46	48.56	19,563	530,467
North-East	62	2,241,624	26.78	62.92	36,155	404,676
South-West	421	2,292,958	30.65	61.37	5446	491,521
East	63	1,709,346	16.79	43.06	27,132	357,173
North	61	887,978	13.62	13.82	14,557	174,779
Central	21	582,320	−9.91	−1.55	27,730	115,090
New Delhi	35	142,004	−20.72	6.19	4057	32,051
Delhi State	1483	16,787,941	21.21		11,320	3,407,586

East, north-east, central, and western districts of NCT Delhi cater to a larger population than other parts of the city. The first map is the dot-density map which helps to understand the relationship between the number of persons residing in the area and the spatial area of that district. The second map is the choropleth map of population density which shows that the north-eastern district is the most densified compared to other districts in terms of population density. The third is a bivariate map showing the decadal population growth rate for two decades, i.e. 1991–2001 and 2001–2011 (Fig. 20.6). The south-western district has witnessed the highest population growth. Central Delhi and New Delhi witnessed a declining population growth during 2001–2011. The north-western district has the largest number of households, while the south, west and south-western districts have more than 500,000 households in each (Biswas and Gangwar 2020).

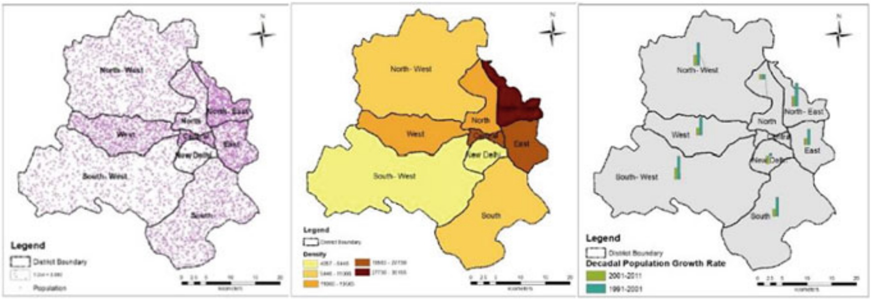


Fig. 20.6 Population distribution, population density and population growth maps of NCT Delhi's districts (Biswas and Gangwar 2020)

Thus, the demography of NCT Delhi shows that the western district has more potential for growth in the future as the eastern district has reached its saturation in terms of accommodating population.

Spatio-Temporal Changes—A Comparison

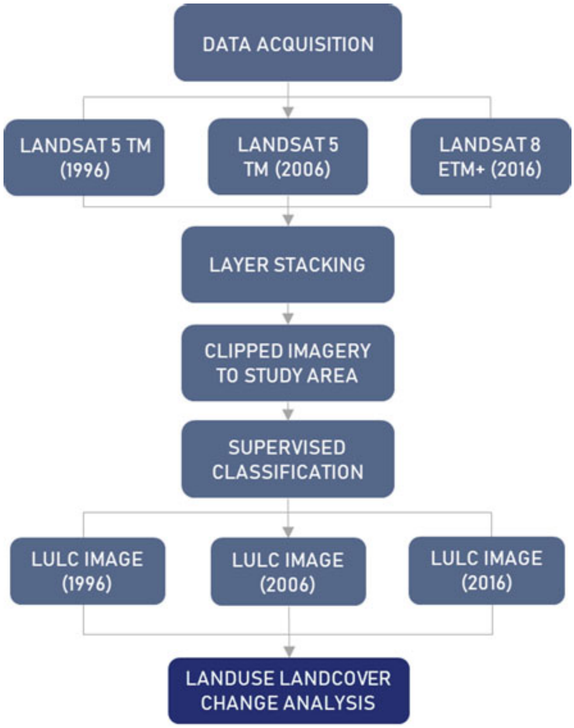
The land use and land cover change technique is used to analyse the spatio-temporal growth of the city of Toronto. The supervised classification in ArcGIS software from the Landsat 4–5 and Landsat 8 imageries for the years 1996, 2006 and 2016 is used for the change detection analysis. The imageries obtained have a spatial resolution of 30 m. The Landsat imageries are retrieved from the United States Geological Survey website. These specific years were selected to correlate with census data availability and the needs of the research. Land use is classified into five categories: built-up area, roads, vacant land, vegetation and water. The limitation of the land use and land cover analysis is that the Landsat imagery received for the year 1996 is not clear and may affect the outcome. The methodology followed to calculate land use land cover change analysis is given in Fig. 20.7.

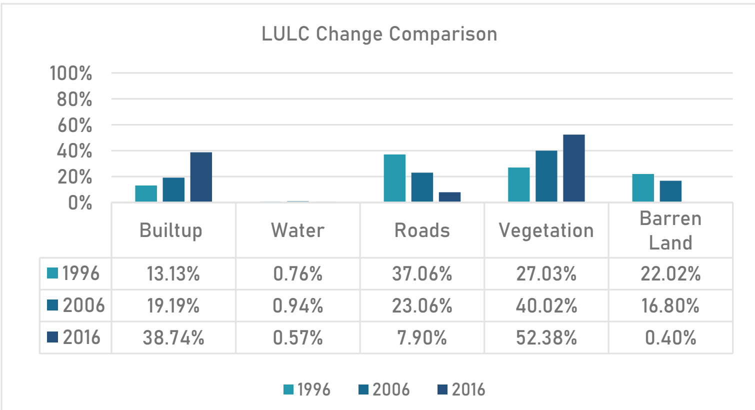
The change in built-up areas for two decades can be visually observed in Fig. 20.8. It shows the concentration of built-up in Etobicoke, York University Heights, Old Toronto, and the downtown area of Toronto, etc. The remote sensing imagery analysis of 1996 may not be accurate due to the poor quality of imagery retrieved.

Toronto, Canada

Comparing the land use land and cover change (LULC) of 2006 and 1996, it is observed that the built-up area concentrated more on the eastern side, i.e. Scarborough, North York, parts of Etobicoke and Malvern. Further comparing the LULC imagery of 2016 and 2006, expansion of city centres such as Midtown Toronto and New Toronto area was observed. The analysis also reveals built-up area densification in downtown, Newtonbrook along Yonge Street, Etobicoke and North York.

Fig. 20.7 Methodology for land use and land cover change analysis process





	Builtup	Water	Roads	Vegetation	Barren Land
1996	13.13%	0.76%	37.06%	27.03%	22.02%
2006	19.19%	0.94%	23.06%	40.02%	16.80%
2016	38.74%	0.57%	7.90%	52.38%	0.40%

Fig. 20.8 Land use and land cover change comparison (1996–2016)

The quantum of change in land use for the two decades, i.e. 1996–2006, and then 2006–2016 can be compared in Fig. 20.8. It can be inferred that the built-up area has increased from 13.13 to 19.19% in 2006, i.e. an increase of approximately 6%. From 2006 to 2016, the percentage of the built-up area almost doubled from 19.19% in 2006 to 38.74% in 2016. The percentage of surface water is only 1% of the total land cover. The decline in roads is particularly observed in 2016. The satellite imagery detects the presence of trees along the roads which covers a large portion of road areas. Since 1996 vegetation has increased at approximately 12% per decade until 2016. In the case of barren land, there was a sudden decrease in percentage between 2006 and 2016 due to a sudden increase in the built-up area.

NCT Delhi, India

In the study by (Biswas and Gangwar 2020), the land use and land cover change analysis is calculated using the thematic services of Bhuvan, the Indian Geo-Platform of the Indian Space Research Organisation (ISRO). This thematic service is used to acquire land use and land cover maps of NCT Delhi for 2006, 2012, and 2018. The collected maps are overlaid to study the change in various land cover categories. The limitation of the study is the very large-scale maps retrieved as the study area and the difficulties in calculating the approximate change in the built-up area at the city scale. Therefore, a macro-level study was performed for more accurate information. The city is divided into 14 $\times$ 14 km grids. The overlaid layers are analysed for each grid, and the approximate percentage change is recorded.

Built-up areas in the south-west, north-west and western districts have increased 5–20% from 2006 to 2018. The 'urban growth monitoring system' of NCT Delhi helped detect the direction of growth in the western districts. One of the reasons for such transformation is the large portion of urbanisable area demarcated in the Master Plan of Delhi 2021.

Water Management in Toronto

In Toronto, the 'Toronto Water Division' is a municipal division under 'Infrastructure and Development Services' that is accountable for managing and monitoring the water supply network. All the facilities related to water supply and its network, such as treatment plants, pumping stations, water mains, are managed by the Toronto Water Division. The water supply system and the treatment facility consist of eighteen pumping stations, four elevated storage tanks, eleven underground reservoirs, four treatment plants and more than 6000 km of water distribution pipeline network (Toronto Water Division 2020). The major water source for the city of Toronto is the Ontario Lake adjacent to the downtown area. The daily water demand in Toronto rises in July, the warmest month of the year.

The behavioural analysis and per capita water consumption patterns are done by analysing the choropleth maps for each ward. The darker colour indicates more consumption. The mapping is done for two periods, i.e. 2006 and 2015. The data for

2016 was unavailable to carry out the analysis. The closest spatial data to the census year is available for the year 2015, which is considered for the research. The analysis will help assess the water security of a decade in terms of total water consumption and per capita water consumption.

Figure 20.9 shows the map of total water consumption of Toronto city in million litres per day (MLD) for the years 2006 and 2015. In 2006, wards 2, 5, 6, 20, 27, 28 and 37 had the highest cumulative water consumption of 11 MLD or more. These areas include parts of Etobicoke, Trinity and Toronto's downtown area. The least total water consumption, i.e. below 4.5 MLD, was observed in wards 13, 17, 18, 29 and 32, covering areas of Parkdale, Davenpor, etc. Between 2006 and 2015, the total water consumption decreased in wards 5, 9 and 6, which are the areas of Etobicoke, and York Centre areas, by approximately 1.45 MLD. In ward number 32, i.e. the East York area, the total water consumption increased by 1.5 MLD. The mapping was done for 2006 and 2015 to study per capita water consumption. The per capita consumption is mapped in litres per capita per day (LPCD). The highest per capita water consumption of 160 L or more is observed in wards 2, 5, 6, 7, 8, 11, 20, 27 and 28, which majorly include large parts of Etobicoke and the downtown area of Toronto (Fig. 20.10).

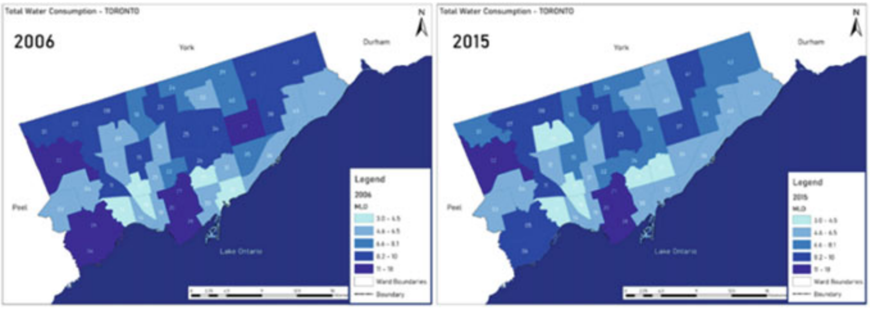


Fig. 20.9 Total water consumption for the year 2006 (left) and 2015 (right) in Toronto

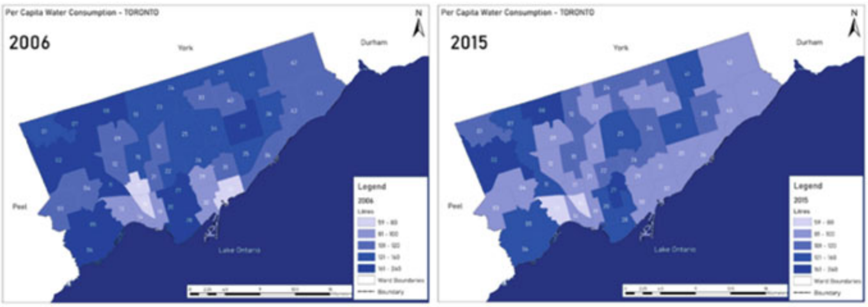


Fig. 20.10 Per capita water consumption for the year 2006 (left) and 2015 (right) in Toronto

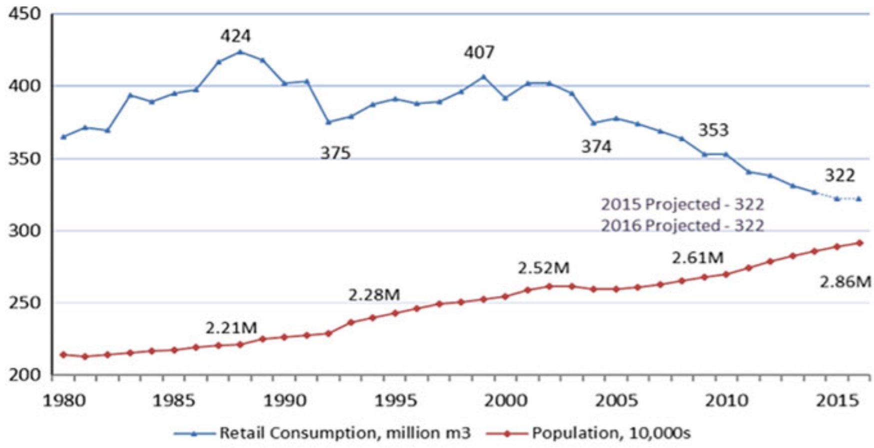


Fig. 20.11 Toronto water consumption comparison with population growth (1980–2015) (Toronto Water Division 2016)

Per capita, water consumption declined by approximately 20 LPCD in Eastern and South-Eastern Toronto between 2005 and 2016. A declining trend is observed for both total and per capita water consumption.

Figure 20.11 compares the water consumption and population of Toronto over 35 years, showing a similar trend of declining water consumption from 2005 to 2015. It can be seen that the population over the years has increased at a significant rate, but water consumption has decreased. The water consumption in 2005 was recorded to be 374 million m^3, and the population was approximately 2.52 million. In 2015, the population expanded to 2.86 million at the rate of 4.5%. However, the water consumption recorded was only 322 million m^3. The weather conditions influenced this decline in water consumption. This decline is justified by water efficiency measures and other significant economic factors (Toronto Water Division 2016).

Bennett (2013) studies the correlation between the decline in water demand and water pricing. From 2005 to 2011, it was observed that a 6% decline in the water main breaks would only contribute 0.06% to the decline in water consumption. Therefore, water main breaks are not a significant factor in decreasing water consumption patterns. The decline in water consumption patterns was assessed through the changes in water pricing. Toronto city implemented an aggressive water pricing strategy for the conservation of water. Water pricing has been revised every year since 2003, with an increment ranging from 6 to 10.8% (Bennett 2013). Toronto witnessed a 24% decline in per capita water consumption due to the rising water price. Before 2008, water pricing was based on a seven-step block rate structure. In 2008, this approach was revised and a general rate for all of the water consumed was adopted for the citizens consuming less than or equal to 6000 m^3. The water pricing increased from CAD 1.35/m^3 in 2005 to CAD 2.28/m^3 in 2011 for residents of the city (1 CAD = 0.75 USD) (Bennett 2013). There are some strategies devised for the conservation of water by the Toronto Water

Division. One of the strategies is the industrial water rate program, which offers discounted water to manufacturers to help sustain economic growth and encourage water conservation. Manufacturers consume more than 5000 m^3 of water annually which belongs to the industrial property tax class (Toronto Water Division 2020).

Water Management in NCT Delhi

Groundwater is widely consumed to meet the growing industrial, agricultural, and domestic water demand in rapidly urbanising Delhi. The aggregate water requirement for domestic and drinking purposes is approximately 913 million gallon per day (MGD). 845 MGD (out of 913 MGD), including approximately 100 MGD from groundwater, is contributed by Delhi Jal Board (DJB). The DJB is responsible for distributing potable water after treating raw water and wastewater disposal. The present deficit in the drinking water supply is about 112 MGD (Biswas and Gangwar 2020).

Approximately, 83% of households have access to the piped water supply. During the summer, water production is consistently maintained at 896 million litres per day (MLD). The largest water supply sources in NCT Delhi are Ganga and Yamuna rivers, followed by Bhakra storage and other groundwater sources. NCT Delhi depends on the neighbouring states to meet almost half of its total drinking water demand. The DJB is continuously working on improving the water supply and the treatment facility in every five-year plan (Planning Department, Delhi 2018). The existing water supply network in NCT Delhi comprises a 14,355 km long water supply pipeline and more than 107 groundwater reservoirs. Besides the conventional water supply network system, NCT Delhi also focuses on other methods to improve access to the water supply. These include adding 407 new water tankers equipped with GPS; 400 M.S hired tankers; 250 newly purchased stainless steel tankers to supply water in the deficit areas. The total metered water supply connections aggregated to approximately 2,082,967 in 2017–2018 (Planning Department, Delhi 2018). At least half of the drinking water demand is met by tap water from a treated source in all the districts. The south-west, west and southern districts fulfil a substantial portion of drinking water demand by tube wells/boreholes (Table 20.4).

The service-level benchmark has set nine indicators and the benchmarking values to measure the current status of water supply in an area. The comparison of the prescribed service-level benchmark suggested by the Ministry of Housing and Urban Affairs (MoHUA) and the present values of NCT Delhi is presented in Table. It is observed that the coverage in NCT Delhi is not adequate and only adds up to 71.5% of the total required connections. However, the per capita water supply provision of 145 LPCD is greater than the suggested value. Other parameters such as the extent of non-revenue water, metering, efficiency in the redressal of customer complaints, collection of water charges and quality of water supplied indicated that the present situation in NCT Delhi is surpassing the benchmarking values of these parameters. However, the continuity of water supplied is only 3 h as opposed to the suggested

Table 20.4 Service-level benchmarking for water supply (MoHUD 2019)

S. No	Indicator	Benchmark	NCT Delhi
1	Coverage of water supply connections	100%	71.5%
2	Water supply per capita	135 lpcd	144 lpcd
3	Extent of non-revenue water	20%	11%
4	Extent of metering	100%	55.3%
5	Continuity of water supplied	24 h	3 h
6	Efficiency in redressal of customer complaints	80%	58%
7	Water quality	100%	99.5%
8	Cost recovery	100%	41.6%
9	Efficiency of water charges collection	90%	78%

duration of 24 h which is very low. Further, the cost recovery of existing water supply management is only limited to a mere 41.6% which should be 100%.

For further assessment, the city can be subdivided into specific hydrogeological units: (a) Older Alluvium—Isolated; (b) Older Alluvium—Eastern and western sides of the ridge; (c) Newer Alluvium—Yamuna flood plain deposits and nearly closed Chhatarpur alluvial basin and (d) Quarzitic Formation—NNE-SSW trending Quarzitic Ridge (Central Ground Water Board 2016). West, south and south-west districts are the areas with the highest potential groundwater reserve. This continuously increasing population of NCT Delhi affects the availability of groundwater. The rate of consumption of groundwater is much more than that of replenishment. The Central Groundwater Board (CGWB) recorded that the net groundwater availability in NCT Delhi is 28,156 ha m (hectare-metre) and the annual replenishment is 29,710 ha m Purohit et al. (2009) observed that the annual groundwater draft for NCT Delhi (as in 2004) was 47,945 ha m of which 21,506 ha m is used for domestic purposes, 20,002 ha m for irrigation purposes, and 4300 ha m for industrial purposes (Purohit et al. 2009). Rainwater harvesting is considered a major mean of groundwater recharge. NCT Delhi is mostly urbanised, i.e. having a high density of the built-up area comprising 142 km^2 roof area, 69 km^2 paved area and the remaining 485 km^2 open area/green area (Central Ground Water Board 2016). It results in a large volume of surface runoff due that diminishes the possibilities of rainwater harvesting as a solution to recharge groundwater.

The central government's Yamuna Action Plan (YAP) initiative attracts attention to the conservation of water resources in NCT Delhi. Under this plan, eleven projects have been identified to conserve the river Yamuna as a water resource. In phase three of YAP, nine projects for the rejuvenation of Yamuna were identified, of which eight focused on sewerage infrastructure (Greens 2019). Approximately, 40% of the treated water is lost due to misuse, leakage in pipelines and un-metered connection. Therefore, water conservation and leak detection are vital for water security in NCT Delhi. The government started to incentivise free water consumption up to 20 kilolitres (kl) per month to avoid misuse of water. Any consumption outside this 20 kl is chargeable.

Discussion and Conclusion

The study of Toronto and NCT Delhi shows that the cities underwent dynamic changes in expanding population and the built-up area. Since the late twentieth century, both cities have experienced rapid urbanisation with the largest percentage of increase in the highly dense built-up class. For Toronto, the built-up expansion took place from downtown Toronto radially. Also, the high-density built-up area sited along Lake Ontario in a ribbon pattern which influenced the growth of the rest of Toronto. In the case of NCT Delhi, the growth of the built-up area was mainly concentrated in the central and eastern regions in the late twentieth century. However, in the past three decades, the built-up expansion densified in the central and eastern regions, and new development took place in the south, west and south-western regions. In comparing the growth of NCT Delhi to the proposed master plan of 2021, the growth of Western Delhi is influenced by the area demarcated as an urbanisable area in the master plan for future expansion. The urban expansion experienced by both Toronto and NCT Delhi puts immense pressure on infrastructure facilities, specifically on water resources.

The Toronto Water Division manages and regulates water across the city. Water consumption has increased in parallel with urban expansion till the 2000s. Water consumption was significantly high in the year 2000. This increased water consumption was rationalised through strategies like water pricing. During 2005–2015, a decline in water consumption was observed amidst a significant increase in population. This decline in water consumption was attributed to the revised water price rates introduced in 2008. The increment in water price was approximately Canadian Dollars (CAD) one/per cubic metre from 2005–2011. The increment in pricing was the strategy followed by the Toronto Water Division's aim to conserve water resources and achieve water security by restricting the citizens from wasting water.

In NCT Delhi, the comparison of the existing facilities through the service-level benchmarking shows a significant shortage in water supply coverage and its continuity provision. Many conservation strategies were devised for NCT Delhi, including water metering strategies. This strategy includes providing piped water supply free of cost up to a consumption of 20 kl/month. An increased tariff is charged to encourage citizens to conserve water beyond this stipulated consumption volume. The deteriorating groundwater table of NCT Delhi is specifically observed at the beginning of the summer season. This is particularly pragmatic in the south and south-western districts. If the piped water network does not penetrate further within the growing settlements, a further increase in groundwater extraction becomes unavoidable. The groundwater depletion will further accelerate due to increased extraction and decreasing groundwater discharge.

In Toronto, aggressive water pricing is implemented to reduce excess water consumption. The revision of water pricing introduced in 2008 significantly impacted water conservation and management. NCT Delhi's water management authority followed a different approach, including a flexible water metering strategy. This strategy includes a free water supply of a fixed amount and a higher water tariff beyond the free cut-off volume. This model ensures that citizens do not waste water beyond the required consumption. These two cities from the global north and global south used different strategies to mitigate the growing gap between demand and supply and attain water security. The difference in economic and development scale between the two cities results in different approaches to water security and overall urban water management. This may create an equitable gap in the accessibility of water facilities in the communities. Toronto may adopt a similar water metering strategy like NCT Delhi to reduce the hardship of paying high water tariffs by students, urban poor, and low-income people.

This research will facilitate policy makers for detailed comparative understanding of land use transformation and water security between global north and global south. The future researches may further explore comparative researches on the conflict between water consumption pattern and built form intensification between global north and global south with high resolution imageries to achieve more accuracy and enabling on-ground strategic interventions by the policymakers.

Acknowledgements We would like to thank the Shastri Indo-Canadian Institute for their financial support under the Shastri Indo-Canadian Research Grant (SICRG) 2018. We would also thank the Indian Institute of Technology (IIT) Roorkee and the University of Waterloo for facilitating this collaborative research.

References

Bennett J (2013) Price works: seasonality and determinants of Toronto's amazing decline in water demand. Sustainable prosperity

Biswas A, Gangwar D (2020) Studying the water crisis in Delhi due to rapid urbanisation and land use transformation. Int J Urban Sustain Dev

Census Backgrounder Report—2016 (n.d.) Toronto: 2017

Census of India (2011) Census 2011. Ministry of Home Affairs, Government of India

Central Ground Water Board (2016) State Unit Office, Delhi

Dutta D, Rahman A (2017) Assessing pattern of spatio-temporal change in NCT of Delhi and its peri-urban areas using geospatial techniques. Springer International Publishing

Greens D (2019) Delhi greens. Retrieved from Delhi Greens: http://delhigreens.com/2018/12/29/here-we-go-again-yamuna-action-plan-phase-iii/

MoHUD MO (2019) Ministry of housing and urban development, Government of India. Retrieved from Ministry of Housing and Urban Development, Government of India: http://mohua.gov.in/cms/Service-Level-Benchmarks.php

Planning Department, Delhi (2018) Economic survey of Delhi 2018–19. Government of NCT Delhi

Purohit R, Shekhar S, Kaushik Y (2009) Groundwater management in NCT Delhi

Ritchie H (2018) Urbanization (UN world urbanisation prospects). Our world in data

Sirkarwar A, Chattopadhyay A (2015) Spatial-temporal analysis of population, land use-land cover and environment: a study of seven most populated city-regions of India. Retrieved May 2019, from https://paa.confex.com/paa/2017/mediafile/ExtendedAbstract/Paper11450/edited.pdf

Statistics Canada (2016) Statistics Canada 2016 census of population. Toronto

Statistics Canada (2019) Canada's population estimates. Retrieved from Statistics Canada

Toronto Census (2006) Statistics Canada. Toronto

Toronto Census (2016) Toronto census Report. Toronto

Toronto Water (n.d.) Retrieved from Toronto: https://www.toronto.ca/city-government/accountability-operations-customer-service/city-administration/staff-directory-divisions-and-customer-service/toronto-water/

Toronto Water Division (2016) Water and wastewater consumption rates and services fees. Toronto Waters, Toronto

Toronto Water Division (2020) Toronto water and environment. Retrieved from Toronto: www.toronto.ca

University of Toronto (2018) Are trees green infrastructure? Municipal policies and green infrastructure definitions. Social Sciences and Humanities Research Council of Canada, Toronto, Canada

Wang L (2015) Examine urban expansion in greater Toronto area using Landsat imagery from 1974–2014

Chapter 21
Livelihood Opportunities and Challenges of Slum Dwellers in the Changing Urban Environment: A Case Study of Guwahati City Slums in India

Trinity Borgohain

Abstract Urbanisation has become a global phenomenon, characterised by the growth of cities which incorporate an increasing growth of population in the urban areas that represent more than half of the world's population. In many developing countries, including India, the rates of urban growth have been higher than that for developed countries during their urban transition as the developing countries experienced higher rates of overall population growth. India witnessed a rapid urban transition with its urban populations increasing from 27.81% in 2001 to 31.16% in 2011, while 52.8% of the world population lived in cities in 2010. On a significant note, among the South Asian cities, India has witnessed a rapid growth of slum population to the total urban population in the last few decades due to the rise of urbanisation in its cities. The slums in India are the manifestation of rapid urbanisation, urbanisation of poverty and exclusionary and unequal processes existing in the cities of India, proportionately involve rural migration to informal settlements in and around the cities. The chapter examines the urban growth and expansion of Guwahati city, the only million-plus city of the Northeastern Region of India, the largest urban centre as well as the gateway to the Northeast India, a region lying on the cross-roads between India and South-east Asia. The chapter analyses the livelihood opportunities and the emerging vulnerable situations and challenges in the slum settlements of Guwahati city of Assam.

Keywords Urbanisation · Guwahati city · Urban migration · Slums · Livelihood opportunities and challenges

Introduction

The urbanisation process is a global phenomenon characterised by the growth of cities that incorporates an increasing growth of population in the urban settlements. In many developing countries, including India, urban growth rates have been higher

T. Borgohain (✉)
Government Model College, Kaziranga, Deering Chariali, Kaziranga, Golaghat, Assam, India
e-mail: borgohaintrinity@gmail.com

U. Chatterjee et al. (eds.), *Urban Commons, Future Smart Cities and Sustainability*, Springer Geography, https://doi.org/10.1007/978-3-031-24767-5_21

than that for developed countries. As per the 2011 Census, India witnessed a rapid urban transition with its urban populations increasing from 27.81% in 2001 to 31.16% in 2011, while 52.8% of the world population lived in cities in 2010. India thus experienced the second largest urban population in the world with 10.57% next to China with 19.54%. With the changing phase of urbanisation in the world, the urban areas account for an increasing share of the world's poor (Haddad et al. 1999), and by 2035, half of the world's poor will be living in urban areas (Devas 2004). Worldwide, almost 1 billion or 32% of urban population are now living in slums. In this context, the Challenges of Slums, a Global Report on Human Settlements 2003, estimated that about 50% of slum dwellers were in South-Central and Eastern Asia combined, 14% in Latin America and 17% in sub-Saharan Africa (UN-Habitat 2003). On a significant note, among the South Asian cities, India witnessed a rapid growth of slum population to the total urban population in the past decades due to the rapid urbanisation in its cities. India's slums comprise the urban populations that increased from 15% of the total urban populations in 2001 to 17.4% in 2011, roughly at 1.37 crore households (Census of India 2011a, b). The slums in India are the manifestation of rapid urbanisation, urban poverty, exclusion and unequal processes existing in the cities, proportionately involve rural migration that are pushed into the informal settlements in and around the cities. The acute shortage of housing and infrastructural facilities is considered to be the major problems plaguing the Indian cities stimulating the growth of slums in cities. The slums are predominantly inhabited by the poor or low-income groups with less or no better living condition in the city environment. The slums are commonly called as *bustees or jhupuri* in Indian city slums that have been defined by the Government of India under the Slum Area (Improvement and clearance) Act of 1954 as predominantly a residential area, where dwellings are by reason of dilapidation, overcrowding, faulty arrangement and lack of ventilation, light or sanitary facilities or any combination of these factors. The slums in Indian cities are emerging in the pathetic situations lacking all the adequate living conditions and thereby facing livelihood challenges at diverse levels.

Rationale of the Study

Urbanisation occurs as individual, commercial and government efforts that create opportunity for jobs, reducing the scarcity of jobs, housing, education, transportation, etc. (Jaysawal and Saha 2014). The increasing trend of urban expansion in India caused several prospects and challenges on the livelihood of the masses living in the cities. In spite of low rate of urbanisation in India in the past two decades, cities have not been able to provide the growing urban population with viable housing, potable water, adequate sanitation, employment that gives them reasonable wages, etc. Today, cities are more complex in their functions and serve not only as administrative headquarters but, equally important, as engines of economic growth, nerve centres of communication and the originators of major social and political movements (Dikshit and Dikshit 2014). With such a wide-ranging role, cities have attracted large mass of population all over the world, and in developed countries, majority of the population lives and works in the cities. Cities provide a variety of choices of economic opportunities which attract a large number of rural populations to move to city away from the native rural land. Consequently, a large proportion of the urban population is constrained to live in slums or informal settlements and depend on the informal sector for their livelihood (Desai et al. 2014). In view of India's rural–urban transition, there is a shift of employment, i.e. out of agriculture to other livelihood opportunities in the cities, affecting the livelihoods of millions of people. It is evident that there is scarcity or few new local livelihood opportunities in the rural places which resulted in permanent circular labour migration to the nearby city areas that replaces the traditional seasonal migration.

In the context of Northeastern Region of India, Guwahati city, the capital city of Assam has experienced urban expansion at a higher rate in the recent decades due to the growth of industrial, commercial and service sectors that has opened multiple employment opportunities catering the needs of the low-income groups. With the changing industrial landscape and growth of its economic activities, the city has not only attracted a substantial amount of capital but also a large proportion of migrant population from and within the city as well as across states of India. This migration pattern generally takes place due to the opportunities and labour flow provided by the city in both formal and informal sectors. The city presents a wide range of activities in various industrial, commercial and service sectors. While the growth in such activities, possibilities of absorption in industrial, allied as well as service sectors, scope of employment in trade and business activities, hawking, retailing, carting and other such possibilities have attracted rural poor to the city. This rural to urban migration of low-income groups is encouraged by the group migration based on the networks with the family members and kins or the people of their own district, region or village who have already settled in the city. It is evident that the rural low-income migrants generally occupy the vacant public and private lands by building their own huts or otherwise by staying on rents under the private landowners which facilitate the long-term settlements in the city structure. After arrival in the city, the low-income migrants living mainly in the slums or informal settlements mostly find low-income jobs in the informal sector of city's economy that include a variety of low-income occupations ranging from daily wage labour, rickshaw pulling, construction work, domestic help, vegetable vending, sanitation work in both formal and informal sectors. Apart from the livelihood opportunities in the form of gainful employment provided by the city to the low-income groups, the slum dwellers face livelihood challenges in diverse contexts, i.e. economic, environmental, social, political, etc.

Informality as Urban Livelihood

The livelihoods of the poor are determined predominantly by the context in which they live and the constraints and opportunities this location presents (Meikle 2002). This is because of the contexts such as economic, environmental, social and political largely determine the assets accessible to people, how they can use these (Meikle 2002: 38) and thus their ability to obtain secure livelihoods. Due to lack of industrial development in Assam in general and Guwahati city in particular, that people are mostly engaged in the tertiary and service sector (construction, trade and commerce, transportation, storage and communication and other services) than primary and secondary sectors of the city economy. The rural people look for new opportunities in the urban areas in terms of employment, physical environment, etc. As a result, rural landless agricultural workers had little incentive to remain in agriculture; instead, they choose to migrate to nearby towns or cities in search of more remunerative non-agricultural jobs. It is important to examine whether they get more remunerative jobs after migration or end up swelling the ranks of unemployed in the urban labour market as predicted by Todaro (1976). But those migrants, who were working in the rural vulnerable situation, see themselves more beneficial working in the urban informal sector. Migrants' livelihoods vary in city structure according to their level of education and the skills they have. The competent and skilled migrants may find urban formal jobs either in the government or in the private sectors. The workforce has increased more than proportionately in the informal low productivity activities which were present in large proportions. Many poorer migrants who have come to the city in search of work have been consumed into the city's informal services such as petty shopkeepers, vegetable sellers, cleaners, domestic help, small shop assistance, cooks and waiters in food joints, mechanics and other assistance in small workshops, construction worker, manual labourers working in the wholesale and retail markets. The type of labour carried out by the urban poor in the city economy was basically the livelihood strategies adopted by them to continue their living in the city since there is the dominance of unskilled and uneducated migrants in the informal sector than other migrants. The rural migrants of the slums of the city are predominantly poor, landlessness, conflict affected and having some expectations with earning in Guwahati.

Study Objectives and Methodology

General Objective

The general objective of the research was to understand the growth of urbanisation in Northeast India and to examine the prospects and challenges of urbanisation on the livelihood of the low-income groups living in the slum areas of the cities of Assam especially Guwahati city.

Specific Objective

The specific objectives of the research were:

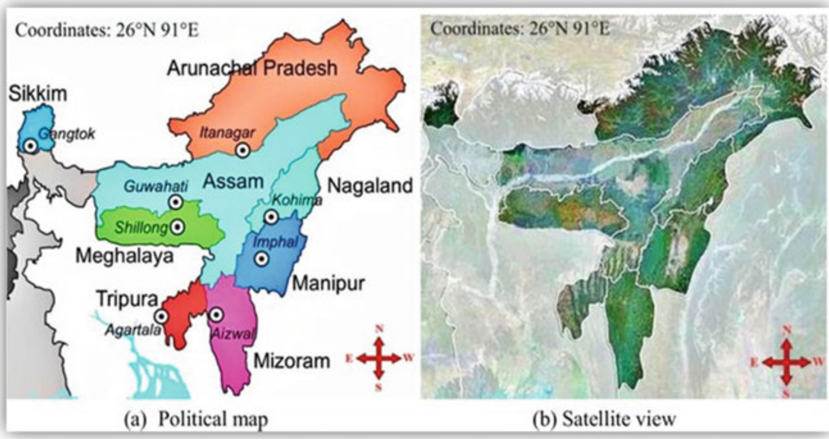
1. To examine the urban growth and expansion in Guwahati city.
2. To trace the growth of slums and squatter settlements in Guwahati city.
3. To examine the slum communities' chances for livelihood and the emerging challenges posed by urban growth in Guwahati city as well as how these issues affect the slum communities' ability to support themselves in their vulnerable living conditions.

Materials and Methods

This chapter is based on both primary and secondary data which were collected in the year 2017. The primary information was collected during the fieldwork carried out in the year. A number of methods were employed during the research such as the use of standardised open-ended interview, key informants' interview, informal conversational interview, observation (participatory and non-participatory) methods through which the primary information was collected from the major study area, i.e. Guwahati city and the case area, i.e. Machkhowa slum, whereas the secondary information was collected from published and unpublished literatures. Out of the 90 notified slums of Guwahati city, a recently emerging slum was selected for the study namely 'Machkhowa slum' as reported in the Guwahati Municipal Corporation (GMC) Slum Report of 2009. The slum is purposively selected for the study with a complete enumeration of populations incorporating a total of thirty-one slum households of the locality. All the slum households were surveyed to collect data on the livelihood opportunities and the challenges and emerging vulnerabilities experienced by the slum dwellers living in the congested space. To analyse the qualitative data associated with other aspects of life of slum dwellers in the urban mainstream, a qualitative textual explanation method is used to gather information on whether slum dwellers either exposed to livelihood opportunities or face challenges in Guwahati metropolitan city.

Northeast India Context—Urbanisation and Slum Growth

The Northeast India is the gateway to South-east Asia sharing international boundaries with China, Tibet, Bhutan, Bangladesh and Myanmar and linked with the rest of India through a narrow passage, popularly called chicken's neck or Siliguri corridor. The region comprises eight distinct and diverse states of Arunachal Pradesh, Assam, Manipur, Meghalaya, Mizoram, Sikkim and Tripura. The region possesses the distinctive socio-cultural heritage or represents Indian ethos of cultural diversity



Map 21.1 Political map and satellite view of Northeast India. *Source* https://doi.org/10.1007/s11356-022-18498—accessed on 14.07.2022

and its rich biodiversity. Since time immemorial, the northeast has been the abode of various ethnic groups of Australoid, Mongoloid and Caucasoid origins who speak Tibeto–Burman, Siamese–Chinese, Austro–Asiatic and Indo–Aryan languages, etc. (Das 2008). The region comprises approximately 225 tribes in the subcontinent out of a total of approximately 450 tribes in India (Map 21.1).

In the past few decades, the region has witnessed a rapid growth of urban population due to its urban expansion that led to the emergence of a recent phenomenon, i.e. urbanisation. The decadal growth rate and the average annual exponential growth rate of urban population of NE region for all the decades were as high as compared to India's figures.

As per the 2011 Census of India, 23.73% of the total population lived in urban areas of India in 1981 which has increased to 31.16% in 2011. Although the statewise percentage of urban population of northeastern states to the total population during the period of 1981–2011 was increasing over the census years, but still low than the national figure (see Table 21.1). As per the latest census figure of 2011 data, Assam stood at lowest level of urbanisation in India sharing 14.08% of state's total population but increased from 9.88% in 1981 to 14.08%[1] followed by Meghalaya sharing 20.07% and Arunachal Pradesh sharing 22.67%, whereas Mizoram sharing 51.58% of urban population to its total population is the highest among the peripheral states of India. In the post-modern world, the rapid urbanisation resulted in the growth of slums as a universal phenomenon in the cities. The Northeastern Region of India is no exception of it. The growth of slums has become a recent phenomenon in the region due to the urban expansion in the class I cities across the region.

[1] Urbanisation Trend in Assam—An Analysis (June 18, 2010). Available at SSRN: http://ssrn.com/abstract=1626922 or http://dx.doi.org/10.2139/ssrn.1626922.

Table 21.1 Growth of urban population, Northeast India, 1971–2011

Sl. No.	States	Percentage of urban population				Annual exponential growth		
		1981	1991	2001	2011	1981–1991	1991–2001	2001–2011
1	Arunachal Pradesh	6.32	12.21	20.41	22.67	9.28	7.00	3.18
2	Assam	9.88	11.09	12.72	14.08	3.29	3.09	2.43
3	Manipur	26.44	27.69	23.88	30.20	2.98	1.21	3.55
4	Meghalaya	18.03	18.69	19.63	20.07	3.10	3.16	2.70
5	Mizoram	25.17	46.2	49.50	51.58	9.57	3.27	2.42
6	Nagaland	15.54	17.28	17.74	28.96	5.58	5.27	5.15
7	Sikkim	16.23	9.12	11.10	24.96	−3.23	4.83	9.29
8	Tripura	10.98	15.26	17.02	26.17	6.19	2.53	5.65
9	All India	23.73	25.72	27.78	31.16	3.09	2.73	2.76

Source Census of India, 1981, 1991, 2001 and 2011. Office of the Registrar General and Census Commissioner, Census of India. (Saitluanga 2013)

Out of the eight states of the peripheral states of India, the state of Assam witnessed the highest growth of slums. Over the years, there has been an upward trend of urbanisation in the state which caused the movement of people from the rural areas to the cities and towns. Out of 88 towns, 31 towns of Assam stood at nearly two lakhs population approximately 197,266 slum populations as per the office of Registrar General and Census Commissioner of India, 2011 (Table 21.2). Of these, the total slum populations of Assam was 117,124 slum dwellers residing in Identified slums; 70,979 in recognised slums; and 9163 in notified slums followed by Tripura with second highest slum population with 139,780 across 15 out of 16 towns, Nagaland with 82,324, Mizoram with 78,561, Meghalaya with 57,418, Sikkim with 31,378 and Arunachal Pradesh with 15,562 slum populations across the slum reported towns in the states. On the other hand, Manipur was among the other states and union territories of India (along with Daman and Diu, Dadra and Nagar Haveli and Lakshadweep) that is free of slums (Census of India 2011a, b).

Guwahati City and Urbanisation: The Area Context

Guwahati is the largest city in the entire Northeastern region of India. As per 1991 census data, it ranks 44th among 5230 urban centres in India (GMC 2006). It is the regional hub of NE India for which all other states in the entire region are based on the city connectivity to the rest of the country. Just after India got independence in 1947, Guwahati became politically an important urban centre in the entire northeastern region when the northeastern states were politically reorganised into seven states. Since then, the city began to serve as the main gateway to the northeast periphery

Table 21.2 Slum reported towns in the Northeastern states of India

Sl. No.	Name of state and union territory	Towns			Slums		
		Statutory towns	Slum reported towns	Total populations	Notified slums	Recognised slums	Identified slums
1	Assam	88	31	197,266	9163	70,979	117,124
2	Tripura	16	15	139,780	0	124,036	15,744
3	Nagaland	19	11	82, 324	0	48,249	34,075
4	Mizoram	23	1	78,561	0	78,561	0
5	Meghalaya	10	6	57,418	34,699	8006	14,713
6	Sikkim	8	7	31,378	31,378	0	0
7	Arunachal Pradesh	26	5	15,562	0	0	15,562
8	Manipur	28	0	0	0	0	0

Source Primary Census Abstract for Slum, 2011, Office of the Registrar General and Census Commissioner, India, New Delhi, 30–09–2013

of India. Meanwhile, Guwahati became the economic hub of NE India wherein the Brahmaputra River is used for mass transportation of goods for the NE India. Over the years, the urban environment of Guwahati city has changed with phenomenal growth of its urban population caused by the influx of migrants or immigrants from both nearby areas or across states and countries to Guwahati city. Guwahati became a Tea Auction Centre in 1970 as one of the largest and busiest tea trading centres in the world. In addition, Guwahati became the city of headquarters or regional offices of several manufacturing and business establishments coupled with the establishment of Guwahati Oil Refinery at Noonmati and other small industries that added industrial impetus and made the city as the important industrial and trade hub in the Northeastern Region of India. The major types of industries in Guwahati include chemicals and fertilizers, engineering industries, petroleum and refineries (Indian Oil Corporation, Noonmati Refinery; India Carbon, CPC Plant) and agro-based industries. The other key industries are such as tea, forest and wood, handloom and handicraft industries.

The urban growth of Guwahati city touched greater height with the shifting of Assam's capital from Shillong (capital of Meghalaya state) to Dispur (in Guwahati) in the year 1972 (in the eastern outskirt of the city) (Borgohain 2021, p. 237). Since then, Guwahati became a new administrative centre of Assam and gained significant political importance as well as the hub of industrial and commercial activities in the entire NE Region of India. This changing phase of the city led to the rise in urban population along with the migrant population. The migrants included businessmen, contractors, construction workers, daily wage earners and job seekers coming from different regions of India such as Bihar, West Bengal and other northeast states or across the international border of Assam. While in the Guwahati Metropolitan Area (GMA), it was estimated at 48.5% during the decades. However, in the rest of the GMA, there was a decline in population growth in the GMC area during 1991–2001 and further decline over 2001–2011. Guwahati has been a whole sale distributor and a retail hub of the region. The main wholesale markets of Guwahati are situated at Machkhowa and Fancy Bazar areas which are the main commercial places in the city. With its expansion in the service sector and growth of its economic activities, Guwahati has not only attracted a substantial amount of capital but also a large proportion of migrant population from within the city as well as other states across India. As per the Census of 2011, the population of Guwahati was 8394 in 1891 which crossed the limit of one lakh in 1961 and became 584,342 in 1991 Census (Nath 2001, p. 55) and 809,895 in 2001 and 963,429 in 2011.

City's Slum Character and Type

Guwahati city has experienced unprecedented growth in its size without any perceptible thought to planning which eventually led to the emergence of slums in different slum pockets of the city structure. The haphazard growth and population explosion during the eighties of twentieth century made the city administration difficult to bridge the demand–supply gap while maintaining the basic or minimum infrastructure of it. The slums are emerging in Guwahati mostly in the municipal area as well as the private land where the urban poor occupying the vacant land across the city. Over the years, a number of surveys were carried out by different organisations in Guwahati city in order to understand the level of existence of slums in the city. The Guwahati Municipal Corporation (GMC) made an attempt in 2009 while preparing a slum report under JNNURM to identify and classify the number of existing slums into different slum pockets with varying characteristics. While doing that, the GMC emphasises the city character in terms of its topography and physiography. However, the GMC Slum Report of 2009 defined the slum as 'a high density settlements having a cluster of minimum 50 dwelling units in class I cities or a minimum of 25 dwelling units for the town below 1 lakh population and where at least 50% dwelling units have semi-permanent structures of less than 25 m^2 area, principally, made of materials such as mud, bricks, wooden plunks, polythene sheets, tin shed or combination of such materials along with the criteria which include the lacking of basic infrastructure and amenities such as water supply, sanitation facilities, toilet, regular pathways etc. and mainly inhabited by the low-income group residents who lack the security over land'.

The survey has identified 90 notified slums of Guwahati city which vary according to their physical condition (plain or non-plain areas), housing type (pucca, semi-pucca and kutcha), land security (permanent, semi-permanent or temporary), access to basic services (privileged or non-privileged), period of residence by the residents (long-term residents with multiple generations and short-term residence) and ethnic composition (place of origin and influence of religious and linguistic affiliations). Being located on the southern bank of the Brahmaputra River, Guwahati city covers both plain and non-plain (hills) areas with minimum or no infrastructure. The slum data shows that there are 52 slum pockets in the plain areas of the city's ecology consisting of 102,336 populations that live in 17,056 households (The Guwahati City Slum Policy 2009). These are such as Valmiki Harijan colony of Dispur, Kumarpara slum, Fatasil Harijan colony, Zupad Patti in Maligaon Satel gate, Arikati *basti* accompanied by another 6 slum pockets existing in the city that carry approximately 17,100 populations living in 2850 slum households. These are the Madrasi Patti located in Maligaon, Gosala Harijan colony, Katabari in Gorsukh, Aakashi Nagar, Rajib Nagar in Beltola and Satgaon of Nabapara, etc.

The slums proliferated in the plain areas of the city also include other slums existing near the railway track or the commercial areas that benefit the slum dwellers to manage their transportation costs. These slums are inhabited by the low-income residents who live in rent under the private landowners. The private landowners of the city generally make huts or build small semi-pucca rooms for the low-income migrants who are mainly engaged with the informal sectors of the city economy. This type of slums is classified into 8 number of slum pockets that are known to be Machkhowa slum, Katabari slum, Athgaon slum, Bihari *basti*, Malatanki *basti*, Nandbam Mazar bazar, Miyan Nagar, Shah Nagar, etc., comprising 16,080 populations scattered throughout the city under 2680 slum households. The slums are also segregated in the non-plain areas or the hills that contain a total number of 24 slum pockets as identified by the GMC Slum Report of 2009 that includes approximately 32,280 populations scattered in approximate 5380 households. While the distinction between slums across plains and non-plain areas made the city ecologically vulnerable in one way and bring to light the other side of it. In 2012, the slum survey carried out by GMC under Rajiv Awas Yojana identified 217 slum pockets constituting a population of 1.39 lakh. The slum survey was based on the identification criteria of slum that indicates a pocket with 10–15 households and without basic amenities was considered as slum. In 2009, GMC had identified a pocket with 25–30 households that lack the basic amenities was considered as slum, while for the survey of 2012, a pocket with 10–15 households and without basic amenities was considered as slum. While the number of slums had increased, the overall slum of population had decreased (Desai et al. 2014).

The Machkhowa Slum: A Case Study

The Machkhowa slum is one of the congested and overcrowded slums of Guwahati city. It is about 30 years ago that the slum has surfaced on a marshland behind the TRP road in the market ward of Guwahati Municipal Corporation Area (GMCA) of Guwahati. Earlier the locality of Machkhowa was a village in the Kamrup Metro district of Assam which later transformed into a commercial place in Guwahati due to the expansion of the city. Being located in the commercial zone of Machkhowa, the slum has come under the criteria of fourth category of identification of slum reported by the GMC slum survey of 2009 that indicates the emergence of congested slums in the city where more than 70% housings are rented. This type of slum has emerged on the private land in the Tarun Ram Phukan (TRP) road of the city surrounded by the commercial buildings, concrete apartments and couple of mosques (Borgohain 2018, p. 212). There is a narrow thick lane (*gali*)[2] which enters the slum passing by a petty tea stall. The street leading to the slum is full of filth composed of stagnant and stinking water of drains which becomes all the dirtier and unhygienic over the years. The lane that leads to the slum remains covered with mud which creates troubles for the slum dwellers especially during their entry and exit to the slum. It has grown on a piece of land, which is owned by a private landowner who give the huts on low rent to the low-income groups.

The case study of Machkhowa slum is based on a series of questions on how the slum dwellers are negotiating with the lives amid poverty, how is the physical condition of the locality wherein the slum dwellers eke out their living with risk which have been pushing them into the periphery of poverty, do they create any community life living in the concerted area in the city, what challenges do they face in their daily life. During the fieldwork, it has come to the light that in the initial phase of its settlement at the core of the city, the slum was illegally occupied by the poor rural migrants who further erected three huts by themselves for their settlements in the locality (the landlord's viewpoint). At the initial stage, the poor had to pay Rs.50/- to the landowner just for occupying the land. Presently, the slum dwellers are paying a rent that ranges from a minimum of Rs. 400/- to maximum of Rs. 1500/- per month, depending upon the size of the family. Now the slum consists of a total of 31 households comprising a total of 109 populations spreading over an area of 3 Katha lands in Machkhowa.

The slum is filled with different types of huts constructed in an extremely haphazard manner. The slum residents call their locality as '*mohalla*'[3] where they have built a network or social relation with the people who are of same socio-economic status and of same place of origin. This regional network helps the migrants immensely in finding out and most of the cases exploring the opportunities available in the city.

Case 1: Madina Hussain, a 42-year-old landowner of the slum who takes care of the huts shared about the history of the emergence of the Machkhowa slum in the TRP road of Guwahati city:

> ……since 1988, I have been looking after the land along with my mother and younger brother especially after the death of my father. My father had bought the land in 1981 that now spreads over an area of 3 Katha land. Initially, only a small kutcha hut was built for us in the land just to keep the land secure. But one day a gang of goons entered and started burning the house, for which my father had decided to create some more huts in the land and to give them on rent to the migrants of the city who were of low-income groups. Earlier only three huts were built in the land basically to protect the land from outside force. At the initial stage we have collected an amount of Rupees 50/- from the migrants just for being settled down on the land. Afterwards they (migrants) were allowed to stay in the land for many years which led to the expansion of the slum with the construction of more huts made of woods and other materials. Initially, the migrants were mainly from the villages of nearby places of Guwahati city especially from the Dhubri district of Assam and economically they were highly marginalized ones in the city. Later, we have continued the business of renting

[2] Gali is a local Assamese term which means a lane of a big road.

[3] '*Mohalla'* is a local term which depicts the neighbourhood.

Table 21.3 Distribution of slum population by age and sex composition

Sl. No.	Age group	Number of males	Percentage	Number of females	Percentage	Total population	Percentage of total population
1	0–6	10	9.17	9	8.26	19	17.43
2	7–17	18	16.51	15	13.76	33	30.28
3	18–30	11	10.09	9	8.26	20	18.35
4	31–40	13	11.93	11	11.09	24	22.02
5	41–50	07	6.42	2	1.83	09	8.26
6	51–60	02	1.83	2	1.83	04	3.67
7	60 above	0	0	0	0	0	0
8	Total	61	55.95	48	44.04	109	100

Source Field Data (2017)

huts to the newcomers in the locality coming from different places of Assam who are mainly the low-income groups and presently we have 31 huts in rent comprising about 109 slum populations (Borgohain 2018, p. 213).

Result and Discussion

Age and Sex Composition

The distribution of the slum population by their age groups enables to understand the demographic composition of the slum indicating the waves of migration of people to the city. The Machkhowa slum consists of two types of populations classified into young and old in terms of age of the slum dwellers. The younger the population is, the tendency of migration is higher to the city (Table 21.3).

The highest concentration of population is found in the age group of 7–17 years that accounts for 30.28% of the total slum populations (Fig. 21.1). The remaining share of slum population falls in the age groups of 0–6 years (17.43%), 18–30 years (18.35%), 31–40 years (22.02%), 41–50 years (8.26%), and the lowest share of population is falling in the age group of 51–60 years sharing 3.67% of the total slum populations.

Religious Composition

The slum neighbourhoods in Guwahati city are emerging mainly on the vacant or public land. These are basically the community-centric locations in the city

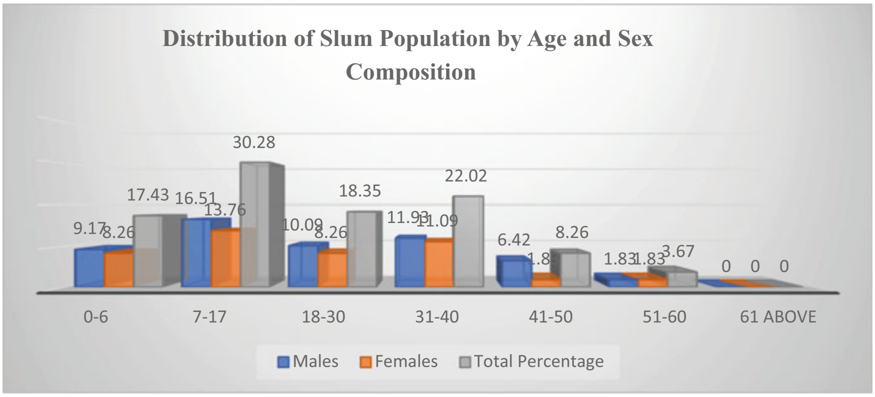


Fig. 21.1 Distribution of slum population by age and sex composition

Table 21.4 Distribution of Machkhowa slum population by religion, sex and age composition

Sl. No.	Religious community	Male population	Percentage	Female population	Percentage	Total population	Total percentage
1	Hindu	2	1.83	0	0	2	1.83
2	Muslim	59	54.13	48	44.04	107	98.17
3	Total	61	55.96	48	44.04	109	100

Source Field Data (2017)

and formed through the line of religious identity, family relations and community networks that ensure the security of their stay in the city structure for a long term (Table 21.4).

The Machkhowa slum is inhabited majorly by the Bengali Muslim community dwellers comprising the highest number of populations, i.e. 98.17% of the total population in the slum (Fig. 21.2), whereas a smaller percentage of slum dwellers belongs to the Hindu religious community sharing 1.83% of the total populations in the slum.

Social Origin of Slum Communities and Migration Patterns

Region of Origin

The Machkhowa slum is not merely aggregations of deteriorated huts or shacks but a place of communities of fellow migrants. These communities are based on a network of place of origin that enables the migrants to get socialised and associated with the complex environment of the city. The inter-district migration has been the common type of migration in the Machkhowa slum. A large number of population in the

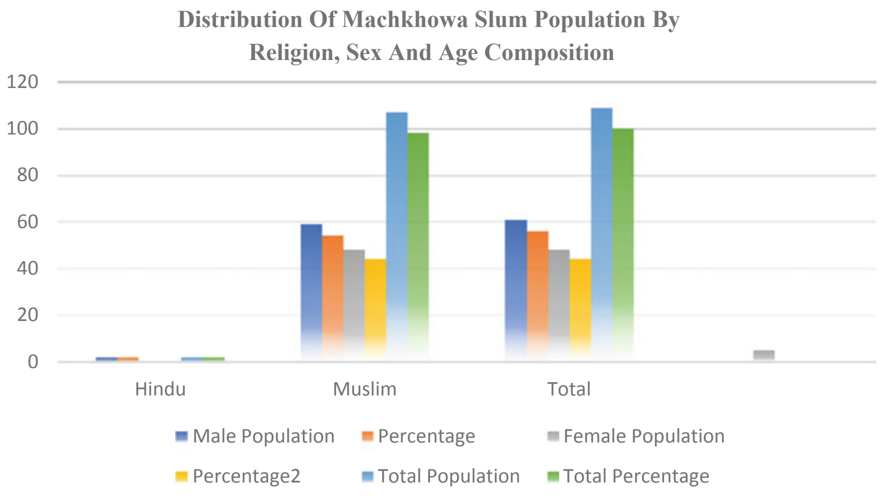


Fig. 21.2 Distribution of Machkhowa slum population by religion, sex and age composition

slum have migrated from two different regions, i.e. Assam and Bihar of the total 31 households sharing 98.17% populations. The populations migrated within the state of Assam include 54.13% male populations and 44.04% female populations who have migrated from the nearby areas of Guwahati (Table 21.5). On the other hand, 1.83%slum populations are the rural adult migrants, migrated from the region of Bihar of India to Guwahati city in terms of obtaining means of sustained livelihood.

The intra-state migration pattern dominates the slum locality. This type of migration happened in the city is mainly encouraged by the regional networks as developed among the slum dwellers who are from the common place of origin (Fig. 21.3). This further enables the low-income groups to cope with their daily livelihood issues in the anonymous city. The movement of rural migrants within the state of Assam has occurred especially from two districts of Assam, i.e., Dhubri and Goalpara. The migrants moved from the Dhubri district of Assam to Guwahati city are sharing

Table 21.5 Distribution of population as per region of origin and district of origin

Sl. No.	State of origin	District of origin	Male population	Percentage of males	Females population	Percentage of females	Total population and percentage
1	Assam	Dhubri	59	54.13	47	43.12	106 (97.25%)
		Goalpara	0	0	1	0.92	1 (0.92%)
2	Bihar	Samastipur	2	1.83	0	0	2 (1.83%)
3	Total		61	55.96	48	44.04	109 100%

Source Field Data (2017)

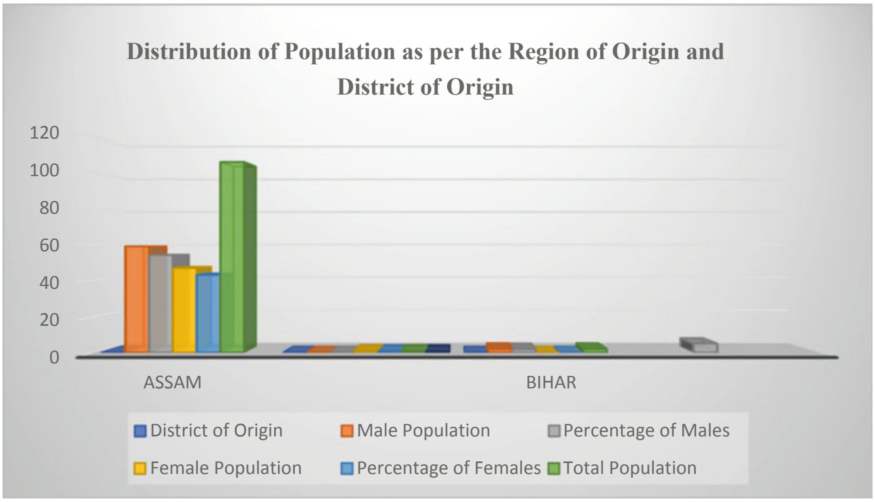


Fig. 21.3 Distribution of population as per region of origin and district of origin

97.25%slum populations including 54.13% male populations and 43.12% female populations. On the other hand, a very less percentage of slum populations have migrated from the Goalpara district of Assam to Guwahati city which includes 0.92% of the total slum populations in Machkhowa. However, the inter-state migration has been a rare case in the slum locality. A very small number of slum populations experienced this migration pattern in the city. These populations are found to be the Bihari Hindus who belong to the Scheduled Castes groups in the city structure.

Reason of Migration

For rural populations, migration is an important way to increase or diversify income and/or to ensure access to assets (Rakodi and Loyd-Jones 2002). Many people do venture out the option of rural–urban migration, owing to the perennial poverty they are suffering from. In many cases, movement becomes temporary or seasonal and complements farm employment. The rural migrants basically adopt short-term or often long-term residence in urban areas in order to deal with their livelihood necessities. The Machkhowa slum dwellers experienced the wave of migration due to a variety of socio-economic and ecological reasons. This wave has been cultivated by both males and females in the neighbourhood. For the male populations, the causes of migration vary with their counterparts. Table 21.6 shows that 5.5%slum populations migrated to Guwahati due to environment-induced displacement as caused by the river bank erosion in their native villages for which they had lost their homes and agricultural land in their native villages. Being reported by the heads of the slum households, this river bank erosion has been an unending and unresolved issue in

Table 21.6 Reasons of migration to Guwahati city

Sl. No.	Reasons of migration	Males	Percentage of males	Females	Percentage of females	Total population	Total percentage of population
1	Due to environment-induced displacement	6	5.5	0	0	6	5.5
2	Income constraints in village	16	14.68	0	0	16	14.68
3	Encouragement by the relatives or friends in the city	11	10.09	0	0	11	10.09
4	Moved with spouse/family	28	25.69	48	44.04	76	69.72
5	Total	61	55.96	48	44.04	109	100

Source Field Data (2017)

their native villages since times that caused livelihood disasters to their life every season.

While there is a growing demand for paid labour or low-paid jobs in Guwahati city, that attracts the rural populations across the state of Assam and India. The evidence shows that 14.68%slum populations have decided to migrate to the city due to the reason of income constraints in their native villages. After arriving in the city, these populations were found to be engaged with the informal sector jobs like construction jobs, petty traders and other services such as domestic maid, and most of the time they became self-employed with petty jobs. Apart from these pressing reasons, rural to urban migration is also encouraged by a series of social factors that caused further migration of rural origin low-income people to the city. This form of migration is stimulated by the city-based relations with fellow villagers who are already or previously settled in the city. The new migrants do maintain a close link with their village members or friends who had previously experienced or acquired the employment opportunities in the city. This further motivates the new-generation migrants to move to the city who are of common rural origin.

There are 10.09% populations in the Machkhowa slum who migrated to the city due to the reason of encouragement and inducement by the relatives or friends of their natal villages (Table 21.6). For instance, the city-based relations and sometimes the fellow villagers advise or often help them to get a job or access to other assets or opportunities in the city. Evidence shows that during the initial days of arrival in the city, the migrants get mostly sheltered by their relations with their village men or relatives for which they receive financial assistance from these networks. The migration pattern associated with the Machkhowa slum has got a gendered dimension. Along with the male population, the female population of the slum have migrated to the city as well as the slum due to the reason of movement with their spouse and children which include 44.04% female populations followed by 25.69% male populations.

Educational Status

Education is considered as one of the important domains, which has the potential to change the life of an individual on diverse levels (Borgohain 2018, p. 218). It is immensely important to comprehend the educational scenario of the slum to understand the socio-economic status of the slum dwellers. The analysis of the educational status of the marginalised sections of Guwahati city slums in general and the Machkhowa slum in particular has been confined to the adult populations including both males and females who are above 18 years of age.

Majority of the slum populations are found to be the illiterate ones. Evidence shows that 56.14% of the adult and old slum populations including both males and females have never acquired any primary education in their entire life time. On the other hand, 42.11% of slum populations including both adult and old slum populations are found as attaining primary education at the primary level (Table 21.7). However, at the secondary level, only 1.75% of the adult and old populations have acquired secondary education. In this regard, there is no woman in the slum who have attained secondary education in their lifetime.

Economic Life and Livelihood Opportunities in Urban Structure

The occupational structure of Machkhowa slum settlement has been categorised into the working (employed) and non-working or dependent populations (Borgohain 2018, p. 237). Table 21.8 shows that out of the total 109 populations in the slum, 47 persons, i.e., 43.11% of slum population are employed in the unorganised sector or the informal economy of the city. Of these, 68.08% are males and 31.91% are females, whereas 56.88% are the non-working or the dependent populations in the slum. Diverse types of occupations are found among the slum dwellers ranging from the local vending to the roadside stall, thela pulling and rickshaw pulling, casual labour and domestic labour.

Of the total slum populations, 36.7% are engaged with the regular salaried jobs especially in the unorganised sector comprising 3.12% male population, who are mainly the shop keepers in the locality. Following this, 3.12% males are found to be engaged with the tailoring jobs in the commercial market of Fancy Bazar of Guwahati. However, in the regular salaried jobs, all working women of the slum are found to be engaged with domestic help wherein they provide services to the gated communities of the city. The domestic services mainly include cooking, sweeping, washing, and

Table 21.7 Distribution of adult and old population as per educational status according to age and sex composition

Sl.No.	Educational status	Age groups												Total population	Percentage of total population
		18–30				31–50				51–60 and above					
		Male	Percentage	Female	Percentage	Male	Percentage	Female	Percentage	Male	Percentage	Female	Percentage		
1	Illiterate	3	5.26	7	12.28	7	12.28	11	19.30	2	3.51	2	3.51	32	56.14
2	Primary	7	12.28	2	3.51	13	22.81	2	3.51	0	0	0	0	24	42.11
3	Secondary	1	1.75	0	0	0	0	0	0	0	0	0	0	1	1.75
4	Higher Secondary	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	Degree	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	All	11	19.30	9	15.79	20	35.09	13	22.81	2	3.51	2	3.51	57	100

Source Field Data (2017)

Table 21.8 Distribution of population by employment status as per sex composition

Sl. No.	Employment status	Occupational type	Males and percentage	Females and percentage	Total population	Total percentage	Total percentage of working population/non-working population (in percentage)
1	Regular salaried jobs	Shopkeeper	1 (3.12%)*	0	1	17	36.17
		Tailoring	1(3.12%)	0	1		
		Domestic worker	0	15 (100%)	15		
2	Casual/daily wage earners	Casual labour as construction worker	16 (50.00%)	0	16	16	34.04
3	Self-employed	Vegetable vendor	6 (5.50%)	0	6	14	29.78
		Petty trader	3 (9.37%)	0	3		
		Thela puller	2 (6.25%)	0	2		
		Rickshaw puller	3 (9.37%)	0	3		
4	Working population	Total population	32 (68.08%)	15 (31.91%)	47 (100%)	43.11	100
5	Dependents/non-working population	Home-based unpaid work	0	11 (33.33%)	11 (17.74%)	62	56.88
		Unemployed but still seeking work	2 (6.89%)	7 (21.21%)	9 (14.51%)		
		Attending education	13 (44.82%)	6 (48.48%)	19 (30.64%)		

(continued)

Table 21.8 (continued)

Sl. No.	Employment status	Occupational type	Males and percentage	Females and percentage	Total population	Total percentage	Total percentage of working population/non-working population (in percentage)
		Other non-working population (children and others)	14 (48.27%)	9 (27.27%)	23 (37.09%)		
		Total	29 (46.77%)	33 (53.22%)	62 (100%)	56.88	
6	Total population		61 (56%)	48(44%)	109	100	100

Source Field Data (2017)
Note Figures within parenthesis indicate percentages over the total in the particular category taken into consideration

so on. This domestic labour has become a common type of occupation for the low-income or no-income families of the urban slums in the city. This has increased in the past years due to the rise and growth of middle and high-income families in Guwahati. This middle-class people are mainly engaged with the government, trade, transportation jobs, etc. Most of the working women in the slum are found to be in the part time domestic services that they work for a minimum of just one or two hours for about 3 to 4 households a day from which they could earn hardly Rs. 1000–4000/-per month. The reason found for being engaged in the respective occupation for the females in the slum was to make the family economically stable along with the earnings of the male heads in the family.

It seems that the rural migrants of the city capitalise employments for other members in the city including family members, friends or village origin fellows. In this regard, 34.04% male populations are engaged with daily wage earning. These working populations are mainly the construction labourers and hardly earn a living in the city. Apart from these working populations, 14% of the total slum populations are found to be the self-employed populations though they are not gainful self-employment. These self-employed populations include vegetable vendors sharing 5.5%, petty trader with 9.37%, thela pullers with 6.25% and rickshaw pullers with 9.37% of the total slum populations.

Evidence shows that street vending is a preferable choice of work for the slum dwellers who are not able to find other jobs in the city. These street vendors mostly sell the vegetable items on the roadside of the Machkhowa and Fancy Bazar areas of the city. While doing that, they face challenges like eviction by the police for occupying the vacant space of the streets for selling goods. To overcome such issues, the street vendors sometimes have to pay a small price to the police. This sort of troubles makes the low-income groups vulnerable living in the city. On the other hand, 9.37%slum dwellers are engaged with petty trading which is another source of livelihood for them. These petty traders build small kutcha shops in the slum neighbourhood especially on the pavements to sell the items like gutkha, tobacco, etc. Moreover, 9.37% slum dwellers are the rickshaw pullers. But their earnings fluctuate with the demands of customers and the traffic rules. Apart from the working populations, the slum comprises the dependent or non-working populations that accounts for 62% of the total slum population. These non-working populations are those in the slum who are dependent upon the earning of others in the family. Of these, 46.77% are males followed by 53.22% females in the slum, respectively, whereas 30.64% are just attending education, 37.09% are the children and other non-working persons in the slum.

Household Income and Economic Adaptation

Income is the significant factor through which the level of participation of slum dwellers in the city economy could be determined. The income structure of slum dwellers at the family level is based on the type of occupation they are associated with (Borgohain 2018, p. 142). The more secured the occupation is, the better income that the slum dwellers could earn. The slum populations are found as economically vulnerable in the city structure in terms of their income level as they are mostly engaged with the low-paid occupations in the city. In this regard, supplementary income for the family becomes necessary for them to reduce the intensity of poverty at the family.

The evidence shows that 54.8% of slum households earn between Rs. 5001–10,000/- per month (Fig. 21.4). These slum populations are mainly the unskilled labourers in the city who are mostly engaged with the informal sector jobs. While 35.4% slum households earn below Rs. 5000/- monthly, the remaining 9.6%slum households earn between Rs. 10,001/- and Rs. 15,000/- per month. The income of these households is a little higher than the other slum households due to the increasing number of earning members in the families. Though the income level of some households is found a little higher than the other households, but their earning is at marginal level as they have no certainty of their employment in the city. The slum dwellers lack opportunities to secured jobs in the employment sector of the city. They are mostly engaged with the contractual or less permanent jobs. Once their job contract gets over, they become unable to find another job within a short period of time or remain unemployed for a long period of time. This sort of economic vulnerabilities brings disasters into the life of slum dwellers because of the income gap or occupational gap between the groups in the economic structure of the city.

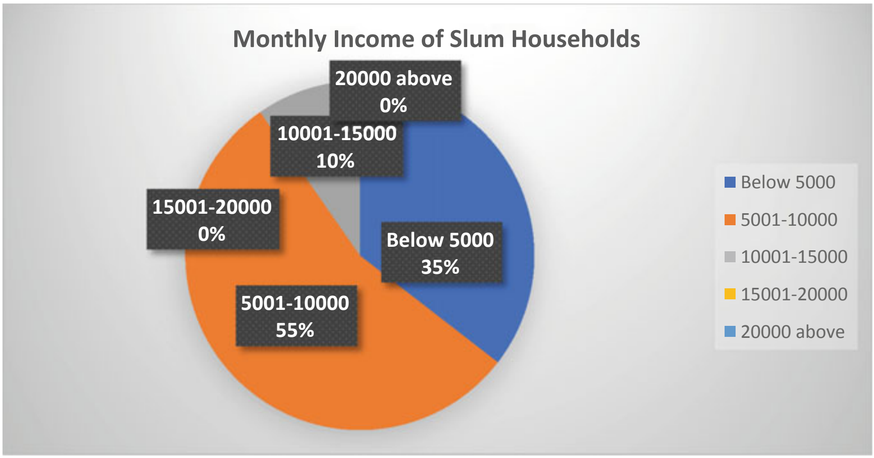


Fig. 21.4 Monthly income of slum households

Livelihood Challenges and Vulnerabilities

Vulnerability may be defined as: a state of dynamic openness and opportunity for individuals, groups, communities or populations to respond to community and individual factors through the use of internal and external resources in a positive (resilient) or negative (risk) manner along a continuum of illness (oppression) to health (growth) (Havrilla 2017). Moreover, vulnerability means 'the insecurity or wellbeing of individuals or communities in the face of changing environments (ecological/social/economic/political) in the form of sudden shocks, long-term trends or seasonal cycles' (Moser 1996). The extent of vulnerability relates both the level of external threats to a household's, individual's or community's welfare and to their resilience resisting and recovering from the external threats (UNDP 1997). Although the slum dwellers of Machkhowa locality find Guwahati city as a destination to fulfil their hopes and dreams, they suffer from a sense of deep insecurity in their livelihood due to their marginalised status. Most of these slum dwellers in Machkhowa slum are found to be the East Bengal origin Muslims, a particular social group that has been suffering persecution in various ways, from various chauvinistic groups in Assam (See Hussain 1993, 1995). Their marginalisation is the extension of the identity crisis they have been suffering from a long period of time. Most of these people are doubted and arbitrarily labelled as 'Bangladeshis' (See Ahmed 2014). Many local miscreants of the city harass them questioning their identity and citizenship. Additionally, they get harassed by the state too, through its repressive apparatuses (See Poulantzas 1969). When we say state, we refer to the concept of Gramscian state which is the combination of political society and civil society (See Gramsci 1971). Living in the condemned space, the low-income groups face certain political issues such as the identity crisis and their negotiation with the urban structure. They are certainly labelled as '*encroachers*' and '*others*' by the mainstream. They even deal with the land insecurity issues in the city space. To evade attacks and evictions from the external forces, the slum dwellers adopt certain ways including carrying personal documents during the movement such as voter card, ration card. These are some of the official documents that the low-income groups are coerced to carry them always, especially by the larger society that is increasingly becoming doubtful.

The entire slum is crowded with dismal huts consisting of only one small room which is used for all purposes including cooking, sleeping and for reading of the school going children in the families, etc. The huts even lack window or ventilation which causes severe health issues. Most of the time, the slum dwellers convert their single room into a further narrower kitchen. They barely have any balcony which is mainly connected with an open drain. The huts have only one door in front. These huts are built in close proximity to one another that do not provide any privacy to the hut members, fundamentally because of the lack of space. The huts are even vulnerable to storms, rains and bad weather. The conditions of the huts are such vulnerable, deteriorated and insanitary that the slum dwellers have to face deconstruction of huts in the monsoon season due to heavy rains. Dysfunctional drainage is another major problem faced by the slum dwellers. Since it is located in a low-lying marshland, the water of the open drains never flows away, and largely remains stagnated, which causes major troubles for the dwellers, especially during the rainy days. Eventually, the drainage water finds its way into the slum and gets mixed up with sewage water. As a consequent to the stagnated water, breeding of mosquitoes takes place in the area and puts the health of the slum dwellers under deep risks.

Adoption of Coping Mechanism or Strategies

The Machkhowa slum dwellers are marginalised in multifaceted areas. They face extreme poverty and vulnerabilities due to their poor socio-economic status in the city. To cope with the livelihood complexities in the new urban environment, the slum dwellers adopt various coping mechanisms or livelihood strategies to sort out their livelihood challenges. Livelihood strategies include those coping strategies designed by the slum dwellers to respond to shocks in short-term and long-term perspective, and accordingly, they design adaptive strategies to improve the circumstances in the long term. These livelihood strategies are determined by the assets and opportunities available to men and women and also by their choices and preferences. The slum populations are mainly engaged in the informal sector of the city economy. They are the low-paid earners in the city. Unemployment is a major problem among the slum dwellers. Most of the time, they even face the problem of losing jobs. In order to deal with this kind of economic challenges, they adopt many economic and household mechanisms. The occupational network is a very common instance among the slum dwellers while obtaining jobs in the city economy. These occupational networks have been associated mainly with the relations they create and sustain with their family relatives and neighbours, private owners who serve in providing access to the shelter and job market along with financial and non-financial support. They are the low-income groups in the city economy who lack the financial inclusion in the formal sector schemes for which they get cut off from the benefits of the formal economic sector of the city. Amid economic hardships, the slum dwellers' livelihood patterns in the city have been institutionalised and structured.

Conclusion

The haphazard and unplanned growth of Indian cities has led to the mass movement of populations from rural to urban space which consequently gave rise to the growth of slums in and around the cities of India. The slum growth in Guwahati city of Assam is mainly caused by rapid urbanisation and development of informal sector of city economy, etc. The slums are mostly proliferated near to the commercial and market areas of the city. The longer or shorter duration of residence of low-income groups in the city impact the livelihood patterns in terms of their access to resources with reference to ecology of slum. Based on the key findings of the study, the slum populations are the floating populations that too are the rural migrants in the city. The livelihood patterns of the low-income groups inhabiting the Machkhowa slum are determined by the economic status and assets available to them in the city structure. The vulnerability of the slum dwellers is associated with a series of disadvantages of poverty compounded with landlessness and other livelihood challenges like identity crisis, eviction, etc. The hope of the people to bring a socio-economic stability in their life, after migrating to the urban space, largely remained elusive. Such a grim scenario condition of the people can be ameliorated only with the state intervention which remains a daunting task.

References

Ahmed R (2014) Assam's D-voters. In: Himal Southasian, 26 May. http://himalmag.com/assams-d-voters/. Last accessed on 21 Jan 2018

Bhattacharjee D, Adhikari K (2010) Urbanisation trend in Assam—An analysis (June 18, 2010). Available at SSRN: http://ssrn.com/abstract=1626922 or https://doi.org/10.2139/ssrn.1626922

Borgohain T (2018) Social life of slum-dwellers: a case study of Guwahati City. Unpublished Doctoral Thesis. Gauhati University, Guwahati. Shodhganga. http://hdl.handle.net/10603/284920

Borgohain T (2021) Slums on railway land in Guwahati City, Assam: a sociological review. In: Mitra S, Bandyopadhyay S, Roy S, Ponce Dentinho T (eds) Railway transportation in South Asia—infrastructure planning, regional development and economic impacts. Contemporary South Asian Studies. Springer International Publishing, Switzerland, pp 235–252. ISBN 978-3-030-76878-2

Census of India (2011a). Census report of India. Registrar General of India and Census Commissioner, India, New Delhi

Census of India (2011b). Provisional population totals from http://censusindia.gov.in/2011b-provresults/prov_data_products_assam.html. Accessed on 8 March 2012. (Source: Master Plan for Guwahati Metropolitan Area-2025, GMDA, 2009, p. 12, and Census 2011b Provisional Population Totals)

Das A (2007) Urban planning in India. Rawat Publications, New Delhi

Das GN (2008) Tribal development in North-East India. Director, Assam Institute of Research for Tribals and Scheduled Castes, Jawaharnagar, Guwahati-22

Desai R, Mahadevia D, Mishra A (2014) City profile: Guwahati. CUE working paper 24, August 2014, Centre for Urban Equity

Devas N (2004) Urban governance, voice and poverty in the developing world. Earthscan Publications Ltd, UK and USA

Dikshit KR, Dikshit JK (2014) North–East India: land, people and economy. Springer, New York London

GMC (2006) City development plan. Guwahati Municipal Corporation, Guwahati

GMC (2009). Guwahati City slum policy, phase-1: identification of slum/urban poor. In: A report with technical support from AAPIL planning consultancy, Surat and Associated Builder, Guwahati, Guwahati Municipal Corporation

Gramsci A (1971) Selections for the prison notebooks. New Left Books, London

Haddad L, Ruel MT, Garett JL (1999) Are urban poverty and undernutrition growing? Some newly assembled evidence. World Dev 27(11):1891–1904

Havrilla E (2017) Defining vulnerability. Madridge J Nursing. Madridge Publishers. ISSN: 2638-1605

http://mohua.gov.in/cms/raji-awasyojana.php. Accessed on 12 Jul 2021

Hussain M (1993) The Assam movement: class, ideology and identity. Manak Publications Pvt. Ltd., Delhi

Hussain M (1995) Ethnicity, communalism and state barpeta massacre. Econ Political Wkly 30(20):1154–1155

Jaysawal N, Saha S (2014) Urbanization in India: an impact assessment. Int J Appl Soc 4(2):60–65. https://doi.org/10.5923/j.ijas.20140402.04

Meikle S (2002) The urban context and poor people. Urban livelihoods. In: Rakodi C, Lloyd-Jones T (eds). Routledge publications

Moser C (1996) Confronting crisis: a comparative study of household responses to poverty and vulnerability in four urban communities. ESD, Washington D.C.

North-East India—Emerging Urbanisation (2018) See http://urban-ecology.in/about/north-eastIndia-emerging-urbanisation/. Accessed on 15 Aug 2018

Nath H, Bhattacharjee, Bezbaruah S (2001) Water supply in greater Guwahati, problems and prospects, chapter 4. In: Alam K, Das NC, Borah AK (eds) Guwahati—The gateway to the east. Concept Publishing Company, New Delhi

Poulantzas N (1969) The problem of the capitalist state. New Left Rev 58(Nov–Dec)

Rakodi C, Loyd-Jones T (2002) Urban livelihoods: a people—centred approach to reducing poverty. Earthscan Publications Ltd., London

Saitluanga BL (2013) Globalisation, urbanisation and spatial inequality in India with special reference to North-east India. Space cult India 1:2

The World Bank (2017) Population living in slums. UN-HABITAT, Washington, D.C. Retrieved December 06, 2019, from https://data.worldbank.org/indicator/EN.POP.SLUM.UR.ZS

Todaro MP (1976) Urban job expansion, induced migration and rising unemployment: a formulation and simplified empirical test for LDCs. J Dev Econ 3:211–225

UNDP (1997) Human development report. Oxford University Press, Oxford

UN-HABITAT (2003) The challenge of slums: global report on human settlements. Earthscan Publication Limited, London

UN-Habitat (2011) Annual report

Chapter 22
Identification of Potential Rooftops for Gardening and Contributions of RTGs to Improve the Socio-economic Condition and Promote a Sustainable Urban Environment in the Changing Climatic Condition of Bangladesh

Sumaia Islam, Md. Rashedul Alam, and Kazi Jihadur Rashid

Abstract Over the last few decades, Bangladesh with a large population is going through rapid urbanisation to meet increasing demands. Anthropogenic activities enhance carbon emissions which ultimately trigger heat stress in the city areas. Habitats for new urbanised people and existing high-rise buildings have already created a scarcity of land. Therefore, one of the probable solutions considered by the researchers to minimise this heat stress is rooftop gardening (RTG). A systematic study has been performed on Dhaka city through a survey, Geographical Information System (GIS) analysis and Key Informant Interviews (KII). This research has identified existing rooftop gardens and potential rooftops for gardening and identified the factors that hinder the process of maintaining RTG. It has also explored the conditions that enable city dwellers to implement rooftop gardens in Dhaka city. Analysis showed that 38% of the rooftops were vegetated, and the other 62% of rooftops were non-vegetated which can be considered potential rooftops for making RTG. The temperature difference between buildings with RTG and without RTG was also measured and analysed through the discomfort index (DI). Several socio-economic barriers, weakness in city governance and lack of environmental consciousness hinder the potential that a rooftop garden can offer. However, some people maintain rooftop gardens for socio-economic and environmental advantages. The research will help policymakers to plan a sustainable urban environment in Dhaka city.

S. Islam (✉)
Urban Management and Development, Institute for Housing and Urban Development Studies, Erasmus University Rotterdam, Rotterdam, Netherlands
e-mail: s.i.orpa47@gmail.com

Md. R. Alam
Department of Government and Politics, Jahangirnagar University, Dhaka, Bangladesh

K. J. Rashid
Remote Sensing Division, Center for Environmental and Geographic Information Services, Dhaka 1212, Bangladesh

U. Chatterjee et al. (eds.), *Urban Commons, Future Smart Cities and Sustainability*, Springer Geography, https://doi.org/10.1007/978-3-031-24767-5_22

Keywords Urbanisation · City governance · Dhaka city · Heat stress · Rooftop garden (RTG) · Sustainable environment

Introduction

In megacity Dhaka, urbanisation is increasing with the rapid growth of population and concrete structures. Urbanisation is extensively characterised as the procedure of urban land extension and inescapable human alteration to the global structure (Grimm et al. 2008; Seto et al. 2011; Wu et al. 2014)**.** Urban green is getting replaced by the concrete structure, and it refers to the effect on urban microclimate with a bunch of micro-heat pockets within the city which increases the urban area's temperature than the adjoining rural areas (Lowry 1967; Oke 1973; Balling and Brazel 1987; Voogt and Oke 1997; Oke 1997). It increases mainly because of the absence of urban green and the lack of required vegetation (Munn 2002; Sarrat et al. 2006). Besides other reasons, urbanisation also affects microclimatic factors like temperature, humidity and air velocity (UN 2016; Zhang et al. 2016). A high density of buildings and other urban structures triggers several environmental and climatic problems in city areas (Ahmed 1995; Landsberg 1981; Oke 1982). Urban Heat Island (UHI) is one of these problems. Urban Heat Island (UHI) is a considerably warmer area than its neighbouring suburban/rural areas due to anthropological events (Oke 1982). It is influenced by several factors like the height of the canopy (Landsberg 1981), toxic building materials, industrialisation, unplanned urbanisation, vehicle and residential warming, aerosol products, petroleum products and excessive use of heating and cooling equipment that led to the variation in thermal properties (Montavez et al. 2000; Ohara et al. 2007).

Shourav et al. (2016) claimed that every decade, the temperature of Dhaka city is increasing at a rate of 0.22 °C. This is an alert to lessening the thermal comfort of city dwellers (Sultana et al. 2021). Diverse health issues are also penetrating with the increase of extreme heat stress and climatic discomfort (Munn 2002; Sarrat et al. 2006)**.** Heatstroke, psychological and nervous issues, insomnia, several airborne and temperature-induced diseases increase, reduction of labour productivity, biodiversity loss, ecosystem imbalance, global warming, UHI generation and power consumption for cooling equipment are increasing intensively along with the temperature rise in Dhaka city (Solcerova et al. 2017).

Besides, emissions of greenhouse gases (GHG) are accelerating, and ozone-harming substances are intensifying (Ulbrich et al. 2008). Exploration has demonstrated that the earth is warming (IPCC 2007). This high temperature initiates the energy consumption rate at its peak in urban areas during the summer season (Roeland et al. 2019). Meanwhile, in Dhaka, only 5% of open and green spaces are available in the southern part (old town), while the northern (new) part of the city has 12% of green and open spaces (Mowla 2011). City green has a big contribution to improving the damaged environment and regulating the urban climate (Stewart and Oke 2009). The greeneries have the cooling capacity to lessen the air temperature profoundly in its proximate area and help in mitigating the Urban Heat Island (UHI) effect (Ahmed 2003) and are also a source of Urban Cool Island (UCI) (Honjo et al. 2003). The need for greeneries for Dhaka city is very important, and the smallest efforts including rooftop gardening, green vertical wall in the urban infrastructure, green façades, etc. can improve the microclimatic condition of the city.

Excessive heat and moist atmospheric conditions create discomfort to the skin and physical sensitivity. To measure the level of discomfort induced by climatic factors, the discomfort index (DI) was proposed by Thom (1959) which is one of the well-accepted indices and is commonly used by researchers (i.e. Bady 2014; Abdallah et al. 2012; Silva et al. 2018). The combined effect of temperature and relative humidity is mainly represented as DI values. The discomfort index is an empirical index gained through a large dataset by observing the relation of discomfort sensitivity with dry-bulb air temperature and relative humidity (Thom 1959; Bady 2014; Sultana et al. 2021).

Researchers have recognised the correlation between the intensification of greeneries in urban areas and decreasing Urban Heat Island effect in the local micro-climate (Takebayashi and Moriyama 2007). We have found several experiments and several research explaining the thermal benefits of rooftop gardens like the thermal behaviour of green roofs (Del Barrio 1998), consumption of solar heat by vegetation (Wilmers 1990) and benefits of green lawn gardens (Onmura et al. 2001, p. 1), energy performance study of green roofs (Niachou et al. 2001), etc. The thermal load applied to the building can be reduced through greeneries which can help to improve the microclimatic condition in the city areas (Wong et al. 2003).

Despite having many benefits, rooftop gardens are not adequate in cities for different reasons (Carter and Keeler 2008). For creating new urban structures, urban green is being demolished. Lack of financial strength is one of the noteworthy factors that restraints the inventive projects of rooftop garden (RTG) in Dhaka. Lack of available credit and funding prevents the urban poor to take suitable areas as leases for initiating food production through gardening (Shariful Islam 2002; Rahman 2014; Islam et al. 2019). Moreover, poverty, price hike and food shortage increase the threat of theft from the garden (Rahman 2014; Safayet et al. 2017). The unavailability of good quality seeds during the harvesting seasons due to enormous demand is another problem. Those who maintain the garden for professional purposes for vegetables, fruits, etc., do not even have proper skills and training in agriculture (Mowla 2010; Rahman et al. 2019). Starting gardening without professional knowledge and proper training may bring unwanted outcomes, which might restrict and discourage people to initiate new projects (Wong et al. 2003; Rahman et al. 2019). Some people have a willingness and sufficient funds for gardening, but they do not have the available manpower and time to take care of the garden. In some houses, they have part-time caretakers for gardens (Rahman 2014). Meanwhile, most of the old area's buildings have poor structural strength which is also a hindrance to initiating rooftop gardening (RTG) (Rahman 2014). Moreover, these zones of Dhaka city have a big threat to seismic hazards because of overcrowding and the low-quality materials of the building base; thus, experts are aware of the probability of building collapse (Shariful Islam 2002; Rahman et al. 2015; Safayet et al. 2017). Unrestricted urbanisation and disobeying building construction code (number of stories and foundation) are the major causes of such kinds of hazards which are happening frequently in Dhaka city. Cascone et al. (2018) stated that a load limit of 1.46 k Nm^2 is appropriate for retrofitting green roof in existing buildings. Another barrier for RTG is the shadow of taller buildings on smaller ones (Shariful Islam 2002). Available and affordable access to land and water especially in the dry season is another concern for the middle class and urban poor of the city (Shariful Islam 2002). Besides all these obstacles, people are not aware of the benefit of rooftop gardening; also, there are not sufficient organised initiatives from the government and private sectors to introduce RTG and extract socio-economic and environmental benefits from it (Mowla 2010; Rahman 2014).

Rationale of the Study

Dhaka is one of the world's fastest-growing cities, and it is rapidly losing green spaces. Previously, many researchers have studied urban green space and especially focused on rooftop gardening. Momtaz et al. (2017) studied 'Possible solutions for reviving urban green in Dhaka city'; Uddin et al. (2016) researched 'Baseline Study on Roof Top Gardening'; Hossain et al. (2019) studied 'Perception and barriers to implementation of intensive and extensive green roofs in Dhaka'; 'Present practice and the prospect of rooftop farming in Dhaka city' was conducted by Safayet et al. (2017), and many other researchers have shown their interest in the rooftop garden through their studies which were found from the literature review. But no attempt was found in the research field of Bangladesh who has worked to find out the potential rooftop areas for gardening using the building footprint of Dhaka city, identify the obstacles to implementing rooftop gardening and identify the level of comfort or discomfort related to having rooftop garden on the building rooftops (Rahman 2014; Rashid et al. 2010a; Islam et al. 2019). The objectives of this study were (i) to identify the existing rooftop gardens and the potential rooftops to initiate gardening in Dhaka city; (ii) to detect the thermal difference and the level of discomfort between two nearby urban residences categorised by rooftop garden (RTG) and non-RTG building; (iii) to identify the factors that hinder or the conditions that enable the city dwellers to implement rooftop gardening substantially in Dhaka city.

Materials and Methods

Study Area

The capital city Dhaka has been declared the 9th largest megacity in the world and is projected to rank 4th by 2030 (United Nations 2019). The geographical location of the city is from 23°42′0″N–90°22′30″E to 23°7′0″ N–90°37′5″E in Central

Bangladesh (Fig. 22.1). The current population of megacity Dhaka is 20 million (in 2020), and the number is anticipated to reach over 26 million by 2035 (RSTP 2015), following the annual growth rate of 4.4% (United Nations 2019). It is becoming busier every day having 55,169 people per km^2 (BBS 2019) which has created tremendous pressure on urban land, utility services and other amenities of urban life. Consequently, the urbanisation rate is growing and imposing an effect on the climate, especially the thermal climate (Hossain 2013). Dhaka city can be characterised as a humid, wet and hot tropical climatic area with a monsoon season. The annual average temperature is 25 °C (77 °F) with the monthly mean temperature varying between 18 °C (64 °F) in January and 29 °C (84 °F) in August (Nur et al. 2022). The city experiences approximately 1,854 mm of rainfall during monsoon (May to September) which is almost 80% of the annual average rainfall (Nur et al. 2022). It has approximately 360 thousand buildings with concrete roof surfaces (Kamruzzaman and Ogura 2007; Hossain et al. 2019). The greeneries and water bodies are at an alarming state, as they are continuously being replaced by concrete surfaces (Ahmed et al. 2005; Byomkesh et al. 2012). These emit a significant amount of heat causing the change in urban areas in the energy balance. A systematic study has been performed on Dhaka city by qualitative and quantitative survey, Key Informant Interviews (KII) are to identify the obstacles and the contributions of rooftop gardening. A Geographical Information System (GIS) analysis has been performed to identify the share of rooftop gardens and potential areas for rooftop gardens in Dhaka city.

Data Description

Both primary and secondary data sources were used to get a comparative analysis, identifying the gaps and interconnections between city dwellers' and policymakers' perceptions of implementing RTGs in Dhaka city. Building footprints were collected in vector format from Rajdhani Unnayan Kartripakkha (RAJUK) and Sentinel-2 image of the study area from the United States Geological Survey (USGS) to identify the potential rooftops for gardening and the share of rooftop vegetation. A semi-structured questionnaire survey was conducted to know the perception and experience of city dwellers to initiate rooftop gardening (RTG) extensively in Dhaka city using the existing and potential spaces. The survey was directed through 'Qualtrics' where the number of the total respondent was 370 considering the whole of Dhaka city as the study area. The survey was led based on probable random sampling. Among the survey respondents (with and without RTG building dwellers), some were selected and communicated to collect the temperature readings through TA298 Digital LCD Indoor Thermometer-Hygrometer. This tool measures temperature at an accuracy of ± 1 °C degree (2 Fahrenheit) and humidity at an accuracy of ± 5% (LABTEX 2021). To explore the thermal benefits of RTG, temperature readings from 15 buildings that have RTG and another 15 buildings that have bare rooftops were collected. The temperature survey was conducted in ten days during the end of summer. In the timeline of ten days, indoor–outdoor readings of temperature and humidity during daytime

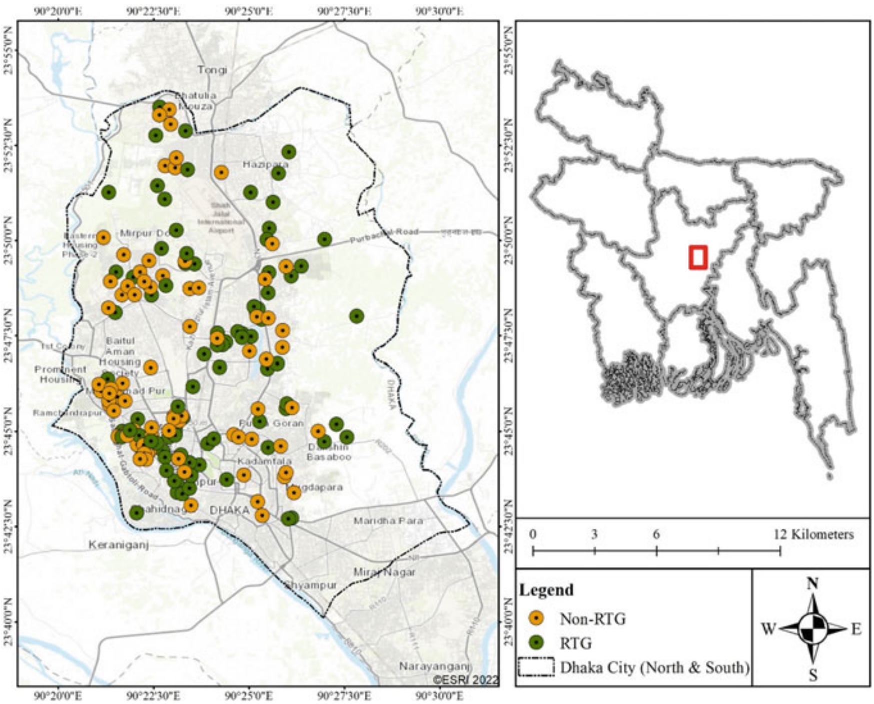


Fig. 22.1 Map showing the locations of the rooftop garden of the respondents in the study area *Source* Author, 2022

(11 a.m.–2 p.m.) and night-time (8 p.m.–11 p.m.) from each top-floor apartment have been collected. In this research, interviews with 20 key informants (Table 22.1) have also been done who are RTG owners, practitioners and experts of government and private organisations and are involved with the planning, designing, monitoring and policymaking. The respondents were chosen with an intention of purposive sampling (Van Thiel 2014). In this survey, only adult persons were considered as the respondent to get relevant, conversant and knowledgeable information. Literature review and case studies have been observed for triangulation and applied the mixed method to validate the research.

Methods

The study was conducted by applying both quantitative and qualitative approaches. The quantitative data and qualitative information were triangulated to get a comprehensive picture of the city dwellers' and policymakers' thoughts on implementing the rooftop garden in Dhaka city. All the procedures adopted from data processing to visualisations in this study were done using MS Excel, R programming, ArcGIS and QGIS.

Table 22.1 Information on KI selection criteria

Category	Number of the sample (KII)
Urban planner	2
Civil engineers	2
Architect	4
Government developmental organisation officers	2
Environmentalist	5
Agriculturalist	1
Rooftop garden owner	4

Data preparation

Sentinel-2 images were processed in the semi-automatic classification plugin (SCP) of QGIS. Raw images were converted to reflectance and corrected atmospherically using the DOS1 method (Chavez 1988). Afterwards, corrected bands were used in geospatial analysis. All the questionnaires were coded and entered into an Excel sheet after checking and cross-checking the collected data. Interview data was transcribed, edited and scrutinised. A comparative rank analysis has been performed by the survey response and key informants' responses regarding the benefits of RTG and corresponding obstacles to implementing RTGs in Dhaka city. Temperature and humidity data were imported to excel and divided into groups based on RTG–non-RTG, indoor–outdoor and day–night.

Geospatial analysis

Two bands such as near-infrared (NIR) and red were used from the corrected image to extract vegetation information. Normalised difference vegetation index (NDVI) is a widely used method for analysing land vegetation change and classifying land cover types (Carlson and Ripley 1997; Guha et al. 2018; Jiménez-Muñoz et al. 2006; Lee et al. 2020). In this study, NDVI has been calculated using the following Eq. 22.1 (Guha et al. 2018):

$$\mathrm{NDVI} = \frac{\mathrm{NIR} - \mathrm{Red}}{\mathrm{NIR} + \mathrm{Red}} \tag{22.1}$$

After the calculation of NDVI, vegetated and non-vegetated surfaces were classified from the layer using density slicing (Lee et al. 2020). Then, the classified raster was converted to a vector layer for spatial join analysis with the building footprint layer. Joined building footprint layer carried information on whether it has overlaid with a vegetated class or non-vegetated class. Finally, buildings were categorised based on the information into two groups such as RTG and non-RTG. Validation was done by adopting a confusion matrix using ground truth data collected from the field and Google Earth Pro. Overall accuracy (87.3%) and kappa statistics (73.2%) were measured from the confusion matrix.

Survey and KII analysis

Cleaned questionnaire data was used to compare perceptions between residents and key informants. Weighted ranks were measured for positive/negative perceptions and difficulties faced by respondents. Grades of the respondents and key informants were given weights ranging between 1, 0.75, 0.5 and 0.25 to the variables marked as 1, 2, 3 and 4, respectively (Hemphill et al. 2002). The percentage of each variable was calculated for each assigned grade by respondents. Finally, the weighted sum for all the variables was measured using Eq. 22.2 (Aydi et al. 2013):

$$S = \sum_{i=1}^{n} Wi * Xi \tag{22.2}$$

where S is the weighted sum for influential measures of variables and Wi and Xi represent the weight and percentage of the ith variable.

Thermal analysis and discomfort index

Processed temperature readings of both indoor and outdoor were imported to *R* and graphed using a boxplot to get the comparison of RTG–non-RTG, indoor–outdoor and day–night. Indoor temperatures and humidity were used to measure discomfort zone among RTG and non-RTG. Several indices such as Robaa index, discomfort index and heat stress index are used as indicators of discomfort (Fountain and Huizenga 1995; Sultana et al. 2021; Thom 1959). Among them, discomfort index was used in this study for quantifying the thermal comfort zone. An increase in DI values increases discomfort, and the DI can be calculated using Eq. 22.3:

$$\mathrm{DI} = T - (0.55 - 0.0055\mathrm{RH})(T - 14.5) \tag{22.3}$$

where DI denotes discomfort index, T is temperature (°C) and RH is relative humidity (%). The classification of discomfort index (DI) (Thom 1959; Sultana et al. 2021) values at different comfort levels is given (Table 22.2).

Table 22.2 Classification of discomfort levels based on the DI values

DI value	Discomfort levels
DI < 21	No discomfort
$21 \leq$ DI < 24	Less than 50% of people feel discomfort
$24 \leq$ DI < 27	More than 50% of people feel discomfort
$27 \leq$ DI < 29	Most people feel discomfort
$29 \leq$ DI < 32	Very strong discomfort
DI ≥ 32	Medical emergency

Results and Discussion

Existing and Potential RTG Scenarios

To evaluate the share of the RTG and potential rooftops for gardening, we have adopted a GIS-based analysis. The result of this analysis shows the geographic location of the roof-top gardens and potential roof-tops for gardening in Dhaka city. In Fig. 22.2a, the green colour represents the location of RTG, and the red colour represents the location of the bare rooftops. Moreover, as shown in Fig. 22.2b, most of the rooftops in Dhaka city do not have an RTG (62%). As presently, Dhaka city is going under rapid urbanisation which leads to the loss of the ground vegetation. The dwellers are failing to keep sufficient ground surface for vegetation after meeting the housing and other amenities demand with limited resources. Therefore, these available bare rooftops can be used as a potential area for rooftop gardening to meet the demand of a city.

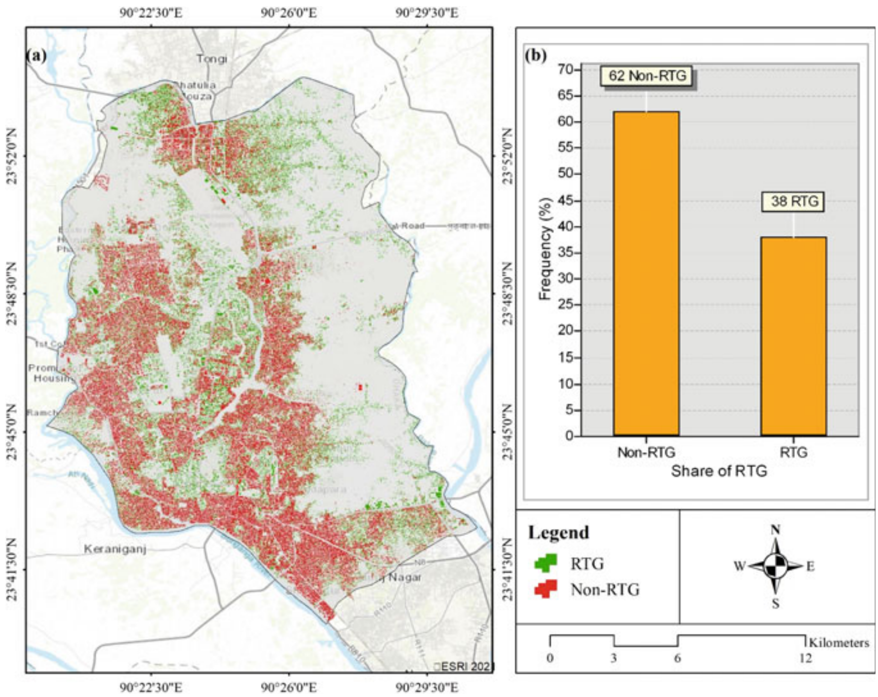


Fig. 22.2 **a** Map of the share of the RTGs and potential RTGs in Dhaka city and **b** Statistics of the RTGs and bare rooftop

The Socio-economic and Demographic Background of the Respondent in the Study Area

The survey of this research was conducted among the Dhaka city dweller, and it was found from the survey that most of the respondents (92.93%, 342 respondents) reside in a full concrete multi-storied building. About 3.26% reside in a single house with a garden, 2.45% lives in a tin-shed building, and the rest of the 1.36% of respondent lives in other types of housing which is representative of the housing situation in Dhaka city. Maintaining a rooftop garden is a fancy thing for slum dwellers after fulfilling their basic needs. Therefore, in our study, they were excluded from the target respondent list. Among the 370 respondents from the mixed type of age group, 163 were male and 207 were female. The young generation (especially girls), middle-aged even older citizens of the city usually pass their leisure by doing gardening, and it is also a pleasant thing for them to do.

In Fig. 22.1, the locations of the survey respondents are shown on a map. We have collected 370 samples, and the results were found tracking their home location. Here, the respondents from Mirpur, Dhanmondi, Zigatola, Gulshan, Mohammadpur, Pallabi, Uttara, Bashundhara R/A, Cantonment and Khilgaon are showing more building locations that have rooftop gardens. Connecting with the map and the survey result, it is found that about 48.77% have rooftop gardens. The GIS-based analysis also shows the wide features of Dhaka city, and the result is not differing much from the survey result. Though 51.23% of people replied that they do not have a rooftop garden in their home, meanwhile in another query where they were asked if they support building a rooftop garden on the building where they live; about 84.60% of the total respondents replied that they want a garden in their home, but several hindrances are restricting them to initiate rooftop gardening.

Purpose of Maintaining Rooftop Garden (RTG)

As previously stated, around half of the respondents have had rooftop gardens. Therefore, we asked the respondent about the purpose of having a rooftop garden (Table 22.3). About 37.39% of respondents said that they do it as a 'hobby or recreation', and some 31.98% said that it is a 'source of healing' for them. About 25% of the respondents said that they make roof gardens because of 'environmental concern', about 3.06% mentioned 'cultural practice' as the purpose of having roof gardens, and 2.03% used and maintain the garden for 'financial purpose'. We also asked the respondents about their knowledge regarding the benefits of rooftop gardens, about 74.29% of respondents replied positively that they know about the benefit and contribution of rooftop gardens to city life, and 25.71% said that they do not know the benefit of the roof garden. Therefore, open space and greeneries are important to influence the quality of life by enhancing environmental livability, economic benefit and social interactions (Sultana et al. 2021). Green areas and open spaces are

Table 22.3 Purpose of maintaining rooftop garden

Purpose of maintaining RTG	Percentage of people who maintains the rooftop gardens
Hobby/recreation	37.39
Environmental concern	25
Financial benefit	2.03
Psychological benefit/source of healing	31.98
Cultural practice	3.6

sources of entertainment to refresh the human mind (Burls 2007). On the other hand, insufficient green areas reduce mental wellbeing, and sometimes, it leads to several psychological and behavioural problems that increase social isolation and hampers the skill and efficiency of the city dwellers (Lindheim and Syme 1983). As many people said that they are aware of the benefit of a rooftop garden, thus the subsequent question was raised regarding ‘air conditioner’. From this study, it is found that the top-floor dwellers can get comfort if they have a rooftop garden on the roof, and this statement is also aligned with Barua and Ikbal (2012). But in response, some 41.04% of people said that they have an air conditioner in their home for comfort. Due to excessively hot weather, people buy an air conditioner in their home who can afford it. The other 58.96% of respondents said that they do not have an air conditioner, but this is not evident that they have a comfortable temperature in their home; rather, it can be related to affordability (Table 22.3).

Thermal Conditions of Buildings with and Without RTG

In Fig. 22.3, plot (a) is representing indoor temperature, and plot (b) is representing outdoor temperature. In the study, buildings having no RTG are showing an indoor daytime temperature range between 27.1 °C and 32.1 °C where the average temperature is 29.54 °C. On the contrary, the indoor daytime temperature range of buildings with RTG is depicting lower temperatures (26–30.6 °C) than the buildings without RTG. The average temperatures are showing a 1.44 °C indoor temperature difference between RTGs and non-RTG buildings in the daytime. At night-time, the indoor average temperature in top-floor apartments is showing a 1.69 °C difference between buildings having RTG and non-RTG. During the study period, the maximum indoor temperature difference at night was 2.4 °C. In the graph, the non-RTG buildings are showing a higher minimum and maximum indoor temperatures at night than the buildings having RTG. The outdoor temperature captured from the buildings having RTG and non-RTG was almost the same except for the night-time temperature of RTG buildings. Two out layers have also been found, one from the night non-RTG indoor temperature and another one from outdoor temperature captured from RTG buildings at night. From the graph, it was noticed that the buildings having RTGs are showing

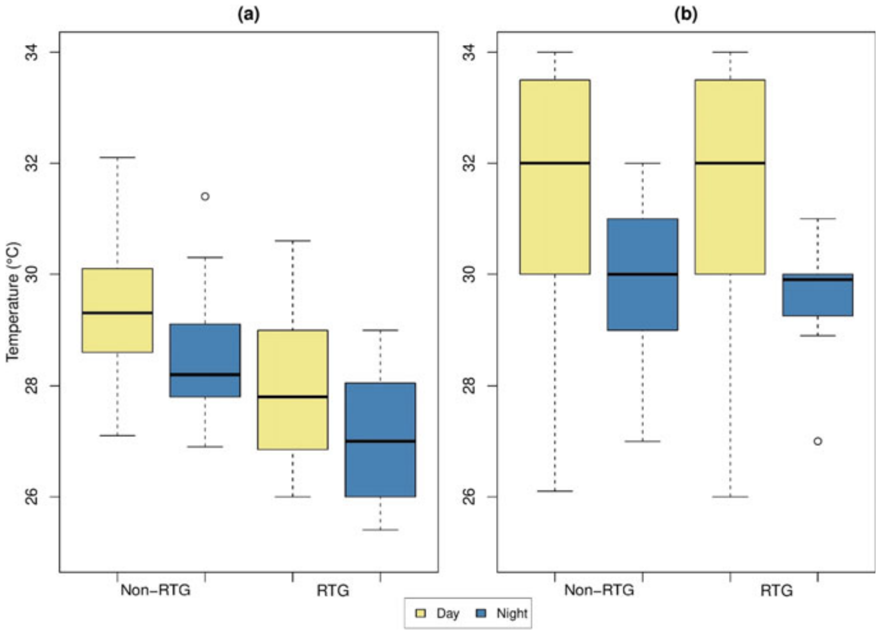


Fig. 22.3 Boxplot comparing temperature among day–night, indoor–outdoor, RTG–non-RTG where **a** and **b** represent indoor and outdoor, respectively

less indoor temperatures both day and night than the indoor temperature of buildings containing no rooftop garden (RTG). Like Niachou et al. (2001), it can be concluded that even a small contribution from any source like rooftop gardens will help to reduce local microclimatic temperature. Surrounding environmental conditions (meteorological and geographic) have a big impact on the performance of rooftop garden (RTG) (Aflaki et al. 2017) which influences the quality and efficiency of a garden to give a proper positive outcome.

Thermal Discomfort Scenarios

In Fig. 22.4, black and blue colours respectively represent the day and night-time discomfort levels of the people residing in the buildings having a rooftop garden (RTG) above their ceiling. Besides, deep red and yellow colours respectively represent the day and night-time discomfort level of the people residing in the buildings having bare rooftops overhead. The graph has been produced based on the values of the discomfort index (DI). Each class represents different comfort levels of city dwellers in DI. The DI values show comfort levels between DI < 21 to DI ≥ 32. The DI density graph shows the gradual increase of discomfort through the X-axis, and the steep curve lines towards the Y-axis indicate the density of the people feeling discomfort at a different stage. In the graph, a, b, c and d panels are the labels ranging between DI < 21 to DI ≥ 32. In section (a), the blue line (RTG night-time) shows the high density of discomfort which comes under the 21 ≤ DI < 24 range and specifically indicates that 'less than 50% of people feel discomfort' at night who lives in the home having RTGs on top of their buildings. On the contrary, the yellow line (non-RTG night-time) shows the lowest density among all.

In section (b), almost all the lines are showing an upward trend of the high density of discomfort. However, the yellow steep line (non-RTG night-time) reaches the peak density range of the graph. This 24 ≤ DI < 27 range is showing that 'more than 50% of people feel discomfort' in different levels of density. The predominant feature of discomfort experienced by the non-RTG building's inhabitants has been identified through the graph discomfort index (DI). Yet, all the dwellers regardless of having RTG or non-RTG above their buildings experience discomfort both the day and night-time due to extreme heat stress and its associated effects. Despite having RTGs on the buildings, the density of discomfort at night-time is higher than during the daytime which is also visible from the graph. These insights from both sections a and b are showing that heat stress sustains even after sunset which is evidence of Urban Heat Island (UHI) in the study area.

In the Figure, section (c) is showing the downward trend of almost all the lines. Though, the difference in the level of discomfort between the buildings holding RTG and non-RTG is still greater. The range 27 ≤ DI < 29 depicts the discomfort of

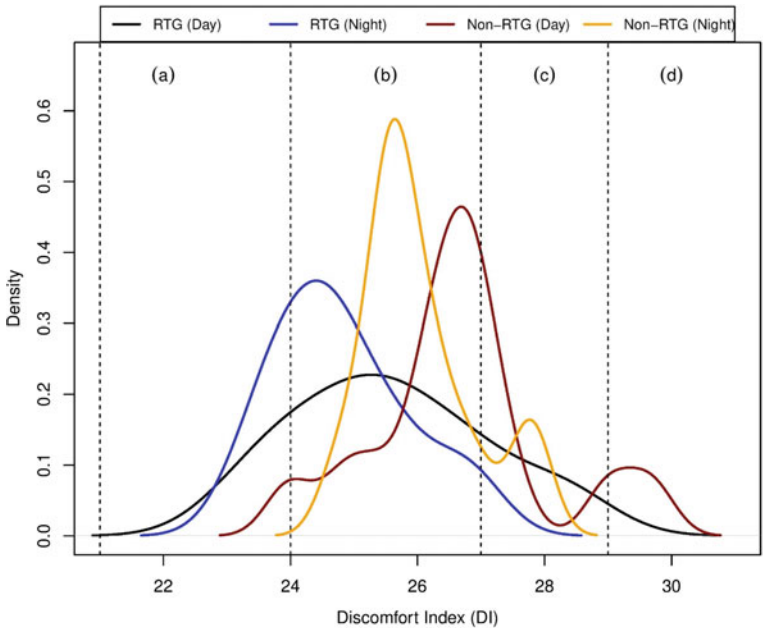


Fig. 22.4 Density plot comparing discomfort values of RTG (day–night) and non-RTG (day–night) where a, b, c and d show gradual rise in discomfort level

'most people' who comes under this class. Lastly, the DI range $29 \leq DI < 32$ of the graphs represents the 'very strong discomfort' which is felt by the people living in buildings having no rooftop gardens (RTGs). Usually, top-floor dwellers of any building feel the most heat stress compared with other floor inhabitants. Building materials and many other factors influence this heat to circulate and transmit to the next floor which affects the building environment consequently. DI values are higher for bare roofs than those green roofs. During the study, relative humidity did not deviate much between bare and green-roofed buildings, but the main variation was detected in temperature. Vegetation shades the roof surface and consumes solar heat for photosynthesis and transpiration, and this process helps in cooling the ambient air (Wilmers 1990). Shaded surfaces emit less long-wave radiation due to lower surface temperatures. It also helps in mitigating the UHI effect in the urban environment by contributing to lowering energy consumption for cooling purposes. In a survey by Onmura et al. (2001, p. 1), it was confirmed that the amount of heat coming into the rooms was reduced by a roof lawn garden which was estimated to be followed by a 50% reduction in heat flux into the room. The evaporative cooling effect from roof lawn gardens is considered to play an important role in reducing heat flux. Meanwhile, Del Barrio (1998) explored the thermal behaviour of green roofs through mathematical analysis. The finding of this study is that green roofs act as a thermal insulator rather than cooling the roofs. But Eumorfopoulou and Aravantinos (1998) said that green roofs can contribute to the thermal performance of buildings, but they cannot become equally effective as the insulation layer. In an energy performance study of the green roof, Niachou et al. (2001) proved that the green roofs contribute to the cooling of the spaces below the roof during summer and keeping warm during winter. Therefore, it has a big contribution to balancing sustainable urban development under the ongoing urbanisation trend (Collier 2013). Therefore, it can be summarised that, even though all the DI values represent different levels of discomfort, among them the dwellers of the buildings having RTG feel the lower level of discomfort. As the study was conducted at the end of the summer, cloudy, drizzling and hazy weather characteristics have been observed during the survey. These features have also influenced the survey findings.

People's Perception of the Positive Impact, Obstacles and Difficulties to Implement RTG

Since Dhaka is a crowded city, approximately more than 70% of the total surface area is occupied by buildings (GoB 2017). Tropical climatic cities like Dhaka experience excessive sunshine and rain making it a warm-humid climate. On hot sunny days, high temperature combined with high humidity makes living condition extremely difficult within the cities. With the ongoing development of the country and within the high densely buildings of the city, it does not have enough open urban green spaces. In this study, the key informants and survey respondents were asked about their perception regarding the wide initiation of rooftop gardens in Dhaka city as an approach to enhance green in city areas. Besides the numerous merits and positive role of RTGs, they have also expressed their concern about some obstacles which are hampering the extensive growth of initiating RTGs in Dhaka city. Most of the responses from the respondents and the interviewees were almost the same regarding the perception of RTG's positive role, obstacles and difficulties to implement RTGs in Dhaka city (Fig. 22.5*)*. Almost 99% of respondents agree with the attempt to **implement an extensive rooftop garden on existing buildings.** Approximately 90% of KII and respondents support that RTGs improve the aesthetics of the surrounding environment, and it can be a source of earning for anyone who systematically maintains the rooftop garden. During the study, it was found that some gardeners grow expensive foreign fruits and yield good profit. They grow plants and grafts with the proper technology and environment and sell at a high price. Among the gardeners, there is also a practice of plant exchange by which all the gardeners meet and exchange their expensive and rare plants which is increasing the positive environment for rooftop gardening. Expert gardeners are also working as consultants and doing business in preparing the soil, fertilizers and irrigation system in new gardens. Some of them also organise seminars and share their experiences and expertise in the seminars which also benefit the gardener community. These exchange events and opportunities are helping the gardeners to know new technologies and learn a lot about rooftop gardening which is also increasing the success rate of the gardens. The average income of the gardeners from selling grafts ranges from USD 6000–7000. These small-scale rooftop gardens also provide support as kitchen gardens to many households which is playing a vital role in food security (Rashid et al. 2010b). Meanwhile, Ascione et al. (2013), Blackhurst et al. (2010), and Carter and Keeler (2008) have stated that usually rooftop gardens lead mostly to financial losses of 19–50% given their limited private benefits which are not in line with the statement of the majority respondents and KII persons. Findings from the survey and interviews are endorsing that RTGs provide financial and other benefits of rooftop gardening like they increase the value of the property, enhance air quality and improve public health, help in psychological healing, can be a source of hobby, help in biodiversity conservation, improve the energy efficiency of the building, etc. In line with Safayet et al. (2017), the interviewees have claimed that RTGs will act as an insulator to restrict heat transmission and absorption by building surfaces and, therefore, help in reducing heat and provide comfort to the building dwellers.

Respondents and interviewees have also stated that most of the existing buildings are not appropriately constructed to provide the garden with a convenient environment. Besides, almost 87% of experts (KII) have also said that it is possible to implement RTGs in existing buildings. However, many existing buildings have construction and design difficulties, as stated by the respondents and interviewees. Preparing the roof for gardening can charge a design and additional construction cost, as stated by almost 70% of the stakeholders. About 50% of respondents consider this as an additional and unnecessary cost which is not supported by the interviewees and RTG practitioners. About 82% of interviewees and respondents have claimed that lack of awareness about a sustainable environment is one of the causes that

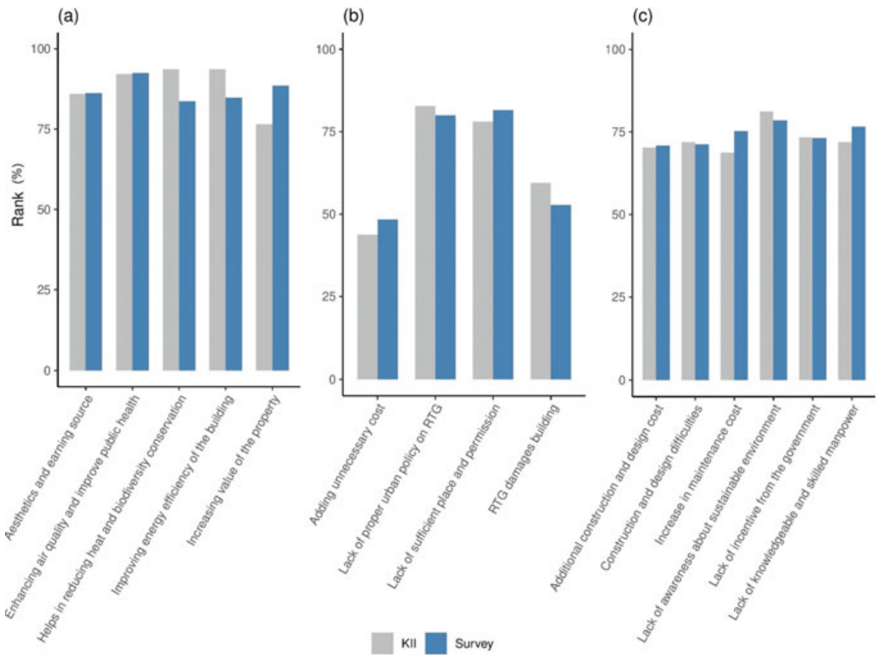


Fig. 22.5 Comparison of KII and city dwellers' perception of the **a** RTG's positive role, **b** Obstacles, and **c** Difficulties to implement RTGs in Dhaka city

affect the growth of RTGs in Dhaka city. About 76.76% of the respondents indicated that the unavailability of detailed and specific urban policy and lack of supporting building code are the significant causes that impact the growth of roof gardens in Dhaka city. Though, Dhaka city policy approves rooftop gardening, as confirmed by 93.75% of interviewees. They also think that incentives from the government to building owners to plan for RTGs can be the best way to encourage them to initiate gardens on their rooftops. About 70% claimed that incentive from the government is not sufficient. Besides, Key informants and survey respondents have recommended that the government can initiate structural and technical support along with incentives and other encouraging packages which can play a vital role to promote rooftop gardens. The interviewees have also provided the information that the city authority has allocated tax benefits for the RTG owner though it will take time to implement successfully (The Daily Star 2019; Safayet et al. 2017). Most of the interviewees were architects, planners, environmentalists, engineers and government city development officials; therefore, they have been asked if they consider roof gardening in their projects; about 56.25% said that they consider green roofs in their projects. About 60% of key informants and 55% of survey respondents consider that RTG may damage buildings, whereas Feng and Kasun (2018) said that RTGs can increase the life span of the roof by shading and covering the roof from thermal, UV radiation fluctuations and stress diurnal. Linking with such thought, almost 80% of respondents claimed that in rented houses, they usually face problems with sufficient space and permission despite having the willingness to do gardens on the rooftop. From the survey, we found that 66% of the respondents who said that they have both willingness and ability to do a rooftop garden have an income level of 45,000 + per month. Only 2% of respondents below 15,000 monthly incomes said that they have both willingness and ability to do a rooftop garden. All the building dwellers are not able to bear the regular maintenance cost of rooftop gardens. Around 43.10% of respondents said that they have maintenance facilities, and 56.90% of respondents feel the need for sufficient maintenance facilities for gardening in a planned way. Among the garden owners, about 52.19% said that they have moderate skill in garden maintenance, and the rest of the respondents maintain gardens with less or no knowledge which usually gives disappointing results; consequently, it demotivates those people to continue gardening. Few people (3.59%) reported other problems like neighbours harming the garden, lack of knowledge about making and maintaining RTG and lack of available and proper soil in the city area. The experts and interested respondents have also recommended providing knowledge about city policy, gardening workshops, and most importantly they have tried to enlighten the inhabitants about the necessity of greenery for maintaining a sustainable and livable city.

Limitations of the Study

(a) Since the resolution of the spatial raster data is 10 m, some features of the raster data would not provide a sharp border.
(b) Indoor temperature was recorded during the end of summer; therefore, the approaching rainy season had an impact on the weather and consequently on survey findings.
(c) The lack of people's consent to capture indoor temperature from their houses influenced the total number of samples.
(d) Time, budget and the pandemic situation have some restrictions on this study to explore more intensely.
(e) Due to the online survey, we did not have control over the respondents and the specific area selection; therefore, we have counted the whole of Dhaka city as our study area for both survey and GIS analysis.

Recommendations

To promote a sustainable urban environment and ensure climate resilient city for urban flocks, the following consideration can be recommended. For instance,

- The government should take proper initiatives along with all related stakeholders and should provide incentives in the price of plants and necessary equipment

and a tax exemption to the rooftop garden owners which will encourage them to implement rooftop gardens.
- The quality nursery that serves good plants and seeds should be monitored by the government, and they should check the quality and variation of plants they have.
- City corporations should promote mass awareness of the ecological balance, the economic significance of rooftop gardens and the aesthetic benefits of rooftop gardens.
- Designing and constructing a building with mandatory provisions for the rooftop garden may be included in the Bangladesh National Building Codes (BNBC). Building regulations and laws must be amended considering the weight and extent of RTG and should encourage building owners to implement it for existing and upcoming buildings.
- Poor governance and corruption should be erased. Besides, they should specify the percentage of green spaces required for property development projects that should be mandatory for each building; thus, developers or house owners follow those rules as an order from the government building code authority.
- Building regulating authorities such as RAJUK should provide a bonus Floor Area Ratio (FAR) to those who are willing to implement a rooftop garden. This measure will allow the house owners to get approval easily which may motivate them to implement this. However, this measure may go in vain if the authority fails to properly monitor the conditions.
- City planning authority and urban local government need to work together to introduce a new policy on this issue to develop an awareness of the need for making the capital city Dhaka green by utilising spaces between two buildings by planting trees instead of raising the wall.
- In the educational curricula, green roofs should include anyone entering the construction industry.
- Proper training and awareness programs should be initiated by the government, and more research should come to spread the knowledge of rooftop gardening.

Conclusions

Dhaka city is a rapidly growing megacity in South-east Asia, and a balanced growth is very important for its sustainable development. From the findings of the survey, we have found that the city dwellers are positively motivated to do rooftop gardens in the houses they reside in. Additionally, there are 62% bare roofs in Dhaka city which brings a good potential for gardening. Though the survey was not conducted widely to cover all parts of the city, a GIS analysis has produced complementary results in support of the bare rooftops. The data collection process has covered a wide range of dimensions to track peoples' perceptions regarding rooftop gardens including the benefits of RTGs and underlying obstacles to implementation across the city. The temperature difference between RTG and non-RTG buildings was also measured and analysed through the discomfort index (DI) which has also explained the positive benefit of rooftop gardens in combating temperature increase and climate change. Despite all the benefits, there are some physical barriers and obstacles to the implementation of RTGs where government can play a vital role to lessen the challenges. The key informants and survey respondents have indifferently stated that the policy of the country is favorable to implementing rooftop gardens, but some adjustment is required for encouragement and implementation. It is suggested for future research design to use simulations of the locations that are distributed uniformly along the whole of Dhaka city to get a better understanding of the mitigation of the UHI effects. Numerical analysis can be conducted to calculate the thermal comfort and temperature change if the potential rooftops for gardening are covered by vegetation. In addition to rooftop gardening, it is important to conduct further research on inventing less heat-absorbing construction materials because rooftop gardening is not the only solution to reducing UHI problems in big cities like Dhaka.

Acknowledgements We express our greatest debt to the omnipotent. This research work is a part of the master's of the first author, and the special thanks go to the *OPEC Fund for International Development* (OFID) for the monetary support they have given through the scholarship during the master's. Our gratitude goes to the Rajdhani Unnayan Kartripakkha (RAJUK) for providing the Building Footprints data of Dhaka city and to all the respondents, roof garden owners and KII interviewees for their response and knowledgeable opinion.

References

Abdallah ASH, Hiroshi Y, Radwan MM (2012) Indoor natural ventilation using evaporative cooling strategies in the Egyptian housing: a review and new approach

Aflaki A, Mirnezhad M, Ghaffarianhoseini A, Ghaffarianhoseini A, Omrany H, Wang ZH, Akbari H (2017) Urban heat island mitigation strategies: a state-of-the-art review on Kuala Lumpur, Singapore and Hong Kong. Cities 62:131–145

Ahmed F, Bibi MH, Monsur MH, Ishiga H (2005) Present environment and historic changes from the record of lake sediments, Dhaka City, Bangladesh. Environ Geol 48(1):25–36

Ahmed KS (1995) Approaches to bioclimatic urban design for the tropics with special referecne to Dhaka, Bangladesh (Doctoral dissertation, Open University)

Ahmed ZN (2003) Natural ventilation in dense residential areas: studying alternatives. Department of Architecture, Bangladesh University of Technology, Bangladesh

Ascione F, Bianco N, de'Rossi F, Turni G, Vanoli GP (2013) Green roofs in European climates. Are effective solutions for the energy savings in air-conditioning? Appl Energy 104:845–859

Aydi A, Zairi M, Dhia HB (2013) Minimization of environmental risk of landfill site using fuzzy logic, analytical hierarchy process, and weighted linear combination methodology in a geographic information system environment. Environ Earth Sci 68(5):1375–1389

Bady M (2014) Analysis of outdoor human thermal comfort within three major cities in Egypt. Open Access Lib J 1(4):1–11

Balling RC, Brazel SW (1987) Time and space characteristics of the Phoenix urban heat island. J Arizona-Nevada Acad Sci 75–81

Bangladesh BSYB (2019) Bangladesh Bureau of statistics, Dhaka

Barua S, Ikbal A (2012) Green roof: a relief in dense urban development. In: Proceedings of ICETCESD, pp 10–12

Blackhurst M, Hendrickson C, Matthews HS (2010) Cost-effectiveness of green roofs. J Archit Eng 16(4):136–143

Burls A (2007) People and green spaces: promoting public health and mental well-being through ecotherapy. J Public Mental Health
Byomkesh T, Nakagoshi N, Dewan AM (2012) Urbanization and green space dynamics in Greater Dhaka, Bangladesh. Landscape Ecol Eng 8(1):45–58
Carlson TN, R (1997) On the relation between NDVI, fractional vegetation cover, and leaf area index. Remote Sens Environ 62(3):241r252
Carter T, Keeler A (2008) Life-cycle cost–benefit analysis of extensive vegetated roof systems. J Environ Manage 87(3):350–363
Cascone S, Catania F, Gagliano A, Sciuto G (2018) A comprehensive study on green roof performance for retrofitting existing buildings. Build Environ 136:227–239
Chavez Jr PS (1988) An improved dark-object subtraction technique for atmospheric scattering correction of multispectral data. Remote Sens Environ 24(3):459–479
Collier R (2013) Prison smoking bans: clearing the air
Del Barrio EP (1998) Analysis of the green roofs cooling potential in buildings. Energy Build 27(2):179–193
Eumorfopoulou E, Aravantinos D (1998) The contribution of a planted roof to the thermal protection of buildings in Greece. Energy Build 27(1):29–36
Feng H, Hewage KN (2018) Economic benefits and costs of green roofs. In: Nature based strategies for urban and building sustainability. Butterworth-Heinemann, pp 307–318
Fountain M, Huizenga C (1995) A thermal sensation model for use by the engineering profession
GoB (2017) National housing policy 2016, ministry of housing and public works. Department of Printing and Publication, Government of the People's Republic of Bangladesh, Dhaka
Grimm NB, Faeth SH, Golubiewski NE, Redman CL, Wu J, Bai X, Briggs JM (2008) Global change and the ecology of cities. Science 319(5864):756–760
Guha S, Govil H, Dey A, Gill N (2018) Analytical study of land surface temperature with NDVI and NDBI using landsat 8 OLI and TIRS data in Florence and Naples city, Italy. Euro J Remote Sens 51(1):667–678
Hemphill L, McGreal S, Berry J (2002) An aggregated weighting system for evaluating sustainable urban regeneration. J Prop Res 19(4):353–373
Honjo T, Narita KI, Sugawara H, Mikami T, Kimura K, Kuwata N (2003) Observation of cool island effects in urban park (Shinjuku Gyoen). In: XV international conference on urban climates, Varsaw, pp 1–5
Hossain MA, Shams S, Amin M, Reza MS, Chowdhury TU (2019) Perception and barriers to implementation of intensive and extensive green roofs in Dhaka, Bangladesh. Buildings 9(4):79
Hossain S (2013) Social formations of the megacity of Dhaka: a review essay
IPCC CC (2007) The physical science basis; summary for policymakers. In: Contribution of working group I to the fourth assessment report of the intergovernmental panel on climate change
Islam M, Al A, Majumder AK, Elahi KT (2019) Study on the status of roof top gardening in selected residential areas of Dhaka City, Bangladesh. Malays J Sustain Agric 3(2):31–34
Jiménez-Muñoz JC, Sobrino JA, Gillespie A, Sabol D, Gustafson WT (2006) Improved land surface emissivities over agricultural areas using ASTER NDVI. Remote Sens Environ 103(4):474–487
Kamruzzaman M, Ogura N (2007) Apartment housing in Dhaka City: past, present and characteristic outlook. In: Building Stock Activation, Tokyo, Japan
LABTEX (2021) TA298 digital LCD indoor thermometer hygrometer clock humidity meter. Labtex Bangladesh. https://labtexbd.com/product/ta298-digital-lcd-indoor-thermometer-hygrometer-clock-humidity-meter/. Accessed 3 July 2022
Landsberg HE (1981) The urban climate. Academic press
Lee K, Kim K, Lee SG, Kim Y (2020) Determination of the normalized difference vegetation index (NDVI) with top-of-canopy (TOC) reflectance from a KOMPSAT-3A image using Orfeo ToolBox (OTB) extension. ISPRS Int J Geo Inf 9(4):257
Lindheim R, Syme SL (1983) Environments, people, and health. Annu Rev Public Health 4(1):335–359
Lowry WP (1967) The climate of cities. Sci Am 217(2):15–23

Momtaz N, Khan M, Morshed M (2017) Green roof: a possible solution for reviving urban green in Dhaka city
Montávez JP, Rodríguez A, Jiménez JI (2000) A study of the urban heat Island of Granada. Int J Climat J Royal Meteorol Soc 20(8):899–911
Mowla QA (2010) Green roof concept for eco-sustainability in the context of Urban Dhaka. In: The international seminar on "GO GREEN", ACA-14 October, pp 25–30
Mowla QA (2011) Crisis in the built environment of Dhaka: an overview. In: Conference on engineering, research, innovation and education. Shahjalal University of Science and Technology Sylhet, pp 11–13
Munn RE (ed) (2002) Encyclopedia of global environmental change. Wiley, Chichester
Nations U (2019) World urbanization prospects the 2018 revision. 2018. Population Division, Department of Economic and Social Affairs, United Nations, New York
Niachou A, Papakonstantinou K, Santamouris M, Tsangrassoulis A, Mihalakakou G (2001) Analysis of the green roof thermal properties and investigation of its energy performance. Energy Build 33(7):719–729
Nur IJ, Sarker MH, Hossain T, Ferdous T, Rahman S, Iqbal B, Hossain MF (2022) Evaluation of ecosystem services of rooftop gardens in Dhaka, Bangladesh. Curr Res Environ Sustain 4:100166
Ohara TAHK, Akimoto H, Kurokawa JI, Horii N, Yamaji K, Yan X, Hayasaka T (2007) An Asian emission inventory of anthropogenic emission sources for the period 1980–2020. Atmos Chem Phys 7(16):4419–4444
Oke TR (1973) City size and the urban heat island. Atmos Environ (1967), 7(8):769–779
Oke TR (1982) The energetic basis of the urban heat island. Q J R Meteorol Soc 108(455):1–24
Oke TR (1997) Urban environments. Surf Clim Can 303–327
Onmura S, Matsumoto M, Hokoi S (2001) Study on evaporative cooling effect of roof lawn gardens. Energy Build 33(7):653–666
Rahman MS (2014) Problems of roof top gardening Atmohammadpur Thana under Dhaka city
Rahman N, Ansary MA, Islam I (2015) GIS based mapping of vulnerability to earthquake and fire hazard in Dhaka city, Bangladesh. Int J disaster risk reduction 13:291–300
Rahman MH, Khan TZ, Raju RA, Huq MJ (2019) Urban eco-sustainability and disaster risk reduction by implementing vertical garden in Dhaka city. In: International conference on disaster risk management, Dhaka, Bangladesh
Rashid R, Ahmed MHB, Khan MS (2010a) Green roof and its impact on urban environmental sustainability: the case in Bangladesh. World J Manag 2(2):59–69
Rashid R, Hamdan M, Khan S (2010b) Financial and environmental benefit of pot plants' green roof in residential building in Bangladesh. World J Manag 2:45–50
Roeland S, Moretti M, Amorim JH, Branquinho C, Fares S, Morelli F, Calfapietra C (2019) Towards an integrative approach to evaluate the environmental ecosystem services provided by urban forest. J Forest Res 30(6):1981–1996
RSTP (2015) Revised strategic transport plan (RSTP), 2015–2035. Dhaka Transport CoOrdination Board, Ministry of Communications, Government of the People's Republic of Bangladesh
Safayet M, Arefin MF, Hasan MMU (2017) Present practice and future prospect of rooftop farming in Dhaka city: a step towards urban sustainability. J Urban Manag 6(2):56–65
Sarrat C, Lemonsu A, Masson V, Guédalia D (2006) Impact of urban heat island on regional atmospheric pollution. Atmos Environ 40(10):1743–1758
Seto KC, Fragkias M, Güneralp B, Reilly MK (2011) A meta-analysis of global urban land expansion. PloS one, 6(8), e23777
Shariful Islam KM (2002) Rooftop gardening as a strategy of urban agriculture for food security: the case of Dhaka City, Bangladesh. In: International conference on urban horticulture, vol 643, pp 241–247
Shourav MSA, Mohsenipour M, Alamgir M, Pour SH, Ismail T (2016) Historical trends and future projection of climate at Dhaka city of Bangladesh. Jurnal Teknologi 78(6–12)

Silva VDPRD, Santos JS, Lima ERVD, Holanda RMD, Sousa EPD, Araújo LED (2018) Future scenarios of thermal bioclimatic conditions in a humid tropical city under urban development. Revista Ambiente & Água 13

Solcerova A, van de Ven F, Wang M, Rijsdijk M, van de Giesen N (2017) Do green roofs cool the air?. Build Environ 111:249–255

Stewart I, Oke TR (2009) Newly developed "thermal climate zones" for defining and measuring urban heat island magnitude in the canopy layer. In: Eighth symposium on urban environment, phoenix, AZ

Sultana R, Ahmed Z, Hossain MA, Begum BA (2021) Impact of green roof on human comfort level and carbon sequestration: a microclimatic and comparative assessment in Dhaka City, Bangladesh. Urban Clim 38:100878

Takebayashi H, Moriyama M (2007) Surface heat budget on green roof and high reflection roof for mitigation of urban heat island. Build Environ 42(8):2971–2979

The Daily Star (2019) Rooftop gardening: Making Dhaka green again. The daily star, April. Available at: https://www.thedailystar.net/city/news/rooftop-gardening-making-dhaka-green-again-1731898

Thom EC (1959) The discomfort index. Weatherwise 12(2):57–61

Uddin MJ, Khondaker NA, Das AK, Hossain ME, Masud ADH, Chakma AS, Chowdhury AA (2016) Baseline study on roof top gardening in Dhaka and Chittagong City of Bangladesh, vol 8. A final technical report under the project of "Enhancing Urban Horticulture Production to Improve Food and Nutrition Security" (TCP/BGD/3503) funded by Food and Agriculture Organization of the United Nations. FAO Representation in Bangladesh. Road, p 4

Ulbrich U, Pinto JG, Kupfer H, Leckebusch GC, Spangehl T, Reyers M (2008) Changing northern hemisphere storm tracks in an ensemble of IPCC climate change simulations. J Clim 21(8):1669–1679

UN (2016) The world's cities in 2016. In: World urbanization prospects: data booklet (ST/ESA/SER.A/392); United Nations, New York, NY, USA

Van Thiel S (2014) Research methods in public administration and public management: an introduction. Routledge

Voogt JA, Oke TR (1997) Complete urban surface temperatures. J Appl Meteorol 36(9):1117–1132

Wilmers F (1990) Effects of vegetation on urban climate and buildings. Energy Build 15(3–4):507–514

Wong NH, Chen Y, Ong CL, Sia A (2003) Investigation of thermal benefits of rooftop garden in the tropical environment. Build Environ 38(2):261–270

Wu J, Xiang WN, Zhao J (2014) Urban ecology in China: historical developments and future directions. Landsc Urban Plan 125:222–233

Zhang W, Zhu Y, Jiang J (2016) Effect of the urbanization of wetlands on microclimate: a case study of Xixi Wetland, Hangzhou, China. Sustainability 8(9):885

Chapter 23
Evaluation of Urban Land Surface Temperatures and Land Use/Land Cover Dynamics for Palakkad Municipality, Kerala, for Sustainable Management

P. Dhanya, K. Jayarajan, and Suresh Selvaraj

Abstract The rapid urbanisation and land use/land cover (LULC) changes have resulted in the unsustainable growth and rise in heat islands (UHI) in Indian cities. Palakkad is one such city in Kerala, which is known for its relatively higher temperatures than other parts of the state. Therefore, this study was designed to quantify the Land Surface Temperature (LST) dynamics of Palakkad city in response to the LULC change during 2001–2021 using temporal Landsat datasets. Landsat Imagery 7 and 8 of 2001 and 2021 for summer and winter months were processed. The analytical outcomes reveal that mean LST for winter season was 27.07 °C during 2001 and that has increased to 28.35 °C during 2020. Whereas in summer, the mean LST that was 28.59 °C in 2001 has escalated to 29.32 °C during 2021. The results also display a significant decline in vegetation cover from 13.4 to 2.48 km^2 and doubling of built-up areas, i.e. from 7.53 to 16.05 km^2 during 2001–2021. Similarly, the areas under water bodies have shrunken from 2.18 to 1.14 km^2 during 2001–2021. Further, the difference in the rise in the mean land surface temperature during the years 2020 and 2001 is more (1.99 °C) during summer season than winter season (1. 28 °C). Diurnal temperature range in LST between 2001 and 2020 LST has increased slightly during winters and decreased (−0.37 °C) during summers. Significant rise in day and night temperature is likely in future under RCP 4.5 scenario. Due to this, a significant increase in urban heat island (UHI) is seen for central, north-western, and north-eastern parts of the municipality. This type of micro-level research throws useful insights into the process of smart city development, policymaking and planning and heat island mitigation within the Palakkad city limits. The drastic rise in urban settlements and reduction in green cover in the north-western parts requires urgent action plans as envisaged in India's NDCs and SDGs for wellbeing of the inhabitants.

P. Dhanya (✉)
Tamil Nadu Agriculture University, Coimbatore, India
e-mail: dhanyaeptri@gmail.com; dhanyapunnoli@gmail.com

K. Jayarajan
Department of Geography Government College Chittur, University of Calicut, Kozhikode, India

S. Selvaraj
SreeSankaracharya University of Sanskrit, Kalady, India

U. Chatterjee et al. (eds.), *Urban Commons, Future Smart Cities and Sustainability*, Springer Geography, https://doi.org/10.1007/978-3-031-24767-5_23

Keywords Urbanisation · Urban heat island · Land surface temperature · Land use land cover dynamics · Sustainable management · Palakkad

Introduction

Urban areas with their high density of population confront pressures such as resource crunch, unhealthy environments and climate change impacts. Similarly changing land use and land cover dynamics due to urbanisation is regarded as the critical factor contributing to global warming. It is evident that the natural vegetation has declined in urban areas (Daneshvar et al. 2019). The modified land surface in cities affects the storage and radiative and turbulent transfers of heat and its partition into sensible and latent components. The relative warmth of a city compared with surrounding rural areas, known as the urban heat island (UHI) effect, arises from these changes and may also be affected by changes in water runoff, pollution and aerosols. Urban heat island effects are often very localised and depend on local climate factors such as windiness and cloudiness (which in turn depend on season), and on proximity to the sea (IPCC 2007). The rapid growth in population in India and a resultant rise in GHG emission levels have caused significant changes in the microclimatic and macroclimatic conditions, especially in cities. Any surge in urban temperature has the potential to disturb people either directly or indirectly (Rahman et al. 2019). McKitrick and Michaels (2004) and De Laat and Maurellis (2006) attempted to demonstrate that geographical patterns of warming trends over land are strongly correlated with geographical patterns of industrial and socio-economic development, implying that urbanisation and related land surface changes have caused much of the observed warming. However, the locations of greatest socio-economic development are also those that have been most warmed by atmospheric circulation changes. Widespread urban expansion is happening across the globe, especially in South Asian countries, and 250 million more people are expected to live in cities in South Asia over the next 15 years (Kotharkar et al. 2018; Ellis and Roberts 2016). Rapid expansion of urban areas causes severe environmental degradation in the thickly populated areas. World Bank has reported that South Asia's urban population grew by 130 million between 2001 and 2011 and is poised to rise by almost 250 million by 2030, and majority are living in informal settlements (World Bank 2016). Moreover, severe environmental degradation is also anticipated due to rapid urbanisation in India (Bharath et al. 2018; Daneshvar et al. 2019).

Intergovernment Panel on Climate Change has warned that the rise in mean temperatures and heat waves in the Indian Ocean caused by climate change are reducing monsoonal rains over central regions while increasing rains in south India, creating flash floods (IPCC 2022). Urban heat island is one of the significant causes of urban sprawl (Raj et al. 2020a). Seasonal distribution of aerosol loading seems to have impacted day and night SUHII in the urban areas of major Indian cities (Pandey et al. 2014). Factors such as coverage area, climate and weather variations, vegetation type, soil moisture, street geometry and construction materials cause or modify the intensity of Urban Heat Island (Thomas and Zachariah 2011). The surge in temperature leads to more recurrent and intense extreme heat events which cause adverse heat-related impacts and rise in physiological discomfort levels for living organisms, human fatalities and economic damages. Apart from this, disparities in evaporative cooling due to impervious surfaces such as roads, sidewalks, driveways and parking lots, buildings and industrial areas may lead to a rise in not only daytime UHI but also nocturnal heat islands.

Advanced spatial information technologies like satellite remote sensing help to understand the spatio-temporal changes that happen in and around the globe. It has become more common to investigate spatio-temporal UHI differentiations and LST changes using the thermal approach of remote sensing. Various remotely sensed indeces, namely the soil-adjusted vegetation index, normalised difference building index and normalised difference drought index, from MODIS, Landsat TM and ETM imagery have been utilised to understand the UHI spatial patterns by many researchers (Bashit et al. 2020; Nguyen et al. 2021; Yang and Santamouris 2018). Moderate Resolution Imaging Spectroradiometer (MODIS) data during the monsoon season (June–August) over megacities of Asia, including Dhaka was utilised to understand the seasonal variation (Itzhak-Ben-Shalom et al. 2017; Kotharkar et al. 2018).

The state of Kerala has faced drastic changes in land use land cover and climate changes in the recent past and is projected to further undergo warming as well as a shift in rainfall patterns and its intensities (SAPCC, Kerala 2014). The rise in temperatures is reported by several researchers. The state is also witnessing severe flooding and landslides in recent years; however, certain research studies suggest that the key problem that Kerala may face is likely to be drought (Mishra et al. 2020). Policy level action plans are envisaged to mitigate and adapt to climate change impacts. Some regions and communities will be more vulnerable to these impacts. Hence, it is the responsibility of the scientific communities to study the local context of vulnerabilities in detail wherever they operate their research. The present study area, Palakkad district, has a unique topography that can influence the local climate. The orography of Western Ghats influences Kerala's climate. Bharathapuzha basin is the largest river basin in Kerala. Apparently, the water flow is relatively less compared to other long rivers in Kerala because a large portion of the basin is located in the drier regions of Palakkad Gap and Tamil Nadu. Loss of forest cover on the Ghats could affect the rainfall patterns and land surface temperatures. A reduction in green cover and rapid urban growth has resulted in flash floods in Palakkad city during the 2019 and 2020 floods. Flash flood was caused due to reduced seepage of excess water from the ground because of reduced green cover to arrest the intensity of runoff and increase in built-up areas, especially in urban and suburban areas. Nikhil Raj and Azeez (2010) has opined that the annual rainfall pattern of all the stations showed a trend of significant decline, as the years proceed. Krishnakumar et al. (2009) have also reported a significant decrease in the south-west monsoon in the state and an increase in the north-east monsoon rainfall.

Ecosystem-based adaptation is essential for the sustainable management of urban areas. Enhancing green cover is considered as the key step in managing and mitigating heat island effects in India's Nationally Determined Contribution

(INDC) (MoEF 2018). Not only national or state action plans, but district administration must also make action plans to tackle climate change while addressing critical issues. Green India Mission is one such program that aims to sequester carbon emissions and negate the impacts of warming and rise in pollution levels. The present study attempts to give a better understanding of the urban heat island effect in the municipality of Palakkad based on satellite remote sensing.

Materials and Methods

Study Area

Palakkad is the largest district in Kerala, located at the foot of the Western Ghats; this is the gateway to Kerala from North due to the existence of the Palakkad Gap in the western ghat. It is bordered on the east by the Coimbatore District of Tamil Nadu, on the north and the north-west by Malappuram district, and on the South by Thrissur District, Kerala. This district is divided into six taluks and seven municipalities. It has a total area of 4482 km^2, out of which 400 km^2 is urban and 4082 km^2 is rural. Out of the total population of Palakkad, 3,119,027 in the district, 676,810 are in urban areas and 2,133,124 are in rural areas. Palakkad Municipality is one of the fast-growing urban centres centrally located in the state. It is located between 09^0 45^I N and 10^0 20^IN latitude and between 76^0 10^I E and 76^0 35^I E longitude (Fig. 23.1). Palakkad Municipality is blessed with many small and medium rivers which are the tributaries (Kalpathy, Malampuzha and Kannadi river) of the Bharathapuzha river. This district is the largest producer of rice hence known as the granary of Kerala. The district is interlaced with hilly tracts and has 136,257 h of reserve forest including Silent Valley, a national park in Kerala.

It has a tropical Monsoon climate. The summers are much rainier than the winters in Palakkad. According to Koppen and Geiger, this climate is classified as Aw. The average annual temperature in Palakkad is 25.9 °C/78.6 °F. March and April are the hottest months on record (Fig. 23.2a) 29.1 and 28.2 °C temperature, respectively. Diurnal Temperature Range (DTR) is maximum during February and minimum during July month. A very high amount of precipitation is received in Palakkad, mainly due to the South-West Monsoon. June and July are the wettest months, and the total annual rainfall is around 83 in (210 cm) with an average 129 of rainy days annually; the major part of the rainfall is from the South-West Monsoon (Fig. 23.2b). December and January are the coolest months on record. Air temperatures range between 20 and 36 °C. June and July have the highest humidity, and February has the lowest recorded humidity over the study period (Fig. 23.2c).

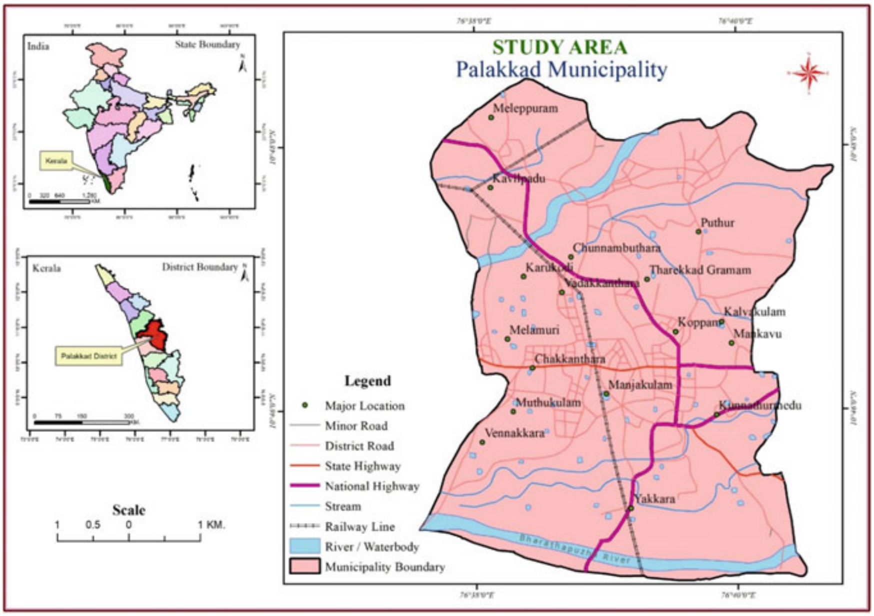


Fig. 23.1 Map of the study area and wider surroundings

Land Surface Temperature

Data Sources

The details of the data sources used for LST Calculation are given in Table 23.1.

Methods

The data on land surface temperature is downloaded from the following websites (Table 23.1). Satellite images, viz. Landsat 7 and Landsat 8, were downloaded from (https://earthexplorer.Usgs.gov/; accessed on 11th January 2022) for the years 2001 and 2020 according to specific paths and rows for the study area during January (winter) and March (Summer) time. Dewan et al. (2021) has clearly stated the reason behind selecting the winter and summer months separately for UHI studies. As for calculating LST and LULC and UHI classification, the images were pre-processed and analysed in QGIS 3.6 and Arc GIS 10.4. The following Table 23.1 flowchart represents the data sources and process of this study. LST, the skin temperature of the ground, is identified as a significant variable of microclimate and radiation transfer within the atmosphere (Suresh et al 2016; Daramola et al. 2018). Landsat 8 OLI data has Thermal Infrared Sensor (TIRS) with two bands (band 10 and band 11 with 100 m resolution) which is useful in providing more accurate surface temperatures.

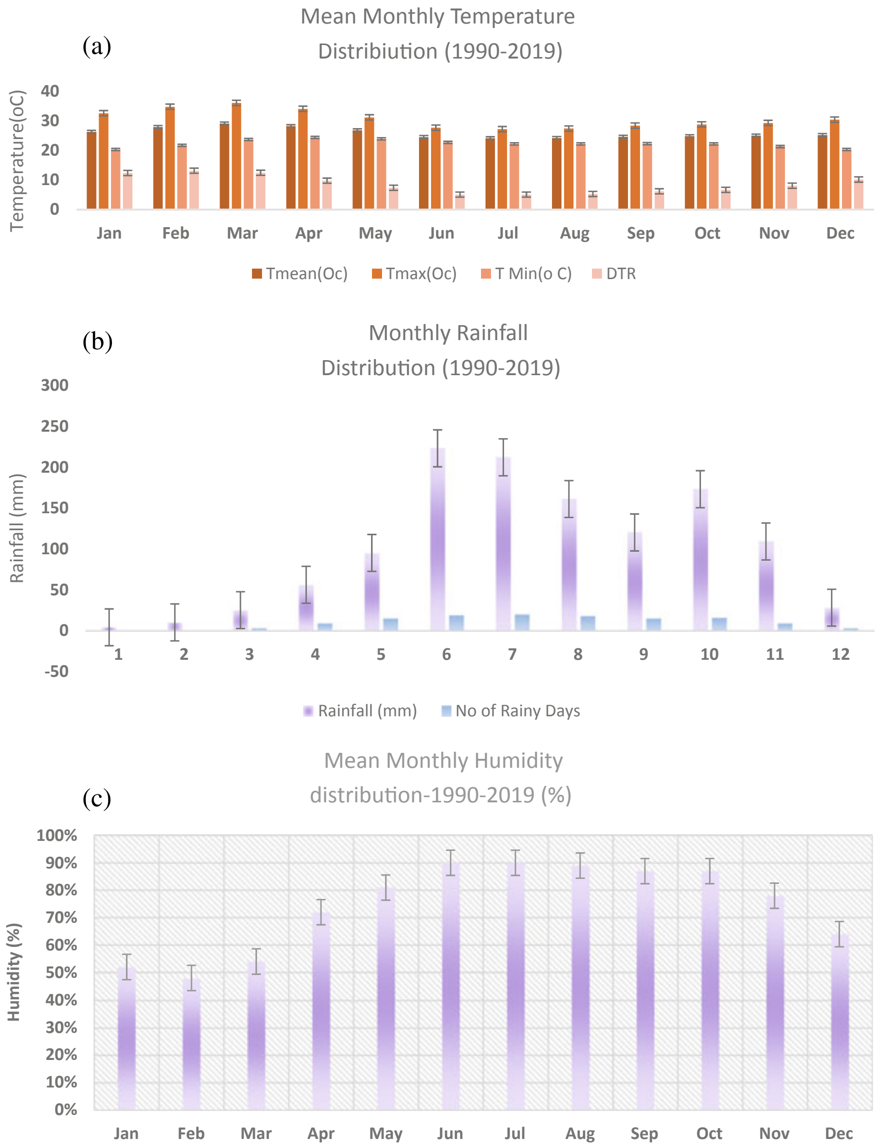


Fig. 23.2 Observed monthly mean climate of the Palakkad city from (1990 to 2019). **a** Mean Temperature distribution. **b** Mean monthly rainfall distribution for Palakkad. **c** Humidity distribution (%)

Table 23.1 Source of data for LST calculations

Sl. No.	Parameter	Data source
1	2001 January LST	https://earthexplorer.usgs.gov/-Landsat 7 ETM+ C1 Level-1,Path 144, Row: 053
2	2001 March LST	https://earthexplorer.usgs.gov/-Landsat 7 ETM+ C1 Level-1,Path 144, Row: 053
3	2020 January LST	https://earthexplorer.usgs.gov/-Landsat 8 OLI/TIRS C1 Level-1,Path 144, Row: 053
4	2020 March LST	https://earthexplorer.usgs.gov/-Landsat 8 OLI/TIRS C1 Level-1,Path 144, Row: 053

In the LST calculation, two algorithms have been employed to retrieve LST from satellite thermal bands, i.e. B6 (60 m resolution) in Landsat 7 ETM+ and TIRS bands from Landsat 8 Operational Land Imagery. To derive LST from Landsat 7, Landsat handbook procedure (https://www.usgs.gov/media/files/landsat-7-data-users-handbook) was applied. There are three steps involved in generating LST from Landsat 7 data. In remote sensing, sensor radiances are generally stored in digital numbers (DN). Therefore, the first step is to convert DN value to the radiance value by applying Eq. 23.1.

$$L\lambda = \left(\frac{(\mathrm{LMAX}_{\lambda} - \mathrm{LMIN}_{\lambda})}{\mathrm{QCALMAX} - \mathrm{QCALMIN}}\right)(\mathrm{QCAL} - \mathrm{QCALMIN}) + \mathrm{LMIN}_{\lambda} \tag{23.1}$$

where $L\lambda$ = Spectral Radiance
QCAL = the quantised calibrated pixel value in DN
LMAX_{λ} = Spectral radiance scaled to QCALMAX in (watts/(m^2*sr*µm))
$LMIN_{\lambda}$= Spectral radiance scaled to QCALMIN in (watts/(m^2*sr*µm))
QCALMIN = Minimum quantised calibrated pixel value (corresponding to LMIN_{λ}) in DN (typically = 1)
QCALMAX = Maximum quantised calibrated pixel value (corresponding to LMAX_{λ} in DN (typically = 255).

Now, the calculated radiance value has been converted to Brightness Temperature (BT) (in Kelvin) by applying Eq. 23.2.

$$T = K2/\left(In\left(K1/L\lambda + 1\right)\right) \tag{23.2}$$

where
T = The at-sensor temperature in Kelvin
$K2$ = The calibration constant 1282.71 in degrees Kelvin
$K1$ = The calibration constant 666.09 in Watts/(m^2 * sr * µm)
$L\lambda$ = The spectral radiance from Eq. 23.1.

Finally, the BT Kelvin value has been converted to degree Celsius through Eq. 23.3.

$$\text{LST} = T - 273.15 \tag{23.3}$$

In contrast to Landsat 7 handbook procedure, in Landsat 8 single Window Algorithm (Suresh et al 2016) has been adopted (Equation-4) to generate LST from Landsat 8 OLI data for the research region (Fig. 23.4). The LST is the relative temperature determined using the following algorithm: BT, the wavelength of emitted radiance and LSE (Choudhury et al. 2021**;** Suresh et al 2016). Vegetation proportion calculation, emissivity calculation, LST calculation, etc., were executed to calculate LST from Landsat 8 data.

$$\text{LST} = \text{BT}/1 + (W * (\text{BT}/p) * \text{In}(e)) \tag{23.4}$$

where

BT= At satellite temperature

W=Wavelength of emitted radiance (11.5 μm)

$p = h*C/S$ (1.438*10∧ −2 mk)

$p = 14380$

e = Emissivity ($e = 0.004$ Pv + 0.986)

Pv = (NDVI-NDVImin/NDVImax-NDVImin)^2

where: BT represents TOA brightness temperature (degree Celsius), and λ represents the wavelength of emitted radiance. Land Surface Emissivity (LSE) is the emissivity of any object and can be defined as its ability to measure the emitted infrared energy required to convert BT readings to surface temperature.

Land Use Land Cover (LULC)

Land use simply refers to the human uses of land. The term land use relates to the human activity or economic function associated with a specific piece of land (Lillesand et al. 2008). It means how the land is being used by human beings (Jensen 2013) or can be considered as the human employment of land (Meyer and Turner 1992). Land use change occurs in various forms, including both changes in area and changes in the intensity of use (Houghton 1994). Fundamentally, it can take two forms: conversion from one category of land use to another and modification of conditions within a category (Meyer and Turner 1992). The present study adopted a modified land use classification of NRSC to reflect the local scenario of Palakkad Municipality. Land use maps were prepared for two different periods: 2001 and 2021. Under Supervised classification, Maximum likelihood technique has been applied for image classification.

Urban Heat Island study

It is anticipated that the detrimental effects of UHI would be intensified in the future as both temperature and amount of urban area are expected to increase (Dutta et al. 2021). The Urban Heat Island study was conducted for winter and summer. The formula used for classification is given below.

$$\text{UHI} = (T - \text{Tm})/\text{Tsd} \tag{23.5}$$

where

T = Actual surface temperature of each pixel;
Tm= Mean surface temperature;
Tsd = Standard Deviation of surface temperature.

Results and Discussions

Changes in Land Use Land Cover and Land Surface Temperatures

The land surface temperature was downloaded and processed to understand the temporal and spatial changes during the summer and winter months. Warming trends are clearly noted for over the analysed period as the mean LST for March month has increased by 5.51 °C than in winter, the rise in warming is 3.38 °C. The observed rise maximum LST for March month is way too higher (4.97 °C) in 2020 than in the year 2001. However, during winter months, the rise in LST in 2020 is 2.35 °C compared to 2001. In the study area, warming is more during March than in winter (Table. 23.2). Warming is more towards the central and southern sides of the Municipality. It is noteworthy that the north-western corner of Municipality that was not much affected by warming in 2001 has been completely altered as a hot spot of warming by 2020. Urban expansion influences the minimum temperature to a greater extent than the maximum temperature in the winter season, and this decrease in temperature variations in the winter period has been earlier reported by several researchers (Gophen 2014; Argüeso et al. 2013) (Tables 23.3 and 23.4).

Table 23.2 LST statistics

Sl. No.	Parameter	Min	Max	Mean	S.D
1	2001 January LST	21.94	31.64	26.20	1.63
2	2001 March LST	24.97	34.46	29.36	1.35
3	2020 January LST	24.48	33.99	29.58	1.24
4	2020 March LST	30.52	39.43	34.87	1.19

Table 23.3 Area under each land use and land cover classes in 2001

Land use land cover	2001 Area in km^2	Area in %
Agricultural land	13.4	47.75
Built-up	7.53	26.84
Mixed trees	4.81	17.14
Open space	0.14	0.5
River/water body	2.18	7.77
Total	28.06	100

Table 23.4 Area under each land use and land cover classes in 2020

Land use land cover	2020 Area in km^2	Area in %
Agricultural land	2.48	8.84
Built-up	16.05	57.2
Mixed trees	6.31	22.49
Open space	2.08	7.41
River/water body	1.14	4.06
Total	28.06	100

The land use land cover analysis has shown that the area under agricultural area or vegetation has reduced by 38% from the year 2001–2020 due to urban expansion. The maximum increase has been noted for the built-up areas. The areas of water bodies also have been reduced by −3.71%. (Fig. 23.3).

Urban Heat Island for Palakkad Municipality

Urban Heat Island Statistics: 2001–2020

Anthropogenic activities have created Urban Heat Islands phenomena in a majority of the cities in India. The Urban Heat Island intensity at Palakkad Urban Municipality (PKDM) can be considered as moderate to high during both winter and summer seasons and is seen to associate well with the surge in settlements. Highest observed urban heat island intensity in PKDM was 8.73 in winter during 2001, which has decreased to 4.9 °C during winter, 2021, indicating an increase in chillness over the period. The maximum observed UHI intensity during summer was 1.21 °C in 2001, and it has increased to 3.02 °C by 2021, indicating increasing extremities. The spatial and temporal distribution of UHI intensity for winter and summer seasons is shown in Table 23.5 and Figs. 23.4, 23.5 and 23.6.

Negative UHI has been noted in the southern, south-western and south-eastern part of the municipality over the study period, and this could be due to the enhanced vegetation cover in these areas as it got a key role in determining UHI. In summer, the change in UHI is 1.63 °C. but in winter the change is negative. In Winter, it shows a reverse trend, and the UHI has decreased by 2.44 °C. The geographical location of the Palakkad gap allows the North-East monsoon to provide rainfall with its impact in lowering the temperature and affects the weather condition of this region, and winter rainfall also enhances the level of water bodies in and around the city.

UHI was found to be higher around central part of the municipality, especially around Nurani, Chandanagar, Meparambu, Vennakkara, Kavilpad, etc. Similar results are reported by other researchers for India. The occurrence of reduced summer UHI has been reported by Shastri et al. (2017). The negative UHI over a majority of urban areas in India during daytime in summer season (pre-monsoon) (MAM), contrary to the expected impacts of urbanisation, was linked with low vegetation in non-urban regions during dry pre-monsoon summers, leading to reduced evapotranspiration (ET), Shastri et al. (2017). Impacts of water bodies and vegetation play a key role in regulating temperature. The areas along tributaries of Bharathapuzha and Malampuzha exhibited comparatively lower UHI. UHI is comparatively low in the southern parts of the municipality where river Bharathapuzha flows. Where there are more settlements and urban impacts are predominant, a positive UHI ensues (Table 23.6).

The drastic and unsustainable modification in land use and land cover is the major causative factor for the sudden rise UHIs. The relatively warmer temperatures in urban areas compared to suburban areas (i.e. UHI) has potential health hazards, such as mortality due to high temperatures and heat waves stress (Raj et al. 2020b, Vijaykumar et al. 2021, UN Report 2019, Rangarajan et al. 2019). As per

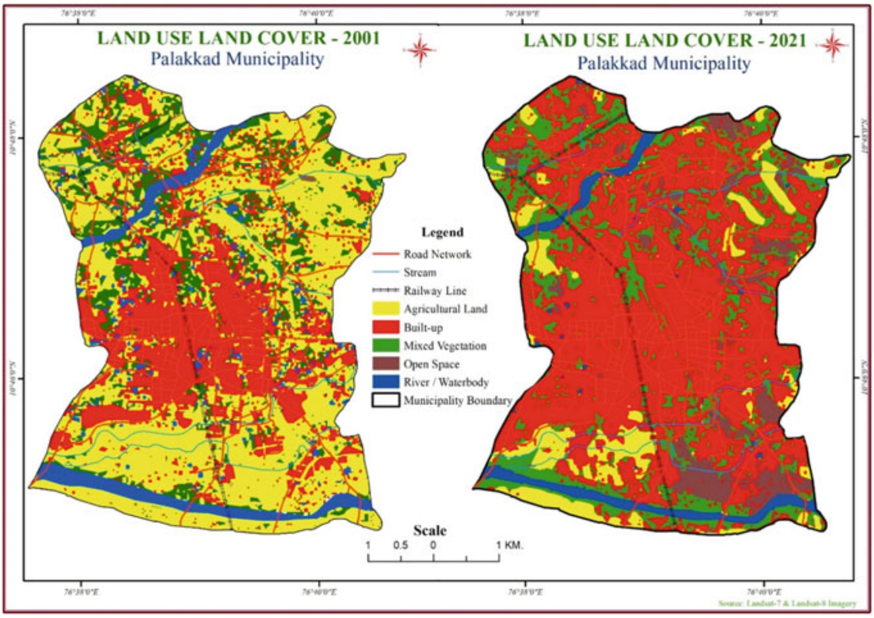


Fig. 23.3 Shows the land use land cover changes. *Source* Landsat 7 and Landsat 8 Imagery

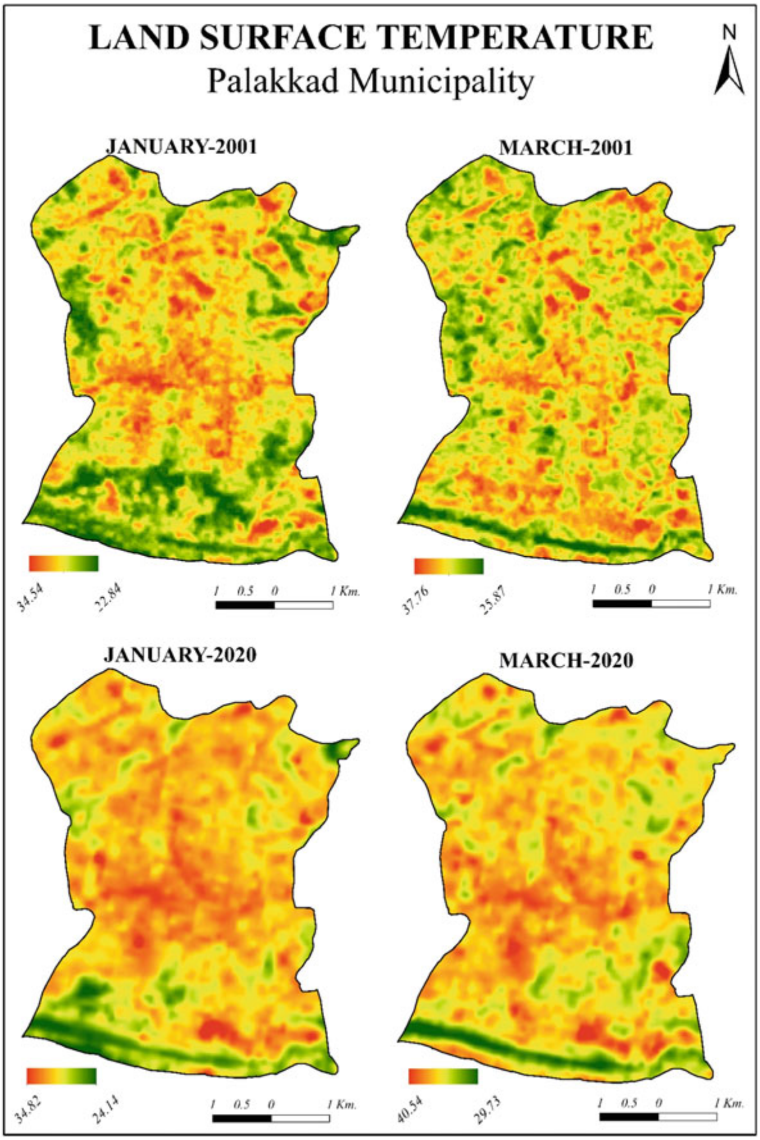


Fig. 23.4 Land surface temperature of Palakkad municipality

the sixth Assessment Report of Inter-Governmental Panel on Climate Change (IPCC 2022), urban heat island effect results from numerous factors: reduced ventilation and heat-trapping due to the close proximity of tall buildings, heat generated directly from human activities, the heat-absorbing properties of concrete and other urban building materials, and the limited amount of vegetation. Rapid urbanisation has exacerbated the effects of global warming in cities (IPCC 2022, Perera et al. 2021,

Table 23.5 Mean LST values for Palakkad municipality

Year	Season	Mean	S.D	Min	Max
2001	Winter (December–February)	27.07	1.32	23.52	31.39
2020	Winter (December–February)	28.35	1.17	24.04	31.93
2001	Summer (March–May)	27.61	1.04	23.19	31.67
2020	Summer (March–May)	29.60	1.10	25.11	33.22

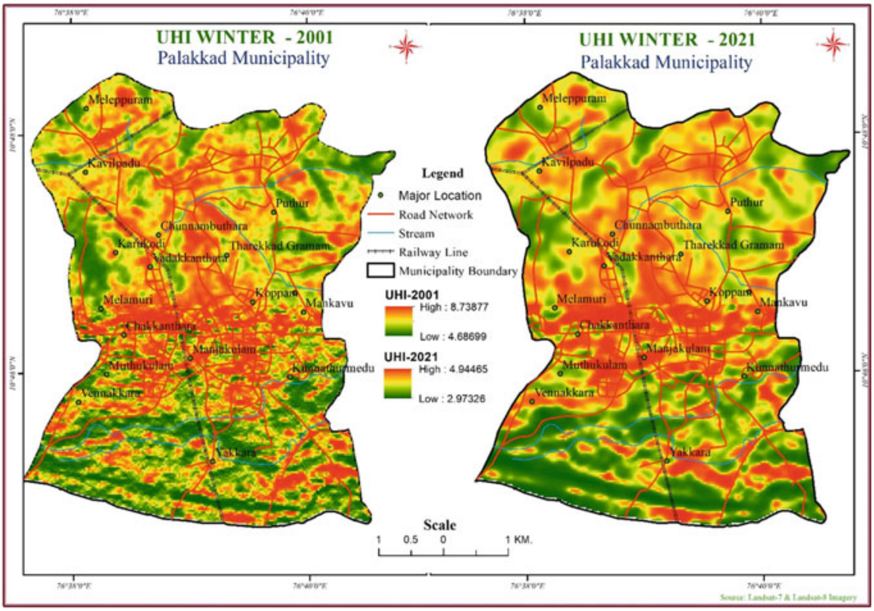


Fig. 23.5 UHI changes during winter in Palakkad municipality

Parsaee et al. 2019, Panmei et al. 2017, Mishra et al. 2018, Jaina et al. 2020, Eric and Kumi-Boateng 2020). Anticipated future urbanisation is likely to augment the projected day and night-time temperatures in cities regardless of the characteristics of the background climate, Brenkert and Malone (2005). UHI in some Indian cities in recent studies was found to be 3.3 °C in Chennai, 8.2 °C in Delhi (Mohan and Kandya 2015), and 2.2 °C in Guwahati (Borbora and Das 2014). A dense network of settlements, construction activities, transport networks, and junctions enhance urban heat islands. Presently, every year is witnessing record-breaking extreme weather events year in Kerala. Especially the urban floods and landslides in Kerala during 2019 has seen some unusual weather activity with rainfall exceeding 50 mm in 2 h has been reported from many places between 8.00 and 22.00 UTC on August 8, 2019 (Mishra et al. 2018). If the year 2019 is any indication of how global warming may continue to impact this area, changes in the cloud structure and kind of strong rain-fall events, and heat islands could represent a serious threat to the urban ecosystems,

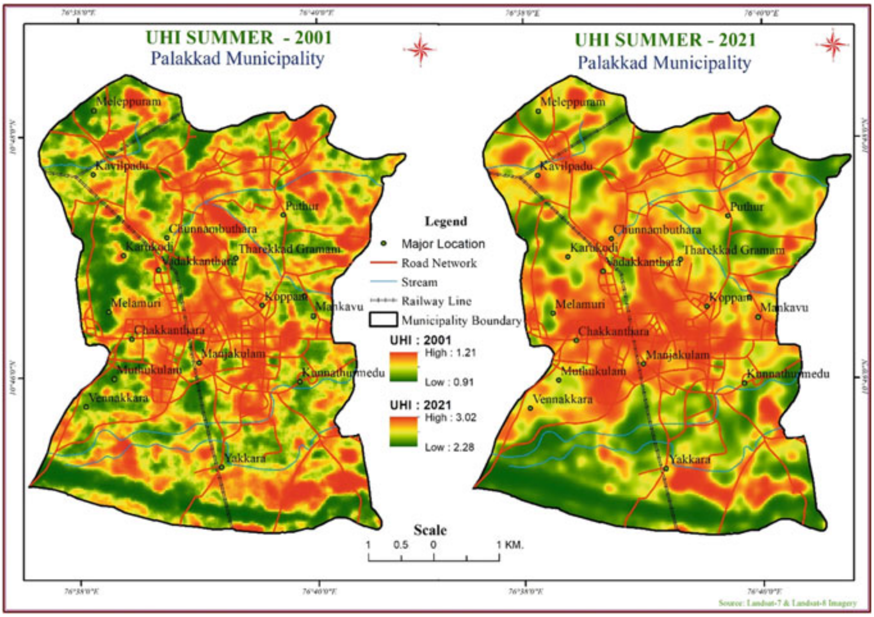


Fig. 23.6 UHI changes during (a) summer in Palakkad municipality

Table 23.6 Descriptive statistics of UHI values for Palakkad municipality

Year	Min	Max	Mean	S.D
Summer-2001	0.91	1.21	1.06	4.01
Summer-2021	**2.28**	**3.02**	2.69	0.20
Winter-2001	4.68	8.73	6.55	0.41
Winter-2021	**2.97**	**4.94**	*4.11*	0.22

which are extremely fragile due to its socio-economic characteristics (Donatti et al. 2020; Hunt and Menon 2020).

Hence, there is a growing concern in India for even intensifying night-time lamination in urban areas for the past one decade, Bose and Chowdhury (2020). India's nationally determined contributions (INDCs) have concentrated mostly on climate change mitigation focusing on adopting greening and afforestation programs, shift to more sustainable renewable energy sources, emission reduction measures, etc. (Aayog 2021). The per capita emission in India is only 1.69 Metric tonnes of CO_2 whereas United States has 17.05 Metric Tonnes of CO_2 emissions. There may be doubling of demand for food grains and animal protein to satisfy growing population demands and similarly demands for ecosystem services in urban areas. Small patches of barren lands and waste lands need to be converted as Miyawaki forests. The self-sustaining Miyawaki forests grow in small patch of lands within two to three years and contribute to the reduction of air and noise pollution, and cools down heat islands. Apart from that, it attracts of local avian wildlife and creates carbon sinks.

Cities in India were facing immigration from rural areas in search of better employment opportunities. However, reverse migration was also seen during the present COVID-19 pandemics (Dutta et al. 2021). A combined impact of weather and heat waves has a considerable impact on the lives of the inhabitants, especially in hot and dry climate zones (Tran et al. 2017). The presence of thick vegetation cover and good climate plays a significant role in regulating heat island effects. An analysis of UHI based on LST derived from satellite observations in Asian megacities shows strong negative associations with the urban normalised difference vegetation index (NDVI) and positive associations with built-up areas (Tran et al. 2006).

Conclusions

This research article aimed to investigate spatio-temporal variations in LULC and LST concerning UHI intensity over Palakkad Municipality, one of the fastest growing/populated/ urbanised districts of Kerala. The results indicated that a significant reduction in vegetated land and water bodies was observed at the expense of built-up areas. In the summer season, the mean LST had increased by 1.63 °C during the study period. The LST outlines indicate that built-up areas under urban expansion exhibited high LST, and there is vast disappearance of the vegetated area near the water bodies (Bharathapuzha) in the municipalities over the study period. Warming is more towards the central and southern side of the Municipality.

Highlights and Way forward

In this chapter, land use land cover change and Urban Heat Island Intensity (UHI) of Palakkad Municipality are dealt with.

- Urban heat island is noted more in the central part of the Palakkad Municipality
- There may be enhanced risks of extreme heat stress and discomfort for the inhabitants living in the centre of the municipality if timely mitigation measures are not taken.
- It is evident from the study that how the high density of settlements and population, lack of natural vegetation/greenness, water bodies and anthropogenic forcing are influencing factors driving UHI impacts.
- The trend of SUHII shows an increase over time (2001–2021) for PKDM. The lost tree coverage must be regained to enhance the cooling effect.
- Further, studies can be conducted to survey the inhabitants' perceptions to validate the outcomes. Apart from that, several drawbacks to this work should not be overlooked. Field-based investigations can be conducted using meteorological instruments like wet and dry bulb thermometers, and swirling hygrometers to substantiate the results derived from remote sensing-derived index were adopted to identify UHI over major the PKDM. The climatic variables and landscape metrics like cover type and albedo can make study furthermore effective, as the factors could have an extensive influence on LST.

Acknowledgment The first authors acknowledge with thanks the Department of Science and Technology–DST-KIRAN division–WOS-B for their financial support.

Conflict of Interest The authors declare that they have no conflict of interest.

References

Aayog N (2021) SDG India index and dashboard 2020–21 partnerships in the decade of action. https://www.niti.gov.in/writereaddata/files/SDG_3.0_Final_04.03.2021_Web_Spreads.pdf

Argüeso D, Evans J, Fita L, Bormann KJ (2013) Temperature response to future urbanization and climate change. Clim Dyn 42:2183–2199

Bashit N, Prasetyo Y, Sukmono A (2020) Analysis of built-up land spatial patterns using multitemporal satellite imagery in Pekalongan city. J Appl Geospat Inf 4:356–362

Bharath HA, Chandan MC, Vinay S, Ramchandra TV (2018) Modelling urban dynamics in rapidly urbanising Indian cities. Egypt J Remote Sens Space Sci 21(3):201–210

Borbora J, Das AK (2014) Summertime urban heat island study for Guwahati city, India. Sustain Cities Soc 11:61–66. https://doi.org/10.1016/j.scs.2013.12.001

Bose A, Chowdhury IR (2020) Monitoring and modeling of spatio-temporal urban expansion and land-use/land-cover change using markov chain model: a case study in Siliguri Metropolitan Area, West Bengal, India. Model Earth Syst Environ 6:2235–2249. https://doi.org/10.1007/s40808-020-00842-6

Brenkert A, Malone E (2005) Modeling vulnerability and resilience to climate change: a case study of India and Indian States in climatic change. Enviorn Build News 72:57–102

Chakraborty T, Lee X (2019) A simplified urban-extent algorithm to characterize surface urban heat islands on a global scale and examine vegetation control on their spatiotemporal variability. Int J Appl Earth Obser Geoinf 74:269–280

Choudhury A, Vazeer Mahammood KHV, Rao D (2021) Land surface temperature and its impact on land use and land cover: long-term rainfall analysis using CHIRPS PENTAD data in Telangana's Mahabubnagar District. Environ Ecol Res 9(6):399–418. https://doi.org/10.13189/eer.2021.090607

Daneshvar MRM, Rabbani G, Shirvani S (2019) Assessment of urban sprawl effects on regional climate change using a hybrid model of factor analysis and analytical network process in the Mashhad city, Iran. Environ Syst Res 8:23

Daramola MT, Eresanya EO, Ishola KA (2018) Assessment of the thermal response of variations in land surface around an urban area. Model Earth Syst Environ 4(2):535–553. https://doi.org/10.1007/s40808-018-0463-8

De Laat ATJ, Maurellis AN (2006) Evidence for influence of anthropogenic surface processes on lower tropospheric and surface temperature trends. Int J Climat 26:897–913

Dewan A, Kiselev G, Botje D (2021) Diurnal and seasonal trends and associated determinants of surface urban heat islands in large Bangladesh cities. Appl Geogr 135:102533

Donatti CI, Harvey CA, Hole D et al (2020) Indicators to measure the climate change adaptation outcomes of ecosystem-based adaptation. Climatic Change 158:413–433. https://doi.org/10.1007/s10584-019-02565-9

Dutta D, Rahman A, Paul SK, Kundu A (2021) Impervious surface growth and its inter-relationship with vegetation cover and land surface temperature in peri-urban areas of Delhi. Urban Clim 37:100799. https://doi.org/10.1016/j.uclim.2021.100799

Ellis P, Roberts M (2016) Leveraging urbanization in South Asia: managing spatial transformation for prosperity and livability. World Bank, Washington, DC. ©World Bank. Accessed from https://openknowledge.worldbank.org/handle/10986/22549 License: CC BY 3.0 IGO on January, 22nd, 2020

Eric S, Kumi-Boateng B (2020) Modelling of land surface temperature changes as determinant of urban heat Island and risk of heat-related conditions in the Wassa West mining area of Ghana. Model Earth Syst Environ 6(3):1727–1740. https://doi.org/10.1007/s40808-020-00786-x

Gophen M (2014) Land-Use, Albedo and air temperature changes in the Hula Valley (Israel) during 1946–2008. Open J Mod Hydrol 4:101–111

Houghton RA (1994) The worldwide extent of land-use change. BioScience 44(5):305–313. https://doi.org/10.2307/1312380

Hunt KMR, Menon A (2020) The 2018 Kerala floods: a climate change perspective. Clim Dyn 54:2433–2446. https://doi.org/10.1007/s00382-020-05123-7

IPCC (2007) Climate change 2007: the physical science basis. In: Solomon S, Qin D, Manning M, Chen Z, Marquis M, Averyt KB, Tignor M, Miller HL (eds) Contribution of working group I to the fourth assessment report of the intergovernmental panel on climate change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA

IPCC (2022) Summary for Policymakers.In: Pörtner H-O, Roberts DC, Poloczanska ES, Mintenbeck K, Tignor M, Alegría A, Craig M, Langsdorf S, Löschke S, Möller V, Okem A (eds) Climate change 2022: impacts, adaptation, and vulnerability. contribution of working group II to the sixth assessment report of the intergovernmental panel on climate change [Pörtner H-O, Roberts DC, Poloczanska ES, Mintenbeck K, Tignor M, Alegría A, Craig M, Langsdorf S, Löschke S, Möller V, Okem A, Rama B (eds)]. Cambridge University Press. In Press

Itzhak-Ben-Shalom H, Alpert P, Potchter O, Samuel R (2017) MODIS summer SUHI cross-sections anomalies over the megacities of the monsoon Asia region and global trends. Open Atmos Sci J 11:121–136

Jaina S, Sannigrahia S, Sena S, Bhattb S, Chakrabortic S, Rahmata S (2020) Urban heat island intensity and its mitigation strategies in the fast growing urban area. J Urban Manag 9(1):54–66

Jensen JR (2013) Remote sensing of the environment: an earth resource perspective. Pearson Education India, 2 edn

Kotharkar R, Ramesh A, Bagade A (2018) Urban heat island studies in South Asia: a critical review. Urban Clim 24:1011–1026

Krishnakumar KN, Prasada Rao GSLHV, Gopakumar CS (2009) Rainfall trends in twentieth century over Kerala, India. Atmos Environ 43(11):1940–1944. ISSN 1352-2310, https://doi.org/10.1016/j.atmosenv.2008.12.053

Lillesand TM, Kiefer RW (2008) Remote sensing and image interpretation. John Wiley & Sons, US

McKitrick R, Michaels PJ (2004) Are temperature trends affected by economic activity? Reply to Benestad. Clim Res 27:175–176. https://doi.org/10.3354/cr027175

Meyer WB, Turner BL (1992) Human population growth and global land use/land cover change. Ann Rev Ecol Syst 23:39–61

Mishra V, Mukherjee S, Kumar R and Stone DA (2017) Heatwave exposure in India in current, 1.5 °C, and 2.0 °C world. Environ. Res Lett 12:124012

Mishra V, Aadhar S, Shah H, Kumar R, Pattanaik D, Tiwari A (2018) The Kerala flood of 2018: combined impact of extreme rainfall and reservoir storage. Hydrol Earth Syst Sci Discuss 1–13. https://doi.org/10.5194/hess-2018-480

Mishra V, Ambika AK, Asoka A, Aadhar S, Buzan J, Kumar R, Huber M (2020) Moist heat stress extremes in India enhanced by irrigation. Nat Geosci 13:722–728

MoEF (2018) Accessed from https://moef.gov.in/wp-content/uploads/2018/04/revised-PPT-Press-Conference-INDC-v5.pdf

Mohan M, Kandya A (2015) Impact of urbanization and land-use/land-cover change on diurnal temperature range: a case study of tropical urban air shed of India using remote sensing data. Sci Total Environ 506–507:453–465. https://doi.org/10.1016/j.scitotenv.2014.11.006

Nguyen C, Chidthaisong A, Diem PK, Huo L-Z (2021) A modified bare soil index to identify bare land features during agricultural fallow-period in southeast Asia using Landsat 8. Land 10:231

Nikhil Raj PP, Azeez PA (2010) Changing rainfall in the Palakkad plains of South India. Atmósfera 23:75–82

Pandey AK, Singh S, Berwal S, Kumar D, Pandey P, Prakash A, Kumar K (2014) Spatio–temporal variations of urban heat island over Delhi. Urban Climate 10:119–133

Panmei C, Divakar Naidu P, Mohtadi M (2017) Bay of Bengal exhibits warming trend during the younger Dryas: implications of AMOC. Geochem Geophys Geosyst 18(12):4317–4325

Parsaee M, Joybari MM, Mirzaei PA, Haghighat F (2019) Urban heat island, urban climate maps and urban development policies and action plans. Environ Technol Innov 14:100341

Perera T, Nayanajith TMD, Jayasinghe GY, et al (2021) Identification of thermal hotspots through heat index determination and urban heat island mitigation using Environment numerical micro climate model. Model Earth Syst Environ https://doi.org/10.1007/s40808-021-01091-x

Rahman MM, Rahman MM, Momotaz M (2019) Environmental quality evaluation in Dhaka City corporation–using satellite imagery. Proc Instit Civ Eng-Urban Des Plan 172(1):13–25

Raj S, Paul, SK, Chakraborty A, Kuttippurath J (2020a) Anthropogenic forcing exacerbating the urban heat islands in India. J Environ Manag 257:110006

Raj S, Paul SK, Chakraborty A, Kuttippurath J (2020b) Anthropogenic forcing exacerbating the urban heat islands in India. J Environ Manag 257:110006. https://doi.org/10.1016/j.jenvman.2019.110006, ISSN 0301-4797

Rangarajan V, Singh R, Kaushal P (2019) Model development and performance evaluation of an earth air heat exchanger under a constrained urban environment. Model Earth Syst Environ 5(1):143–158. https://doi.org/10.1007/s40808-018-0524-z

SAPCC (2014) downloaded from https://envt.kerala.gov.in/wp-content/uploads/2019/10/Kerala-State-Action-Plan-on-Climate-Change-KSAPCC-2014-August.pdf

Shastri H, Barik B, Ghosh S et al (2017) Flip flop of day-night and summer-winter surface urban heat island intensity in India. Sci Rep 7:40178. https://doi.org/10.1038/srep40178

Suresh S, Ajay Suresh V, Mani K (2016) Estimation of land surface temperature of high range mountain landscape of Devikulam Taluk Using Landsat 8 Data. IJRET: Int J Res Eng Technol. eISSN: 2319-1163, pISSN: 2321-7308

Thomas G, Zachariah EJ (2011) Urban heat island in a tropical city interlaced by wetlands. J Environ Sci Eng 5(2):1–7

Tran H, Daisuke U, Shiro O, Yoshifumi Y (2006) Assessment with satellite data of the urban heat island effects in Asian mega cities. Int J Appl Earth Obs Geoinf 8:34–48

Tran DX, Pla F, Latorre-Carmona P, Myint SW, Caetano M, Kieu HV (2017) Characterizing the relationship between land use land cover change and land surface temperature. ISPRS J Photogram Remote Sens 124:119–132. https://doi.org/10.1016/j.isprsjprs.2017.01.001

UN Report (2019) The urban nexus: integrating resources for sustainable cities United Nations publication 2019, ST/ESCAP/2859. https://circulars.iclei.org/resource/the-urban-nexus-integrating-resources-for-sustainable-cities

Vijaykumar P, Abhilash S, Sreenath AV, Athira UN, Mohanakumar K, Mapes BE, Chakrapani B, Sahai AK, Niyas TN, Sreejith OP (2021) Kerala floods in consecutive years—its association with mesoscale cloudburst and structural changes in monsoon clouds over the west coast of India. Weather Clim Extrem 33:100339. https://doi.org/10.1016/j.wace.2021.100339

World Bank Report (2016) Ellis, Peter, and Mark Roberts.In: 2016. Leveraging urbanization in South Asia: managing spatial transformation for prosperity and livability. South Asia development matters. World Bank, Washington, DC. https://doi.org/10.1596/978-1-4648-0662-9

Yang J, Santamouris M (2018). Urban heat island and mitigation technologies in Asian and Australian Cities—impact and mitigation. Int J Urban Sci 2(3):74; Yang Y, Cao C, Pan, X, Li, X, Zhu X (2017) Downscaling land surface temperature in an arid area by using multiple remote sensing indices with random forest regression. Remote Senss 9:789

Chapter 24
Geographical Analysis of Municipal Waste Management—A Case Study of Patna Municipal Corporation (Bihar, India)

Saroj Senapati, Gouri Sankar Bhunia, Soumen Brahma, and Manju Pandey

Abstract Municipal waste management (MWM) has become a worldwide ecological priority in the last two decades, attributed to the rising capacity of waste produced as a consequence of the development of a mass consumer society. This study is emphasised to perceive the clusters of high and low waste generation zones in the Patna Municipal Corporation (PMC) and evaluate the geographical contributions of waste. Ward-wise municipal waste, population and area data were collected from the Central Pollution Control Board (CPCB) and the Government of Bihar's Urban Development and Housing Department. Descriptive statistics of waste features were estimated through Microsoft excel. Geographical Information system was worn to investigate the geographical discrepancy of the waste types grouping at the micro-level. Cluster analysis is performed to demarcate the geographical cluster of waste generated based on the Getis-Ord G_i^* statistic. Outcome of the research shows that the average rate per capita solid waste (SW) generation is 12.22 tonnes per day (TPD) $\pm$ 3.80 for the entire municipal corporation. Results also showed a strong positive correlation between total waste generation and population number and meagre relation with the area. The high waste-generated clusters of the ward are found in the west of the PMC, and low waste-generated cluster is observed in the central part of the PMC. Our results recommend that MWM should be well matched to the spatial characteristics of the ward in a conundrum.

Keywords Waste generation · GIS · Getis-Ord G_i^* statistic · Patna Municipal Corporation

---

S. Senapati
Department of Geography, Atal Bihari Vajpayee Viswavidyalaya, Bilaspur 495009, Chhattisgarh, India

G. S. Bhunia (✉) · S. Brahma
Department of Geography, Nalini Prabha Dev Roy College, Bilaspur, Chhattisgarh, India
e-mail: rsgis6gouri@gmail.com

M. Pandey
Government Mata Shabari, Navin Girl's College, Seepat Road, Bilaspur 495009, Chattishgarh, India

U. Chatterjee et al. (eds.), *Urban Commons, Future Smart Cities and Sustainability*, Springer Geography, https://doi.org/10.1007/978-3-031-24767-5_24

Introduction

The deficiency in modern solid waste management measures, united with the high population growth rate and growth in commercial progress in developing nations' metropolitan areas, obscures efforts to boost infrastructure and amenities. In underdeveloped countries, per capita solid waste generation in urban residential areas is substantially lower than in developed countries; even so, developing countries' ability to obtain, process, discard, or recycle solid wastes in a cost-effective manner is severely reduced when compared to developed countries (Mahmood et al. 2018). Solid waste generation has become a serious challenge in recent years as a result of uncontrolled urban population expansion and industrialisation. The quantity of municipal solid waste (MSW) created per capita in developing nations like India is anticipated to increase at a pace of 1–1.33% yearly, with the majority of MSW being preserved on land in an improper manner. Decision-makers and waste management planners must be able to deal with the problem's increased complexity, ambiguity, multi-objectivity and partisanship with an effective SWM system (Sumathi et al. 2008).

Waste management data must be linked to the area's socio-economic and ecological factors (Passarini et al. 2011; Mihai 2012). The layout and dynamics of any location are influenced by factors like as climate, population, infrastructure and power imprints (Mengozzi 2009). In general, the urban population density will have a beneficial impact on garbage output, and only economies of scale pushed by urbanisation will be able to reverse the trend and minimise gathering when density is higher (Mazzanti and Zoboli 2008). Waste statistics in underdeveloped countries are dependent on approximations due to the lack of garbage weighing systems. Kumar et al. (2009) calculated the amount of rubbish gathered from several Indian cities estimated by the number of trips/day of waste management amenities from several wards/zones of the municipality. Furthermore, depending on the population of these cities, they determined the waste generation rate in kg/capita/day. In undeveloped countries, the proportion of waste collected is similar, with regional differences owing to climatic, cultural, industrial, infrastructure and regulatory factors (Mihai 2012). The composition of garbage is influenced by geographical location, population living standards and energy source (Ngoc and Schnitzer 2009).

Solid waste management (SWM) is a huge concern for any city, but particularly for one in the developing world that is speedily urbanising with little or no planning. Patna Municipal Corporation (Bihar, India) is one of the fastest-growing Indian cities in terms of population size and urbanisation. Patna's growth has been uncontrolled notwithstanding a four-fold increase in numbers from 473,000 in 1971 to 1.68 million in 2011 (Alakshendra 2019). There has been a sudden transition in the country's waste management systems over the last few years. The current policy, the Union government's flagship Swachh Bharat Mission (SBM) 2.0, emphasises on waste isolation, waste processing (wet and dry) and reducing waste exhaled to sanitary dumpsites. According to Pandey (2014), the city of Patna generates roughly 1200 tonnes of waste each day, comprising both organic and inorganic waste, and this figure is anticipated to treble by 2036. Household waste accounts for 40% of the city's overall waste production. There were 860 secondary and community dumping stations in the city as of 2016 (Pandey 2014). Furthermore, rubbish was transported to the main landfill in open municipality vehicles from approximately 860 dumping stations. Until recently, citizen demonstrations and revolts forced the waste sites to be relocated to diverse locations throughout the city.

In the past few decades, Geographical Information Systems (GIS) have become increasingly crucial in the decision-making process. It also enables a digital data inventory for the site's long-term assessment (Gizachew et al. 2012). Academics and scientists have widely used geospatial technique-based multi-criteria decision analysis (MCDA) during the last couple of decades to indicate that sanitary landfilling is the most acceptable waste disposal strategy (Coban et al. 2018). Due to the Patna Municipal Corporation's (PMC) lack of financial resources and inadequate facilities, inappropriate trash disposal occurs, leading to the ever-increasing cycle of difficulties (Zurbruegg 2003). The goal of this study is to detect the clusters of high and low waste generation zones in the Patna Municipal Corporation and to evaluate the geographical contributions of waste. Furthermore, the current study investigates the relationship between waste generation in terms of area and actual population at the micro-level.

Study Area

Patna, also named as Pataliputra, is one of the oldest extant places in the nation. It is the state capital of Bihar and has been a thriving centre of governmental, commercial and educational activities in recent years. It is on the southern bank of the Ganga, between latitudes 25°30′N and 26°45′N and longitudes 85°0′ E and 85°15′ E (Fig. 24.1). River Son runs at the western edge of the Patna Municipal Corporation (PMC). According to the Bihar Urban Development Ministry, PMC encompasses 99.45 square kilometres (Swarup et al., 2020). According to Census 2011, the city is divided into 72 wards, which are organised into four circles: New Capital Circle (Western Zone), Kankarbagh Circle (Southern Zone), Bankipur Circle (Central Zone) and Patna City Circle (Eastern Zone). The city has a population of 1.7 million (16, 83,200). Patna's climate is humid subtropical, with hot summers from March to June, monsoon from June to September and warm winters from November to February. Patna's and the region's significant seismic hazard is another remarkable aspect.

Inappropriate planning causes traffic problems in the streets, causing delays in the waste collection since waste carriers are unable to reach the location, leaving rubbish to remain uncollected. PMC currently generates 1000 metric tonnes of waste per day, with 'a big portion of junk lingering in various parts of the city, making the environment unclean and uncomfortable'. In cities, population density has a substantial influence on the amount and quality of garbage accumulated. It also differs depending on the nature of residential, economic and manufacturing areas, occupational structure, economic status, eating habits, dietary needs, educational level, living standards and lifestyle of residents.

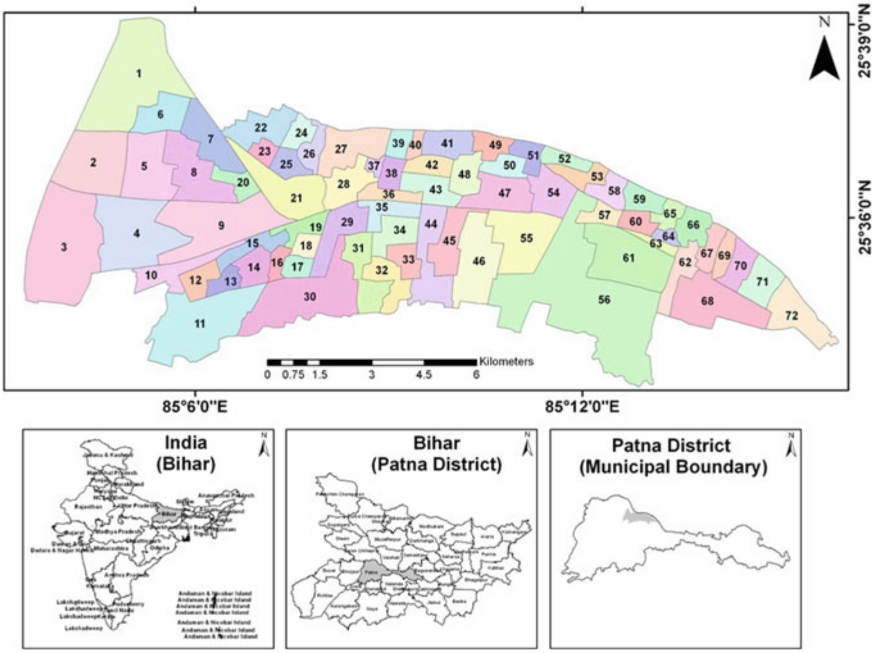


Fig. 24.1 Ward map of Patna Municipal Corporation

Materials and Methods

Data Collection and Processing

The study began with secondary data collection, which was acquired and used from a multitude of sources. The essential information is based on the study area's ward-by-ward waste characteristics, actual population and area. Data on garbage collection per capita per day is collected from the Central Pollution Control Board (CPCB) and the Government of Bihar's Urban Development and Housing Department.

$$\begin{aligned}&\text{MSW Quantity disposed per day}\\&\quad = \text{No. of vehicles} * \text{vehicle carrying capacity}\left(\frac{\text{kg}}{\text{trip}}\right)\end{aligned} \tag{24.1}$$

(*Close Tipper vehicles 1000 kg/trips, Open Tipper vehicles 1500 kg/trips, Mini Tipper vehicles 500 kg/trips, Auto Tipper vehicles 500 kg/ trips, ECart vehicles 400 kg/trips*).

The ward map of Patna is gathered from the Patna Municipal Corporation Office. The Ward map is georeferenced in Universal Transverse Mercator (UTM) projection system with World Geodetic System (WGS) 84 datum and North 45 Zone.

A digital database of PMC ward maps is prepared on the GIS platform through a heads-up digitising method using Q-GIS v2.4.0 software. Furthermore, in the GIS environment, geospatial maps such as administrative ward-wise locations, waste generation density maps and geographical distribution maps of various categories of garbage were created using various tools. The aforementioned parameters' geographical and thematic data representation will offer a real entropy and the rank of certain components inside a particular location of Patna city.

Statistical Analysis

In cities, population density has an extensive influence on the amount and quality of garbage generated (Swarup et al. 2020). It also differs depending on the nature of residential, commercial and industrial regions, occupational structure, income level, eating habits, nutritional intake, educational level, living standards and lifestyle of residents. Based on prior research, two variables, population and area, were found as having an impact on Patna's MSW generation rates. Descriptive statistics of waste characteristics were analysed. Kurtosis (Ku) is an indicator of distribution's relative peakiness. When the degree of peakedness is more than 3, distribution is said to be leptokurtic; when the level of peakedness is equal to 3, it is mesokurtic; when the extent of peakedness is less than 3, it is platykurtic. Skewness (Sk) is a metric that measures asymmetry. The tail of distributions with a magnitude of skewness greater than 0 ($Sk > 0$) is said to be positively slanted, indicating an availability of low values. When the tail of the dispersion is skewed towards low values, it is negatively skewed ($Sk < 0$), indicating an abundance of high values. Furthermore, the statistical forecasting study was performed using past historical data and prognostic indicators, namely population and area, in Microsoft Excel (version 13.0) software for MSW generation. The relationship between ward-wise total waste generation (y) as dependent variables and population ($\times 1$) and area ($\times 2$) as independent variables was evaluated using logarithmic correlation analysis.

Cluster Analysis

Cluster analysis is used in ArcGIS software to delimit the spatial cluster of waste-generated areas in Patna Municipal Corporation using the Getis-Ord Gi* statistic and a fixed distance band (Mitchell 2005). The resulting Z-score spatially defined the states with high or low waste-generated wards of clusters. Positive and larger Z results suggested more intense clustering of the high amount of waste-generated wards, whereas negative and lesser value of Z-scores indicated clustering of the low amount of waste-generated wards. A Z-score close to zero demonstrates that there is no discernible spatial clustering. The Getis-Ord Gi* statistic is computed by the cluster analytical technique for each ward in a dataset. The resulting Z-score indicates where wards with a maximum or minimum waste created volume clusters geographically. This technique examines each ward in the framework of neighbouring wards. The Getis-Ord local statistic is as follows:

$$G_i^* = \frac{\sum_{j=1}^{n} w_{i,j}x_j - \overline{X}\sum_{j=1}^{n} w_{i,j}}{s\sqrt{\frac{\left[n\sum_{j=1}^{n} w_{i,j}^2 - \left(\sum_{j=1}^{n} w_{i,j}\right)^2\right]}{n-1}}} \quad (24.2)$$

where x_j is the amount of waste generated in wards j, w_i, j is the spatial weight between features i and j, and n is the total number of wards:

$$\overline{X} = \frac{\sum_{j=1}^{n} x_j}{n} \quad (24.3)$$

$$S = \sqrt{\frac{\sum_{j=1}^{n} x_j^2}{n} - \left(\overline{X}\right)^2} \quad (24.4)$$

Because the $G_i{}^*$ statistic is a *z-score*, no additional measurements are obligatory (Jana and Sar 2016).

Results

Density of population, socio-economic background, commercial activity level, cultures and city/region all accelerate the level of garbage production. Assessing the quantity and attributes of MSW in PMC and predicting future waste production are critical components of effective waste management planning (Rana et al. 2014). To enable for much more effective demand for a good and recycling, waste management must include waste segregation at the source. Isolating dry (inorganic) and wet (biodegradable) trash would have been beneficial and should be the concern of the waste producer. The outcomes of the research show that the average rate per capita solid waste (SW) generation is 12.22 tonnes per day (TPD) ± 3.80 for the entire municipal corporation. The maximum per capita rate of waste generated is 22 TPD, collected from ward no, and the minimum waste is collected from 5.0 TPD (Table 24.1), collected from the ward no. The average wet waste collection rate is 7.34 TPD with a standard deviation of ± 2.29 in PMC. The maximum rate of wet waste collection is #13.03 TPD (ward no. 31), and the minimum rate of the wet waste collection was done from ward no. 23 (#2.87TPD). The mean dry waste collection rate is 4.77 TPD in the PMC with a standard deviation of ± 1.48. The maximum amount of dry waste was collected from ward no.31 (#8.77 TPD), and the minimum quantity of dry waste is collected from ward no. 23 (#1.87 TPD). The estimated average sanitary waste collection is 0.04TPD ± 0.025, and the estimated average domestic waste collection rate is 0.043TPD ± 0.013 in the study area. The kurtosis value is greater

Table 24.1 Descriptive statistics of waste characteristics in Patna Municipal Corporation

Type of waste	Minimum	Maximum	Mean	Std. Dev	Skewness	Kurtosis	1st quartile	3rd quartile
Total waste (in TPD)	5	22	12.22	3.80	0.59	3.03	9.5	14
Wet waste (in TPD)	2.87	13.03	7.34	2.29	0.62	3.06	5.68	8.38
Dry waste (in TPD)	1.87	8.47	4.77	1.48	0.62	3.07	3.73	5.45
Sanitary waste (in TPD)	0.02	0.14	0.08	0.025	0.425	0.06	3.05	0.09
Domestic waste (in TPD)	0.02	0.08	0.043	0.013	0.745	3.37	0.03	0.05

than 3 for each type of waste generation, except sanitary waste. Waste distribution is positively skewed in the study area.

While per capita waste generation is an important criterion for evaluating consumption and production rates, the total quantity of garbage generated by the community served by the management system is more important in planning and design. The per capita garbage production rates for various population categories have been estimated using the information provided by the municipal government. For the 72 municipal wards under the Patna Municipal Corporation, data analysis was conducted to approximate the interdependence of total solid waste generated with the population and the area. The results of the data analysis are depicted in Fig. 24.2. Results of the analysis showed a strong positive correlation ($R^2 = 0.9429;$ $P < 0.0001$) between population and total waste generation. A medium positive correlation ($R^2 = 0.2694;$ $P < 0.05$) is observed between the area and total waste generation.

Figure 24.3 depicts the current geographical distribution form of population and garbage density across Patna's 72 administrative wards. The population and MSW production results were divided into five categories, namely very high-density, high-density, medium-density, low-density and very low-density wards. The amount of municipal solid garbage generated is unswervingly proportional to the size of the ward and the population (Aragaw et al. 2016). In the PMC, the maximum waste (>20 TPD) was generated in wards 1, 3, 5, 30, 31, 47 and 58, typically detected in the west and south and small pockets in the north of the study area. The low amount of waste (<8 TPD) generated in wards 6, 9, 16, 18, 23, 25, 37, 38, 39 and 40 is frequently portrayed in the central location of the PMC. Moreover, the medium waste was generated in the north, east and south-east of the PMC (Fig. 24.3).

There were some outstanding spatial waste generation clusters covering strategic areas. Figure 24.4 depicts each cluster analysis of waste generation that revealed

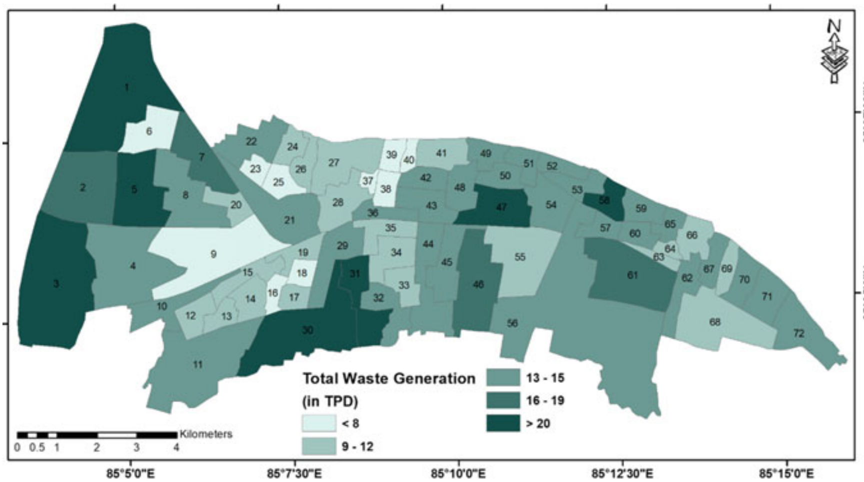


Fig. 24.2 Total waste generation in Patna Municipal Corporation

statistically significant high waste-generated wards and low waste-generated wards ($P < 0.01$). The analysis revealed different geographical patterns of highly waste-generated wards conditions, which were mostly spread in the PMC.

A correlation study was performed to understand the connotation between wet waste, area and population in PMC (Fig. 24.5). Results of the analysis showed a strong correlation between wet waste and population characteristics ($R^2 = 0.9443$; $P < 0.001$) whereas a meagre correlation was calculated between wet waste generation and area ($R^2 = 0.2834$; $P < 0.07$). The map for wet waste cluster generation shows that the west and a small pocket of the east have a high amount of wet waste-generated wards; however, the central part of PMC has a low amount of wet waste-generated wards (Fig. 24.6).

The resident influences waste composition because higher-income groups consume more parcelled goods, leading to higher quantities of plastics, paper, glass, metals and textiles (Sridevi et al. 2012). Variations in generation and composition of waste can have a significant impact on waste management procedures. The majority of organic waste comes from households, while inanimate waste comes from construction, decimation and road cleaning. In this research, a strong positive correlation is found between dry waste generation and actual population ($R^2 = 0.9445$; $P < 0.0007$), while a moderate positive correlation is observed between area and dry waste generation ($R^2 = 0.2832$; $P < 0.05$) (Fig. 24.7). The output of cluster analysis showed three clusters of a high volume of dry waste generation, distributed in the west and south of the PMC. The less quantity of dry waste-generated cluster is portrayed in the central part of the PMC (Fig. 24.8).

Because the quantity and techniques of solid waste moved from landfills are mostly decided by generated trash, the creation of sanitary and domestic waste provides insight that ensures improved waste management effectiveness (Noufal et al. 2020).

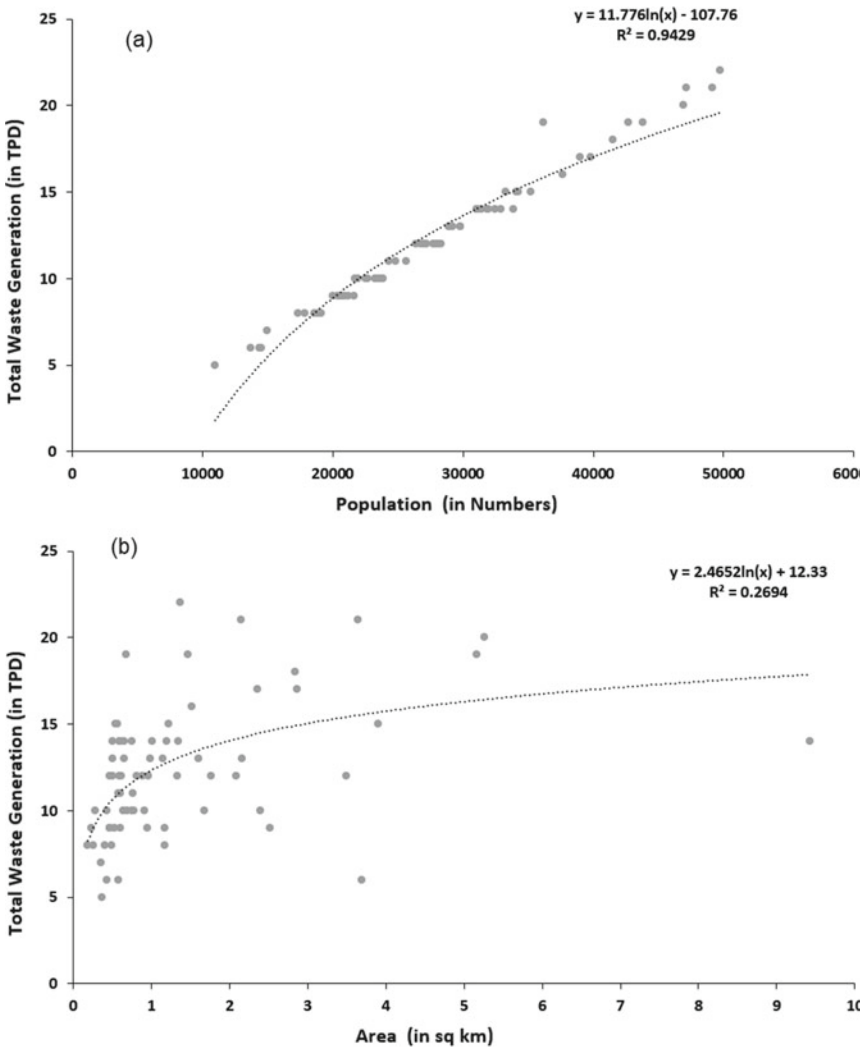


Fig. 24.3 Logarithmic relationship between total waste generation and actual population

Moreover, the Pearson correlation co-efficient test was done to understand the relation between sanitary waste generation and population ($R^2 = 0.8499$; $P < 0.0004$) and the area ($R^2 = 0.2574$; $P < 0.08$) in Patna Municipal Corporation (Fig. 24.9). Figure 24.10 represents the correlation analysis between domestic waste generation with population ($R^2 = 0.8829$; $P < 0.008$) and area ($R^2 = 0.2323$; $P < 0.04$).

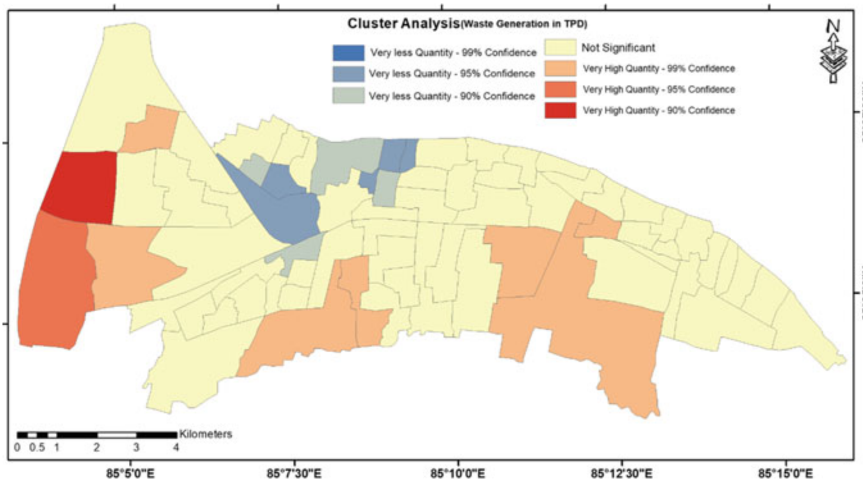


Fig. 24.4 Cluster analysis of total waste generation (in TPD) in Patna Municipal Corporation

Discussion

Geographical settings from a particular country, region, or city have an even greater impact on waste management strategies that are underdeveloped. As a result of the low population assisted by sanitation facilities and poor set-up, uncleared garbage is dumped in open landfills, damaging the surrounding ecosystem. All independent variables, comprising economic considerations, social traits and geographical boundaries, are proven to have a considerable impact on MSW disposal in developing nations (Chen 2010). Desmond (2009) makes spatial insights into the strategic environment assessment by describing methodologies for calculating trash amounts based on various demographic and socio-economic indicators (SEA studies). Without a territorial strategy for domestic waste management, according to Le Dorlot (2004), it will be challenging to execute national and international guidelines and ideas at the local level. Spatial evaluation aids in comprehending the geography committed to waste management, and technological resolutions should be tailored to the particular region (Monika 2010). Along with the waste generation indication, the waste composition is an important consideration when putting in place a waste management system. Municipal waste composition analyses (Gidarakos et al. 2006; Burnley et al. 2007) can assist policymakers in selecting treatment and recovery technologies or, in the worst-case scenario, trash disposal sites. By adjusting current waste management strategies, forecasts about the evolution of recyclable trash volumes can be established based on data on waste generation and composition (Sokka et al. 2007).

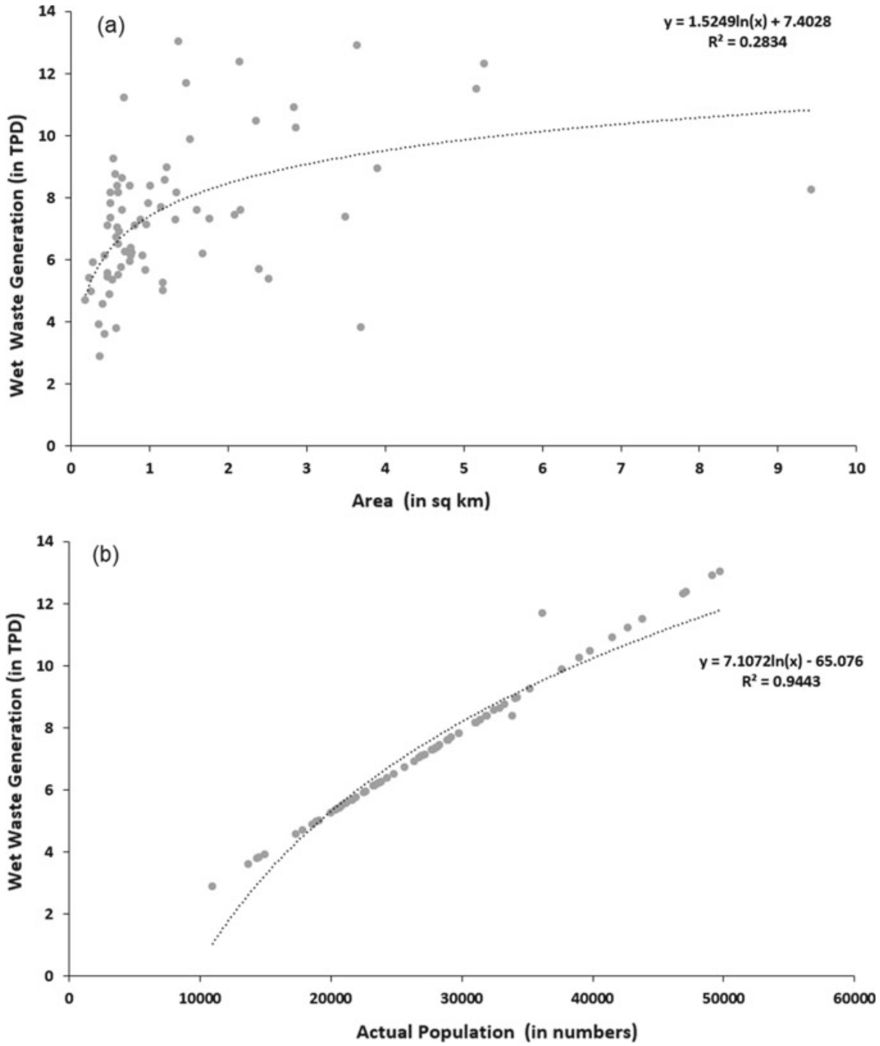


Fig. 24.5 Logarithmic regression analysis between wet waste and population characteristics

The composition of waste in PMC varies by ward and is determined by variables such as population, ward area, land use, floating population, commercial activities, health and educational infrastructure, traditional practices, people's level of progression, socio-economic status and community outreach. Our results showed a strong positive correlation between waste generation and population numbers. A medium relationship is observed between the waste generation and area. The low waste-generated cluster is observed in the central part of the PMC (ward no. 21, 24, 26 and 27) which may be attributed to most of the area being covered by the railway stations and administrative offices in PMC. This area is mostly characterised by a floating population, and the actual population number is very less. Moreover, the high waste-generated clusters are observed in the west and south of the PMC that may be attributed to the significant proportion of organic content in household solid waste produced from domestic sites because of the agrarian economy and high level of consumption of the residents. Composting as a technique of reducing the amount of garbage that must be transported to the landfill, as well as transferring the organic part of waste into compost, is achievable due to the high organic fraction composition. If waste is not gathered, the organic part degrades, emitting foul odours and damaging ground and surface water through leachates, as well as attracting flies and rats to rubbish stacks in the street.

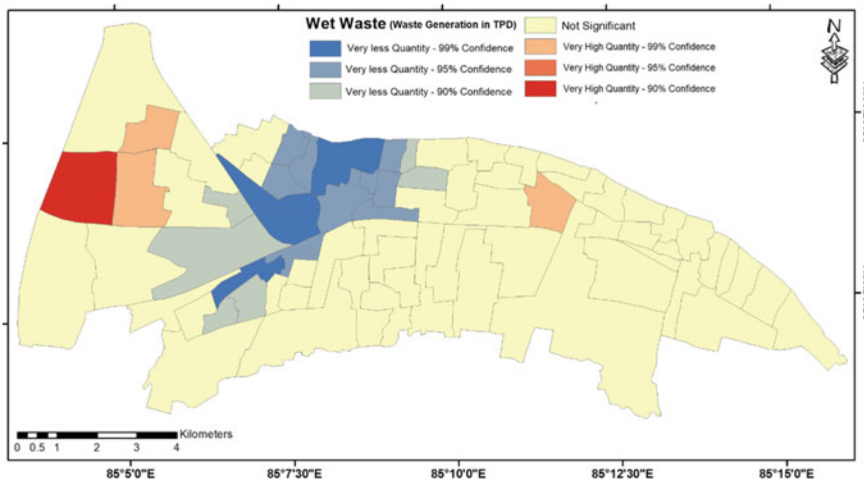


Fig. 24.6 Cluster analysis of wet waste generation (in TPD) in Patna Municipal Corporation

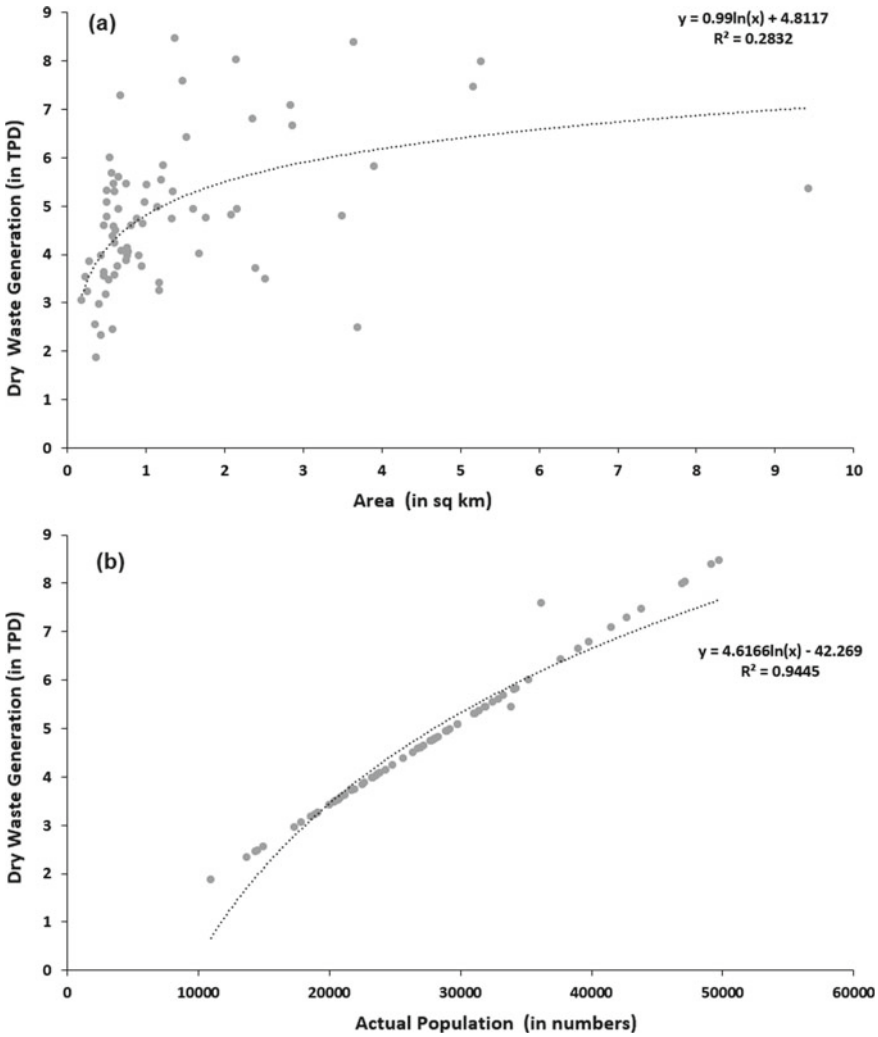


Fig. 24.7 Logarithmic regression analysis between dry waste and population characteristics and area

There is a need for capacity building at all levels. All school learners should understand the importance of trash management, the effects of inadequate MSWM on public health and the environment, and each individual's waste management responsibilities. This will encourage citizens to regard garbage as a resource opportunity.

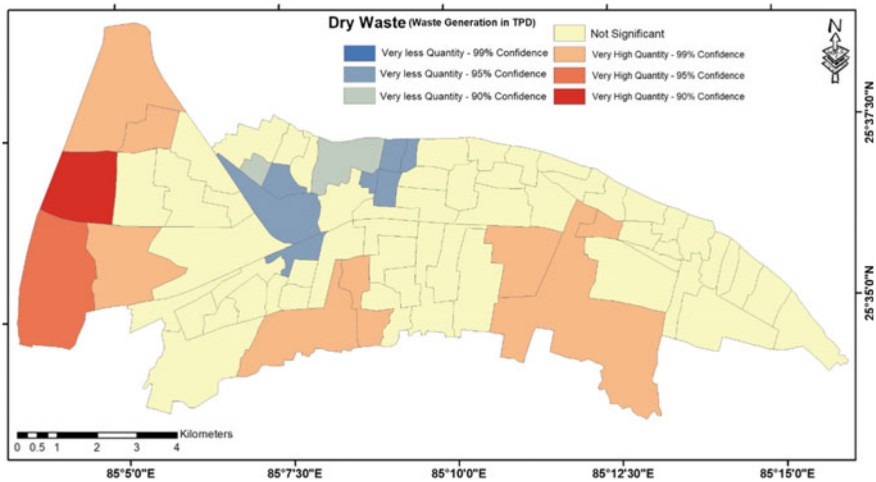


Fig. 24.8 Cluster analysis of dry waste generation (in TPD) in Patna Municipal Corporation

Conclusion

SWM is being attempted to become a critical concern in Patna Municipal Corporation as a result of population increase, notably the expansion of megacities. Inadequate waste infrastructure, the informal economy and garbage dumping are now relied upon by PMC. Community engagement in waste management has substantial problems, and there is a lack of waste management responsibilities in the neighbourhood. Waste management that is both financially and socially viable must safeguard maximum supply delimitation from waste while also ensuring the safe dumping of biowaste through the progress of concocted dumpsite and waste-to-energy amenities. PMC appearances several contests in the waste management sector associated with waste policy, waste implementation and the accessibility of adequately trained personnel. Patna will linger to endure underprivileged waste management and the repercussions for human health and the environment until these crucial constraints are satisfied.

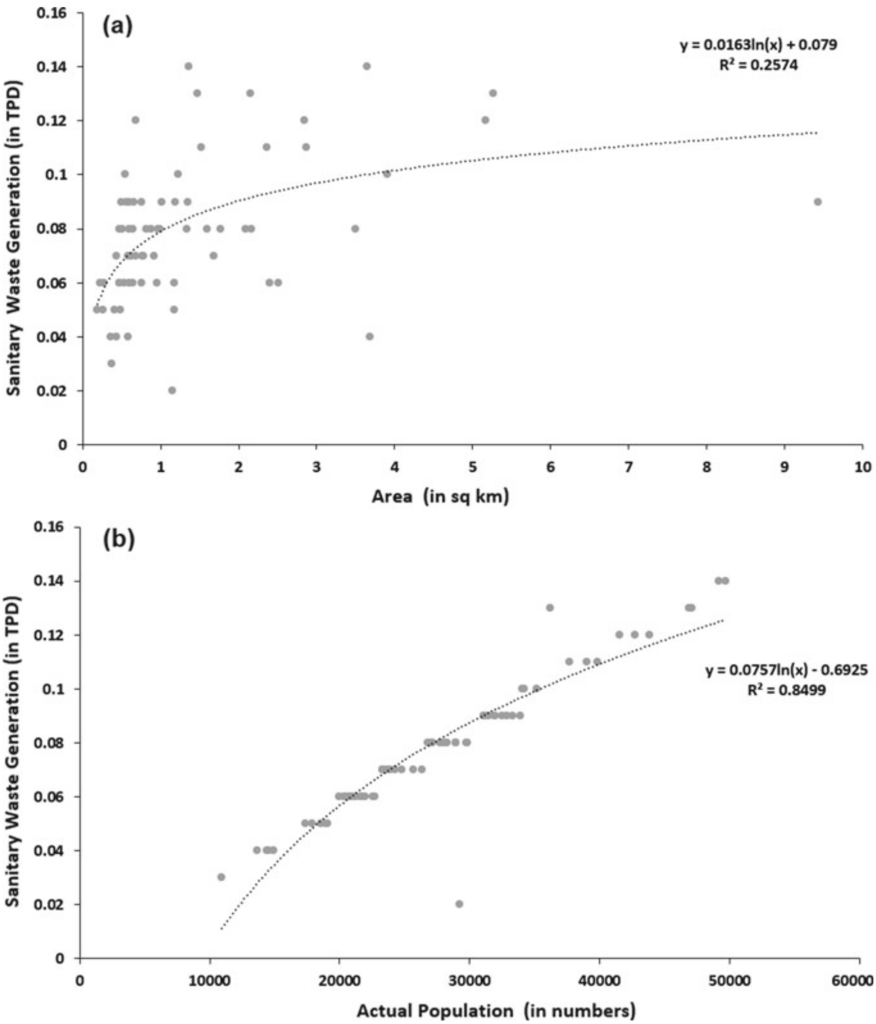


Fig. 24.9 Logarithmic regression analysis between sanitary waste and population characteristics and area

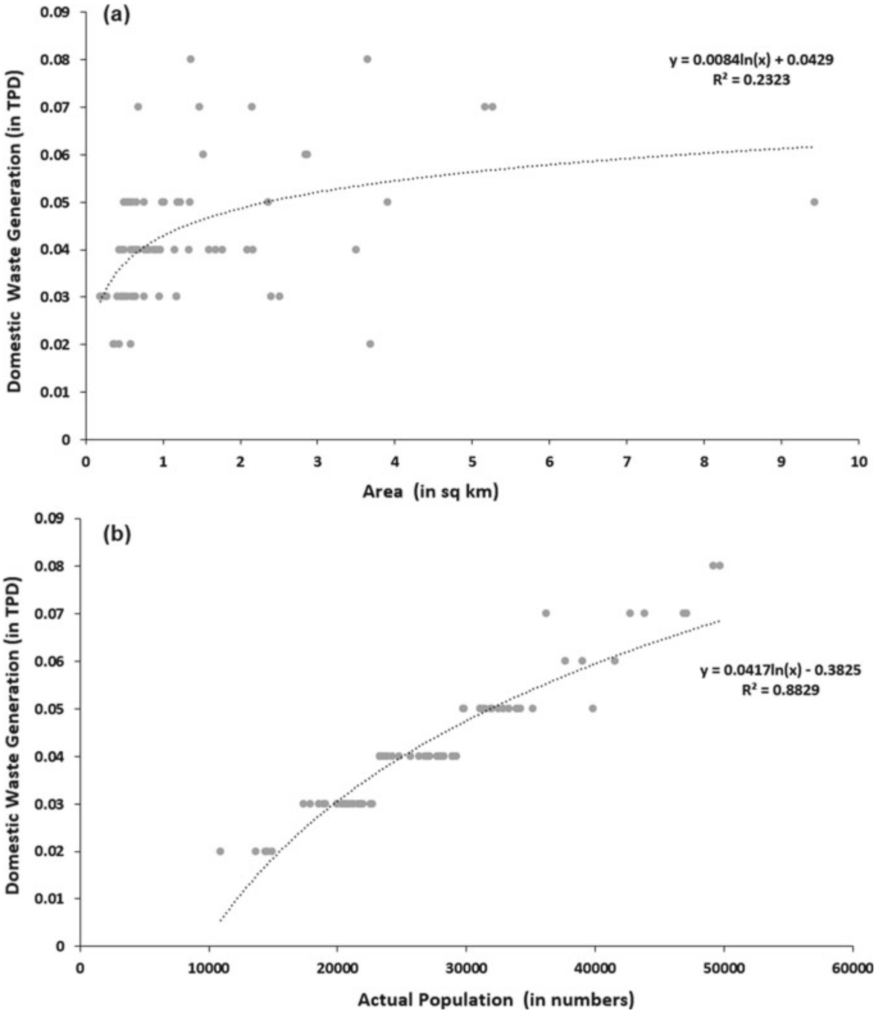


Fig. 24.10 Logarithmic regression analysis between domestic waste and population characteristics and area

Acknowledgements Thanks to the Patna Municipal Corporation Authority and Urban Development and Housing Department of Govt of Bihar for freely proving the data.

Funding No.

Conflict of Interest No conflict of interest.

References

Aragaw TA, Wondimnew A, Asmare AM (2016) Quantification, characterization and recycling potential of solid waste: case study Bahir Dar institute of technology. Int J Sci Res 5:2415–2420. https://doi.org/10.21275/v5i6.NOV164799

Alakshendra A (2019) City profile: Patna, India. Environ Urban Asia 10(2):374–392

Burnley SJ, Ellis JC, Flowerdew R, Poll AJ, Prosser H (2007) Assessing the composition of municipal solid waste in wales. Resour Conserv Recycl 49:264–283

Chen CC (2010) Spatial inequality in municipal solid waste disposal across regions in developing countries. Int J Environ Sci Tech 7(3):447–456

Coban A, Ertis IF, Cavdaroglu NA (2018) Municipal solid waste management via multi-criteria decision making methods: A case study in Istanbul, Turkey. J Cleaner Prod 180:159–167

Desmond M (2009) Identification and development of waste management alternatives for strategic environmental assessment (SEA). Environ Impact Assess Rev 29(1):51–59

Gidarakos E, Havas G, Ntzamilis P (2006) Municipal solid waste composition determination supporting the integrated solid waste management system in the island of Crete. Waste Manage 26:668–679

Gizachew K, Suryabhagavan KV, Mekuria A, Hameed S (2012) GIS-based solid waste landfill site selection in Addis Ababa, Ethiopia. Int J Ecol Environ Sci 38:59−72

Jana M, Sar N (2016) Modeling of hotspot detection using cluster outlier analysis and Getis-Ord Gi* statistic of educational development in upper-primary level, India. Model Earth Syst Environ 2:60. https://doi.org/10.1007/s40808-016-0122-x

Kumar S, Bhattacharyya JK, Vaidya AN, Chakrabarti T, Devotta S, Akolkar AB (2009) Assessment of the status of municipal solid waste management in metro cities, state capitals, class I cities, and class II towns in India: an insight. Waste Manag 29(2):883–95

Le Dorlot E (2004) Les déchets ménagers: pour une recherche interdisciplinaire. Strates 11:1–10. misenligne

Mahmood S, Sharif F, Rahman AU, Khan AU (2018) Analysis and forecasting of municipal solid waste in Nankana City using geo-spatial techniques. Environ Monit Assess 190(5):275. https://doi.org/10.1007/s10661-018-6631-5. PMID: 29644486

Mazzanti M, Zoboli R (2008) Waste generation, waste disposal and policy effectiveness Evidence on decoupling from the European Union. Resour Conserv Recycl 52:1221–1234

Mengozzi A (2009) Waste growth challenges local democracy. The politics of Waste between Europe and the mediterranean: a focus on Italy. Calif Ital Stud J 1(1):1–21

Mihai F (2012) Geography of waste as a new approach in waste management study. In: Papers of the geographic seminar "Dimitrie Cantemir", vol 33, pp 39–46

Mitchell A (2005) The ESRI guide to GIS analysis, 2nd edn. ESRI Press, Redlands

Monika KJ (2010) E-waste management: as a challenge to public health in India. Indian J Commun Med 35(3):382–385. https://doi.org/10.4103/0970-0218.69251

Ngoc UN, Schnitzer H (2009) Sustainable solutions for solid waste management in Southeast Asian countries. Waste Manag 29(6):1982–95. https://doi.org/10.1016/j.wasman.2008.08.031

Noufal M, Yuanyuan L, Maalla Z, Adipah S (2020) Determinants of household solid waste generation and composition in Homs City, Syria. J Environ Public Health, 7460356. https://doi.org/10.1155/2020/7460356

Pandey MK (2014) Solid waste management in Patna. National Solid Waste Association of India

Passarini F, Vassura I, Monti F, Morselli L, Villani B (2011) Indicators of waste management efficiency related to different territorial conditions. Waste Manage 31:785–792

Rana PR, Yadav D, Ayub S, Siddiqui AA (2014) Status and challenges in solid waste management: a case study of Aligarh city. J Civ Eng Environ Technol 1:19–24

Sokka L, Antikainen R, Kauppi PE (2007) Municipal solid waste production and composition in Finland—Changes in the period 1960–2002 and prospects until 2020, Resources, Conservation and Recycling 50:475–488

Sridevi P, Modi M, Lakshmi MVVC, Kesavarao L (2012A) Review on integrated solid waste management. Int J Eng Sci Adv Technol 2:1491–1499
Sumathi VR, Natesan U, Sarkar C (2008) GIS-based approach for optimized siting of municipal solid waste landfill. Waste Manag 28(11):2146–2160
Swarup S, Verma U, Kumar R (2020) Implementation of new technologies in solid waste management of Patna: an appraisal of Patna municipal corporation. Poll Res 39(4):1122–1130
Zurbruegg C (2003) Solid waste management in developing countries: A sourcebook for policy makers and practitioners: EAWAG/SANDEC

Chapter 25
Analytical Study of Biomedical Waste Management Scenario in Kolkata City: Sustainability Challenges

Sushma Sahai

Abstract Biomedical wastes (BMW) are considered as potentially hazardous. Due to the rapidly changing scenario in health care and dynamic disease profile, the urgency is felt to evolve and implement waste management strategies for safe, sustainable and cost-effective methods of BMW disposal. Though the pandemic has highlighted challenges of infectious waste management, scientific and universal BMW strategies are yet to take a structured form. This study attempts to investigate the trajectory of BMW from the source of generation to final treatment and disposal. Adopting the methodology of stratified sampling a comparative analysis of eight government hospitals in Kolkata, this research seeks to highlight the adverse impact of the irrational treatment and disposal of BMW on environment and social health. Waste audits conducted at the ward level facilitated documentation of different categories of wastes identified the source and quantum of each category. This quantitative evidence highlighted lack of compliance of the BMW Management Rules, 2016, and revealed lacunae throughout the waste chain. Occupational hazards of the stakeholders particularly of the rag pickers and the nexus of unauthorised commercialisation of urban BMW pose sustainability challenges. The need of the hour is to find solutions which would bridge the gap between clinical sciences and social sciences. Advocacy for sustainable BMW management would formulate strategies which would adhere to a resilient hospital ecosystem and maintain the delicate balance of environmental health and social justice, rather than merely emphasise on end-of-pipe technology solutions.

Keywords Biomedical waste · Waste audit · Environmental health · Social justice · Occupational hazard · Commercialisation

S. Sahai (✉)
Department of Geography, Loreto College (University of Calcutta), Kolkata 700071, West Bengal, India
e-mail: sushmasahai@gmail.com

U. Chatterjee et al. (eds.), *Urban Commons, Future Smart Cities and Sustainability*, Springer Geography, https://doi.org/10.1007/978-3-031-24767-5_25

Introduction

Researching on public health has emerged as one of the disciplines which has been in the spotlight ever since the outbreak of the COVID-19 pandemic. The last couple of years has witnessed an unprecedented volume of published literature focusing on health and disease. As urban population witnesses an alarming growth and exerts pressure on an already overburdened city ecosystem, there is a need to recognise the threats faced by the health sector. A virus several trillion times smaller than a pin head cut across political boundaries and infected nations across the globe. The pandemic brought to the forefront glaring inequalities and lacunae in the health sector. This was the second major jolt the country woke up to after the outbreak of plague in Surat in 1994. The already strained urban municipal faced the looming challenge of the disposal of the gargantuan proportions of Biomedical Waste (BMW). This includes infectious and non-infectious waste. A total of 15–20% healthcare waste is infectious, while 80–85% is non-infectious (Chartier 2014). The absence of proper waste management, lack of awareness about the health hazards from biomedical wastes, insufficient financial and human resources, and poor control of waste disposal are the most critical problems connected with healthcare waste (Plianbangchang 2005). There is a strong probability that blood-transmitted diseases such as AIDS, hepatitis B, hepatitis C and tuberculosis could be transferred to sanitary staff through poor handling of the hospital waste (Almuneef and Memish 2003).

Rationale of the Study

Biomedical waste is defined as any waste, which is generated during the diagnosis, treatment or immunisation of human beings or animals, or in research activities pertaining thereto, or in the production or testing of biologicals (Government of India 1998). Alarming percentage of the BMW lies strewn within the hospital premises. Within the gamut of solid waste management, the management of hazardous BMW has been a neglected field and the lack of estimates of this contaminated waste has been the greatest challenge to adhere to Biomedical Waste Management (BMWM).

The geo-medical approach, which gives emphasis on the environmental and ecological system, was not in vogue till the last couple of decades. This approach provides the base for the development of geographical pathology or more popularly called ‘Geomedicine’ or ‘Geography of Health’. This discipline provides a scientific basis for the understanding of the wholeness of life, which needs ‘medical care and insight wedded to a knowledge of environmental circumstances that make for health’ (Macnamara 1980). Most of the medical scientists first seek the vectors of health imbalances in ‘pathogens’, but human ecologists are first concerned with the etiology of disease within the environmental perspective, called as ‘geogens’. Accordingly, to Jacques May, the founder of the American School of Medical Geography, geogens is responsible for the pathogenesis of disease (Dutt 1973). Keeping this in mind, an attempt has been made to study disease ecology related to BMW. This exercise involved the examination of physical and socio-economic factors that influence the BMWM process, the aspects that are mostly neglected by medical scientists.

Materials and Methods

Study Area

Kolkata, the third-most populous metropolitan area in India, is home to more than 14.1 million people (Census of India 2021). This region has 401 private hospitals and nursing homes and 43 government hospitals (Government of West Bengal 2018).

Criteria for selecting Samples

- The technique of Stratified Sampling was used to categorise the hospitals into stratas depending on their bed strength, and two government hospitals each from four categories of hospitals, classified on basis of bed strength, were selected (Fig. 25.1).
- The selected hospitals were in wards of Kolkata Municipal Corporation (KMC) which boast a substantial population density and are primarily in residential areas (Fig. 25.2).
- The selected hospitals are General Hospitals, which unlike Special Hospitals generate different categories of BMW.

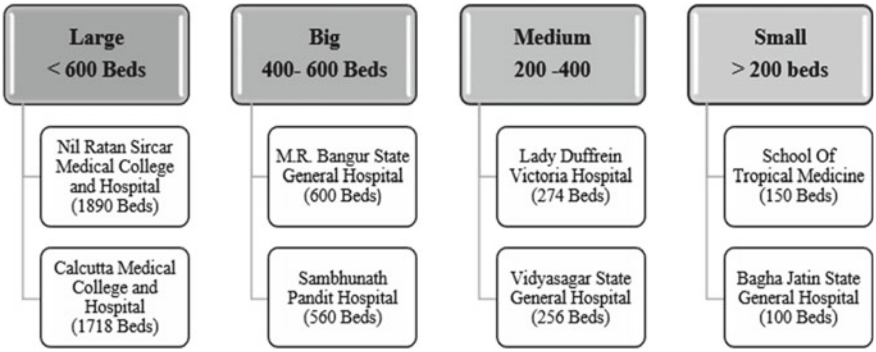


Fig. 25.1 Case study hospitals

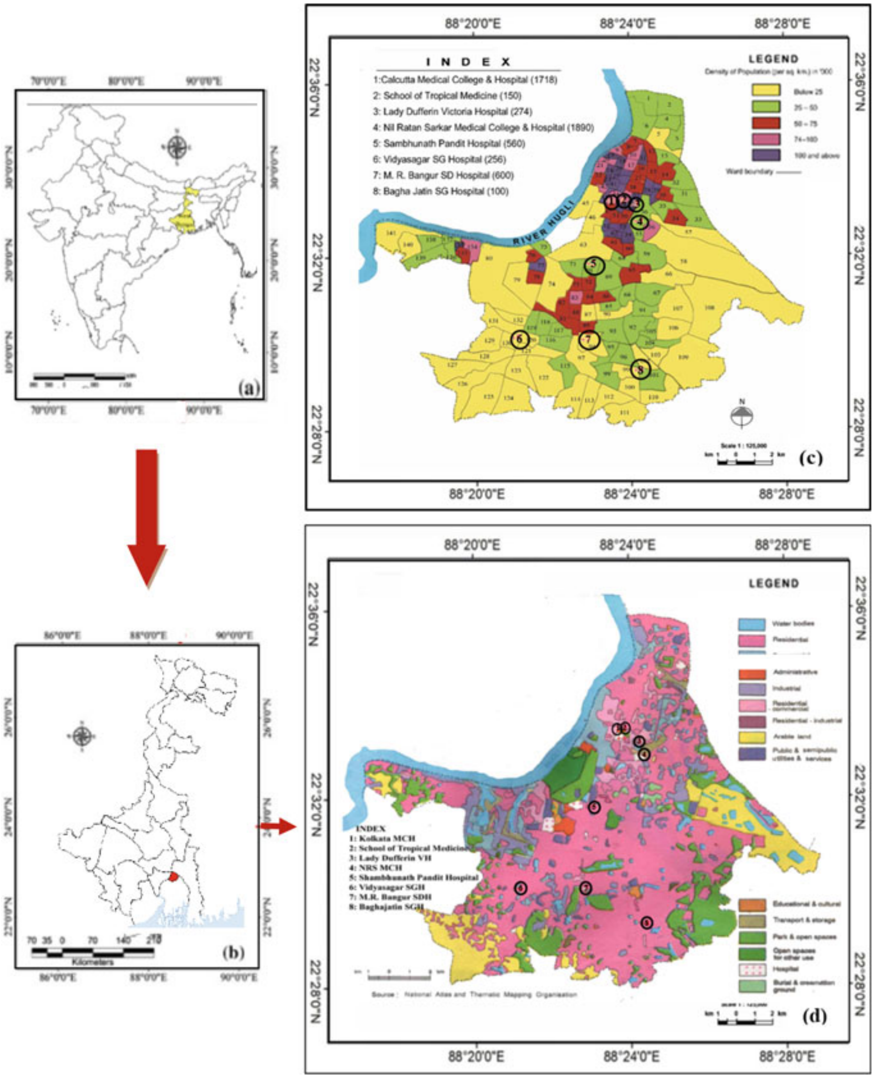


Fig. 25.2 Location of study area **a** India, **b** West Bengal, **c** Kolkata Municipal Corporation wards showing selected hospitals and population density, **d** Land use map

Methodology

The foundation of this study was an intensive literature review, which provided an overview of the BMWM scenario and associated fields of research. This enabled identifying the dearth and possible gaps in published literature. The research design was formulated, which aimed at clearly defined, relevant and time-bound analysis.

Institution-based cross-sectional study was conducted to quantify BMW. Empirical research involving a blend of interviews, participatory appraisal and comprehensive waste audit was carried out adhering to the principles of confidentiality and authenticity between 2017 and 2019. Simple random sampling technique was used for the selection of the stakeholders**.** Two hundred structured and semi-structured interviews were conducted with hospital authorities, ragpickers and sanitation workers to trace the status of BMW within and outside the hospital premises**.** This method is good for dealing with dispersed populations, like ragpickers and scavengers wherein the sample depended on the area of their operation and the accessibility of the surveyor to these locations. Non-statistical considerations were taken while selecting samples. It also involved comparisons and attempts to discover the cause-and-effect relationship.

Medical Waste Audit

As per International Chamber of Commerce (ICC), audit is defined as *'a management tool comprising a systematic, documented, periodic and objective evaluation of how well environmental organization, management and equipment are performing with the aim of contributing to safeguard the environment by facilitating management control of environmental practices, assessing compliance with company policies and regulatory requirements'*. (Prasad 2000). This is not restricted only to industries but holds true in the case of hospitals as well. Such an analysis would enable hospitals to identify options for waste minimisation and reduce the potential liabilities on the environment.

Environmental Compliance Audit Program

The purpose of the program is to:

- ensure compliance with all applicable legislation, policies and best management practices;
- minimise environmental impact;
- establish due diligence. (Maclean 1996).

A well-executed medical waste audit would:

- identify sources, waste category and quantities generated;
- highlight areas with inefficiencies and weak management;
- highlight areas for waste reduction;
- initiate development of cost-effective waste management strategies;
- generate awareness among the workforce regarding the threats posed by BMW;
- help to improve process efficiency.

Methodology for Medical Waste Audit

Undertaking a waste audit involves observing, measuring, recording data, collecting and analysing waste samples. To address the complex task of estimating the quantity of BMW generated, a Medical Waste Audit was conducted in each of the selected hospitals.

The first phase of Pre-assessment involved a detailed on-site survey of each of the wards of the selected hospitals. The quantitative component of the survey was implemented with measurement of different coloured bags stored in each ward with a calibrated spring balance capacity range from 100 g to 50 kg.

The second phase involved the creation of an inventory of inputs and outputs of the BMWM system which aided in deriving a material balance. Computation of a material balance was a challenge for the following reasons. Firstly, the output will never equal the input, for example, Infectious Anatomical and Pathological waste like amputated body parts, foetuses and body tissues form an important part of the output generated but can never be quantified when calculating the inputs. Secondly, even if the inputs like sharps are tabulated, the output cannot be ascertained accurately due to siphoning and illegal pilferage. Hence, in the former case the output would be greater than the input, while in the latter, it would be vice versa.

The third phase of synthesis highlighted a comprehensive scenario. It not only acted as a guide for both short and long-term activities involved in the phases of waste management but also aided in regular monitoring. It offered checks and balances at every stage of BMWM. The implementation of the Waste Audit aided not only in the documentation of the quantum of different categories of BMW generated but provided answers for the discrepancies witnessed. A structured overview of the BMWM process from generation to disposal not only qualitatively but also quantitatively formed the backbone of this study.

Results and Discussion

This section is organised under three themes, viz. phases of BMWM, epidemiological impact and recycling of BMW. The phases include storage, transportation, treatment and disposal.

Phases of Biomedical Waste Management

Storage

The first and integral stage of BMW is the storage of the waste at the point of its generation. The heterogeneity of BMW calls for the planning and implementation of appropriate storage facilities.

Fig. 25.3 Waste bags without biohazard symbol along stairway, N.R.S Medical College and Hospital

Plastic Bags

Plastic bags were used for storing BMW. These bags were not puncture—proof, leak—resistant and did not indicate the biohazard symbol. They were ordinary polythene bags used for grocery and did not fulfil the criteria of thickness and durability (Fig. 25.3). The lack of awareness and sincerity of the nurses and housekeeping staff was evident in all the hospitals. Regular visits to the wards showed that though coloured waste bags inside bins were placed at appropriate locations, the healthcare workers were ignorant of the colour codes specified in the BMW Management Rules and dumped a specific category of waste, in a colour bag not designated for that category of BMW. For instance, sharps were dumped into yellow bags, which were meant for infectious anatomical wastes (amputated body parts, placenta, etc.). The first stage of the cumbersome process of waste management was crucial, as this emphasised on segregation as per the BMW Management Rules, 2016 (Government of India 2016). Disregarding segregation and mixing different categories of BMW would have severe ripple effects. This malpractice was the greatest drawback of the management process and defeated the objective of documenting the quantum of each category of BMW generated from specific wards. The waste bags were more than one-third full and not tied up which resulted in spilling of the contents throughout transit and were breeding grounds for pathogens.

Fig. 25.4 Open tub with non-segregated BMW–Sambhu Nath Pandit Hospital

Fig. 25.5 Inconsistent colour coding–Bagha Jatin State General Hospital

Containers

Containers used for the collection of BMW should conform a similar colour coding as the waste bags. In Sambhunath Pandit Hospital, a ward with a capacity of 32 patients had 12 open plastic tubs. Further accentuating the problem of storage of BMW, these tubs without lids, which were the recipient of all types of wastes ranging from vomitus, faeces, plastic tubes to pus and blood-soaked dressings, were found to have perforations caused by the sharps collected in them (Fig. 25.4). A common feature in all the hospitals was the inconsistency in the colour of the waste bag placed within the bin. This was contradictory as blue bins indicated the disposal of sharps and the black bags indicated general waste (Fig. 25.5). Malpractice of this nature was a hindrance for efficient waste management, as it provided an erroneous figure of the quantity of the specific BMW.

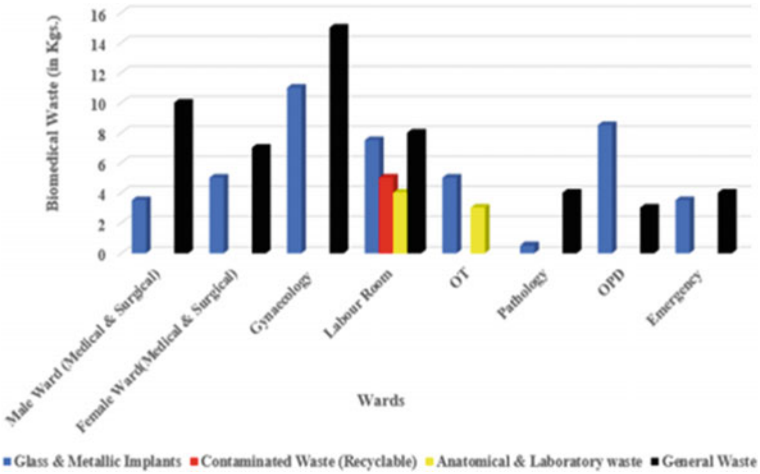


Fig. 25.6 Ward wise average quantum of biomedical waste generated per day—Bagha Jatin State General Hospital

Waste Audit in the Wards

The various categories of BMW generated in each of the wards of all the eight hospitals were weighed over a period of three days consecutively on January 11–13 and July 6–8, 2019. The findings and associated remarks of each hospital have been dealt with individually in the following section.

During the survey, it was observed that though the biomedical waste-coloured bags were weighed, the black bags containing general waste were ignored and dumped in the vat. Contrary to the prescribed guidelines of Government of West Bengal, both the general non-infectious waste and the highly contaminated BMW were thrown in the same vat in Bagha Jatin SG Hospital, Sambhunath Pandit Hospital and Lady Dufferin Victoria Hospital. This practice defeated and negated the effort taken to segregate not only the different categories of BMW but also general waste.

Findings

- Only 3.42% (4 kg) of infectious syringes, catheters, tubing and gloves of the Red category of BMW were generated on an average per day. The Labour Room was the sole ward, which disposed needles, sutures, etc.
- Infectious Anatomical wastes were generated in only two of the eight wards, i.e. Labour room and Operation Theatre (OT). This comprised 6.84% of the waste stream.
- Glass and Metallic Implants were disposed in all the wards, with the Gynaecology and Outpatient Department (OPD) generating a maximum of 10 kg each. On the other hand, pathology generated the least, i.e. 0.5 kg. This category of waste constituted the largest share of waste, amounting to 38.89% (Fig. 25.6).

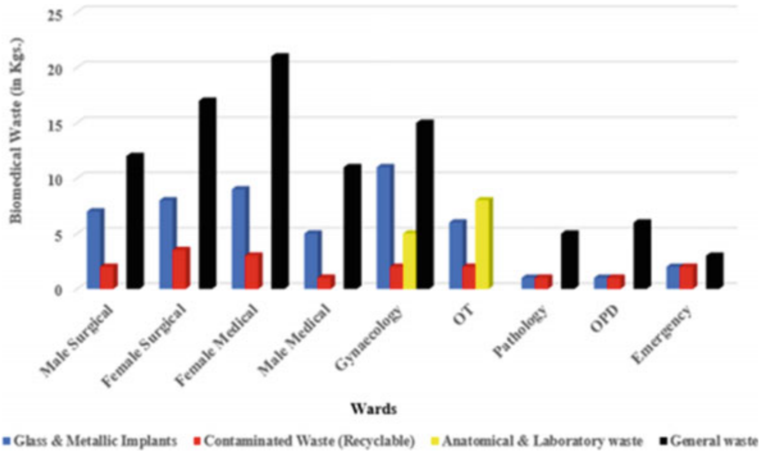


Fig. 25.7 Ward wise average quantum of biomedical waste generated per day—School of Topical Medicine

Remarks

- Sharps, which includes needles, glass, etc., is an indispensable device and was used by the doctors and nurses of each ward. As per the Government of India notification, each ward of a hospital had to be equipped with at least one needle cutter/destroyer. Once they were mutilated, they were kept in 1% bleaching solution. Callousness on part of the nursing staff and the sweepers resulted in dumping of this waste in either the yellow or blue waste bag, defying the prescribed guidelines.

Findings

- All the wards disposed moderate proportions of syringes (without needles and fixed needle syringes). It constituted 10.26% of the total quantum of waste. The Male and Female Surgical wards generated a maximum of 2 and 3.5 kg. of infectious sharps, respectively.
- The quantity of Infectious anatomical waste constituting 7.62% was the least. The OT disposed 8 kg while the Gynaecology ward generated 5 kg.
- Glass and Metallic Implants topped the list constituting 29.33% of the total waste generated. The maximum of 11 kg, i.e. 22% of this category, was churned out by the Gynaecology ward, followed closely by Female Medical and Surgical wards that disposed 9 kg and 8 kg, respectively (Fig. 25.7).

Remarks

- Though infectious syringes and gloves were disposed from all the wards, the quantity of the output registered was very small. This could be attributed to the lack of training and callousness on the part of the waste handlers who dumped

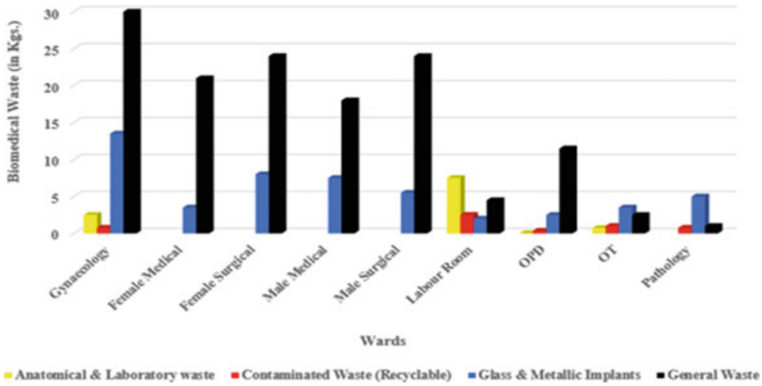


Fig. 25.8 Ward wise average quantum of biomedical waste generated per day—Vidyasagar State General Hospital

sharps into yellow and black bags which were designated for anatomical and general waste, respectively.

Findings

- Syringes (without needles and fixed needle syringes) formed a paltry proportion of the total waste generated, i.e. 2.46%. The maximum output of 3 kg. was registered from the Labour room, whereas the same from the OT, Pathology and OPD ranged between 0.5 and 1 kg.
- Anatomical and laboratory waste constituted only 5.69% of the total waste stream. A maximum of 8.5 kg. was discarded by the Labour room, which primarily comprised of placenta, body tissue and foetuses. The OT and OPD disposed a meagre 540 g and 30 g, respectively.
- Broken or discarded glass, medicine vials and ampoules (Blue category) constituted the largest share, amounting to 23.98%. The Gynaecology ward registered the maximum output of 15.5 kg., followed by Male Medical, Surgical and Pathology which generated 5 kg. of the same, respectively (Fig. 25.8).

Remarks

- It was difficult to comprehend that a 256-bedded hospital disposed only 2.46% of syringes and gloves. Regular visits to the hospital showed widespread use of this category in all the wards. The sharps after on-site treatment in 1% bleaching solution were not disposed every day but were stored in a puncture-proof cardboard box.

Findings

- The red category comprising syringes, intravenous tubes and sets, and catheters constituted the least amount, i.e. 6.24% of the total waste stream. The Labour

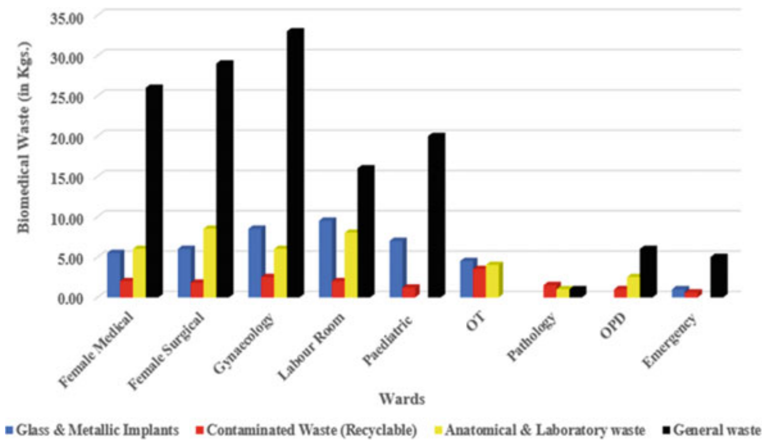


Fig. 25.9 Ward wise average quantum of biomedical waste generated per day—Lady Dufferin Victoria Hospital

room and Gynaecological ward registered an output of 2 kg each. On the other hand, it was surprising to note that only 1 kg of the same was generated in the Female Surgical, Pathology and OPD—all areas consuming large quantities of syringes, needles and gloves.

- Medicine vials and ampoules were disposed in all the wards except Pathology and OPD. This category made up 18.62%, thus representing the largest component of the entire BMW generated. The Labour Room churned out a maximum of 9.5 kg, followed by Gynaecology ward that registered an output of 8 kg.
- The second largest share of 16.53% was of the Anatomical Wastes. A maximum of 8.5 kg was disposed by the Female Surgical ward, and this was followed closely by the Gynaecological ward generating 8 kg of the same (Fig. 25.9).

Remarks

- Though Infectious sharps were disposed from all the wards, the quantity of the output registered was very small. This could be attributed to the lack of training and callousness on the part of the waste handlers who dumped sharps into yellow and black bags which were meant for anatomical waste and general waste, respectively.

Findings

- Syringes and gloves comprised major proportion of the Red category, 4.79% of the total waste. The Gynaecology ward generated a maximum of 6 kg but three of the wards, viz. Male Surgical, Female Medical and Emergency disposed a meagre 0.1 kg. Surprisingly, OT which has sharps and gloves as the major input registered no output.
- Glass and Metallic Implants were generated in all the wards, with the Gynaecology ward disposed a maximum of 4 kg followed by the Female Medical ward, which generated 3 kg. This category constituted 9.93% of the total quantum of waste.

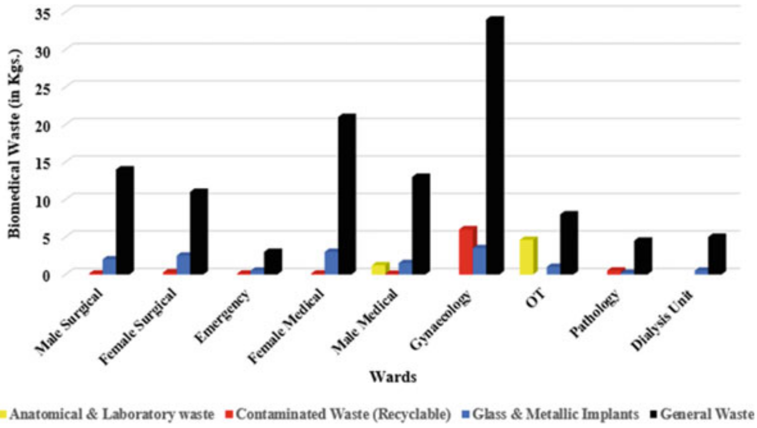


Fig. 25.10 Ward wise average quantum of biomedical waste generated per day—Sambhu Nath Pandit Hospital

- Anatomical and laboratory waste constituted 2.90% of the total waste generated, which was low in comparison with the smaller hospitals like Bagha Jatin Hospital and School of Tropical Medicine. This waste was, surprisingly, generated in only two wards, viz. Male Medical and OT disposing 0.3 and 4 kg, respectively (Fig. 25.10).

Remarks

- The OT and Dialysis units did not generate a single kg of Syringes (without needles and fixed needle syringes), intravenous tubes and sets though the medical procedures involved the widespread use of the same. This could be attributed to the lack of training and callousness of the waste handlers who were seen dumping used sharps like syringes and sutures in yellow waste bags meant for anatomical wastes.

Findings

- The share of Contaminated Waste (Red) was the least, i.e. 6.48%. The Gynaecology ward and Male Surgical wards registered maximum output of 2.5 kg each. A paltry amount of 0.50 kg was disposed each from the OPD, OT and Paediatric ward.
- Glass and Metallic Implants constituted the largest share of BMW amounting to 25.18%. The Female Surgical ward disposed 11.5 kg. The Biochemistry ward and Blood bank were on the other end of the spectrum generating 0.75 and 1.5 kg of the same.
- Only 7.61% of the total BMW comprised Anatomical waste. The Maternity ward registered an output of 8 kg, whereas the Labour Room and the OT disposed 4.5 kg each (Fig. 25.11).

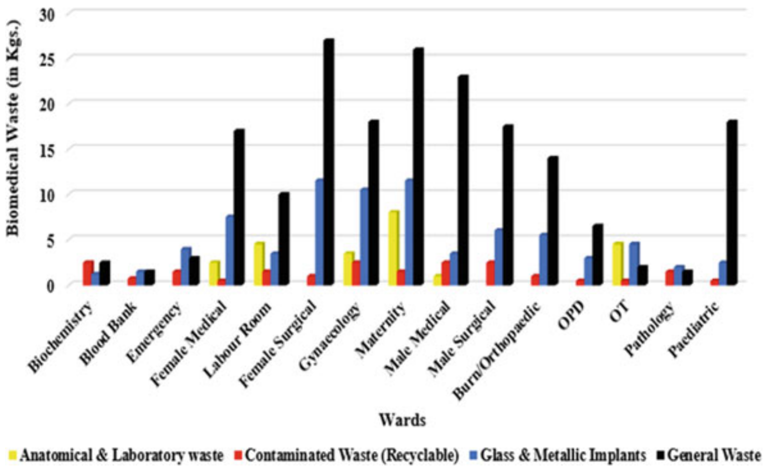


Fig. 25.11 Ward wise average quantum of biomedical waste generated per day—M. R. Bangur State District Hospital

Remarks

- For a 600-bedded hospital, a meagre 7.61% of syringes, catheters and gloves as part of Contaminated waste was difficult to comprehend. Two reasons were identified as an outcome of the shadowing exercise, firstly, the callousness of the waste handlers with respect to segregation and, secondly, the regular siphoning as well as subsequent illegal recycling by the ragpickers based in the adjoining slums.
- Since the Yellow bags were not always full to the optimum, the sweepers ignorantly dumped its contents into red and black bags, thereby defeating the very purpose of segregation. This reflected not only their level of awareness but also lack of training with respect to handling hazardous waste.

Findings

- Contaminated waste dominated by sharps constitute 6.65% of the total waste generated with a maximum of 4 kg, being disposed by the Gynaecology and OT each. On the other hand, 1 kg of sharps was disposed of by Labour rooms and Neonatal Wards each.
- Glass and Metallic Implants constituted the largest share, i.e. 21.38%, with the Female Medical Wards generating a maximum of 13 kg, followed by OT with 9 kg. They were followed by Female and Male Surgical Wards disposing and 7.5 kg and 6 kg, respectively. On the lower end of the spectrum were the Pathology and Radiotherapy wards that generated 2 kg each and Plastic Surgery 1 kg.
- A maximum of 7 kg of Anatomical and Laboratory waste was generated from the Gynaecology and OT each, with Female Surgical ward following close behind which disposed 6.5 kg. The total share of this category was 12.83% (Fig. 25.12).

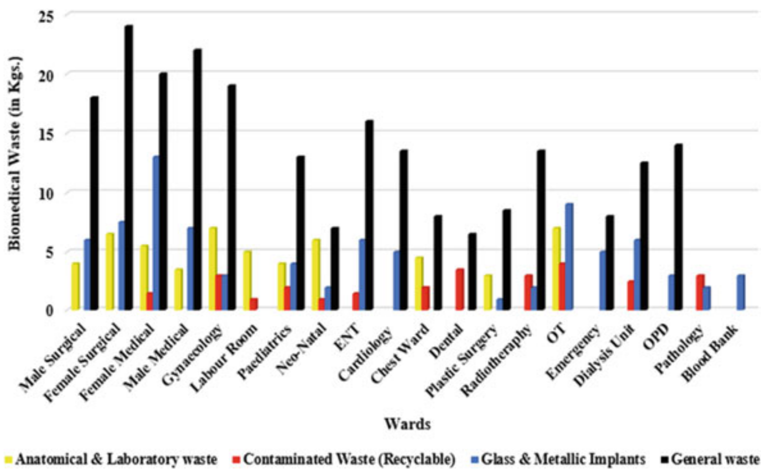


Fig. 25.12 Ward wise average quantum of biomedical waste generated per day—Calcutta Medical College and Hospital

Remarks

- It was surprising to note that both Male and Female Surgical wards, Male Medical, OPD and Emergency wards did not register any quantity of Contaminated waste (recyclable). This was attributed to siphoning and illegal recycling of used syringes.

Findings

- It was interesting to note that not a single kg of Glass and Metallic Implants (Blue category) was generated in any of the wards. This was difficult to comprehend as large quantities of the same were seen, especially in the Gynaecology, Female Medical and Paediatrics.
- Syringe (without needles and fixed needle syringes) part of Contaminated Waste constituted 13.89% of the total waste was generated maximum from the OT and minimum from Labour room amounting to 14 kg and 1 kg, respectively. This category also included disposable items such as intravenous tubes and catheters.
- Anatomical waste comprised 18.11% of the total waste stream. Visits to the Labour room showed that, though large quantities of this waste category were generated, not even one yellow waste bag was transported to the vat within the hospital (Fig. 25.13).

Remarks

- The biggest hospital of the city (1890 beds) did not generate Glass and Metallic Implants. The survey revealed that the main reason was, firstly, the lack of availability of blue bags and secondly, the callousness on the part of the hospital authorities to implement segregation.

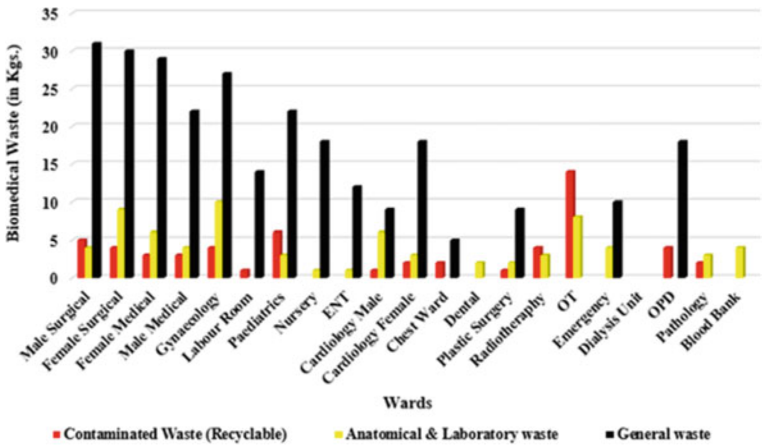


Fig. 25.13 Ward wise average quantum of biomedical waste generated per day—Nil Ratan Sircar Medical College and Hospital

- The Infectious anatomical waste generated in the Labour room was dumped into the black bags meant for general waste. This was due to the lack of sincerity, training and callousness of the nurses and sweepers.
- Though sharps (Contaminated wastes) were generated in most of the wards, it seemed far below the actual quantum used. E.g. the Labour room where approximately 6–8 deliveries were carried out on an average each day, disposed a meagre 1 kg of sharps. Two reasons were identified for this loophole, firstly siphoning and illegal recycling of sharps and secondly the lack of proper segregation whereby the sharps were disposed in black bags.

Quantum of Biomedical Waste Per Bed Per day

The consolidated results of the waste audit conducted, revealed that five out of the eight hospitals under study, generated an average of 250–500 g of BMW per bed per day. The smaller hospitals, viz. Bagha Jatin State General Hospital (SGH) and School of Tropical Medicine, generated 575 and 537 g of BMW/bed/day, respectively. The medium-sized Vidyasagar State General Hospital (SGH) and Lady Dufferin Victoria Hospital registered a daily output of 277g and 343 g of BMW/bed/day, respectively (Table 25.1). Ironically, on the other end of the spectrum, the bigger hospitals N.R.S. Medical College and Hospital and Sambhunath Pandit Hospital registered a meagre output of 68 g and 47 g of BMW/bed/day, respectively. These figures were lower than the anticipated quantities and hence raised several pertinent questions. Sudden and regular visits to N.R.S. Medical College and Hospital revealed that significant quantities of BMW were dumped into black bags or were carelessly thrown into the chute. A close examination of the exit of the chute revealed piles of unsorted BMW. Since this area was not enclosed and easily accessible, they attracted not only animals

Table 25.1 Consolidated results of Waste Audit

Hospital	Contaminated waste (recyclable) (%)	Glass and metallic implants (%)	Anatomical and laboratory waste (%)	Total BMW (%)	General waste (%)	Total waste (kg/bed/day)	BMW (kg/bed/day)
Bagha Jatin SG Hospital	3.42	38.89	6.84	49.15	50.85	1.175	0.575
School of Tropical Medicine	10.26	29.33	7.62	47.21	52.79	1.137	0.537
Vidyasagar SG Hospital	2.46	23.98	5.69	32.13	67.87	0.863	0.277
Lady Dufferin Victoria Hospital	6.24	18.62	16.53	41.39	58.61	0.828	0.343
Sambhunath Pandit Hospital	4.79	9.93	2.90	17.62	82.38	0.264	0.047
M. R. Bangur State District Hospital	6.48	25.18	7.61	39.27	60.73	0.515	0.202
Calcutta Medical College and Hospital	6.65	21.38	12.83	40.86	59.14	0.245	0.100
N.R.S Medical College and Hospital	13.89	0	18.11	32	68	0.213	0.068

but also scavengers, who recycled these hazardous wastes. Though Medical College and Hospital registered 100 g of output, it was plagued with problems like N.R.S. Medical College and Hospital.

Waste Collection Records

In order to institutionalise the BMWM system at the ward, a waste segregation register should be maintained to record the number and weight of bags being generated from the wards. Three out of eight hospitals, which maintained registers, were Vidyasagar SG Hospital, Calcutta Medical College and Hospital and N.R.S. Medical College and Hospital. The nurses documented the number of bags (colour wise) generated in the ward under their supervision. The register was then signed by the Ward Master. This task of keeping an inventory not only facilitated the smooth passage of BMW from the wards to the common storage site but also ensured transparency and accountability of the waste handlers. On a long-term basis, this would ensure a check on siphoning of waste bags, during internal transit as seen in M. R. Bangur Hospital, Calcutta Medical College and Hospital and N.R.S Medical College and Hospital for vested interests.

Findings of the Waste Audit in the earlier section are a testimony of the fact that segregation at source was not implemented efficiently, which resulted in mixing of different categories of waste and generated unreliable data on quantum of specific waste category. The registers revealed that though the numbers of waste bags disposed were entered the weights of the same were not documented. This was a drawback as a comprehensive statement of total BMW quantum generated could not be computed. Thus, a sustainable environmental audit conducted highlighted areas of inefficiencies and could offer measures to adopt strategies for rational BMWM.

Transportation

Transportation was carried out in two stages, viz. Primary and Secondary methods. Primary transportation includes the transportation of the infectious waste from each of the wards to the temporary storage area within the hospital premises. On the other hand, secondary transportation comprises the final transportation of the waste from individual hospitals to the ultimate treatment and disposal site.

Primary Transportation

The collection of BMW from the wards was done with the help of trolleys and wheelbarrows. This is contrary to the guidelines set up by the Ministry of Health and Family Planning, Government of West Bengal, which emphasises that BMW should be transported in dedicated trolleys. Moving a step forward towards segregation, it states that the General Waste should be transported in black coloured trolleys and

BMW should be transported in red coloured trolleys, marked with the Biohazard symbol (Government of West Bengal 2003). It should be further kept in mind that the trolleys should have the following features:

(1) easy to load and unload;
(2) easy to clean and disinfect;
(3) no sharp edges for preventing damage/tearing of waste bags.

While estimating the number of trolleys that would be required for segregated internal transportation, the following features should be taken into consideration:

(1) layout of the hospital building;
(2) ease of operating the trolleys;
(3) time required for internal transportation;
(4) expected number of bags to be generated daily (Government of West Bengal 2003).

Keeping all these guidelines in mind, the transportation network and its efficiency were observed and documented.

All the hospitals, except Lady Dufferin Victoria Hospital, used trolleys. These trolleys were not dedicated trolleys as per the norm but were ordinary trolleys with no compartments. Vidyasagar State General Hospital was the only exception, which employed dedicated trolleys where the compartments had a lid. This facilitated collection and storage of different categories during transit. Complying with the prescribed guidelines, each of the trolleys bore the biohazard symbol, which eased the process of identification of infectious waste from the general Waste. In the case of all the other six hospitals, the trolleys neither had compartments nor lids. This kind of irrational transportation had the following disadvantages:

- BMW and General Waste were transported in the same trolley, which increased the quantity of infectious waste, as the general waste was in close contact with the BMW.
- Due to non-compliance of the trolleys and majority of the bags not fastened, infectious waste spilled not only into the trolley but also along the corridors and campus of the hospital.
- The poorly designed and ill-maintained trolleys acted as breeding grounds for pathogens.

Secondary Transportation

It is important to trace the route of secondary transport of BMW, as it is during transit that the potential of disease transmission is the maximum. In order to provide a structured overview of the shortest possible route taken by the agency entrusted with the treatment and disposal of infectious BMW from each of the selected hospitals, the approximate distance covered from each hospital under study to the treatment facility has been computed (Table 25.2).

Table 25.2 Distance between selected hospitals and treatment facility

Zones	Hospitals	Distance from each hospital to treatment facility (km)	Average distance (km)
North	Calcutta Medical College and Hospital	14.25	
	N.R.S. Medical College and Hospital	16.38	15
	School of Tropical Medicine	14	
	Lady Dufferin Victoria Hospital	15.25	
Central	Sambhunath Pandit Hospital	20.5	
South	M. R. Bangur State District Hospital	23	25
	Vidyasagar State General Hospital	25.25	
	Bagha Jatin Hospital	26.88	

This reveals not only the high economic costs involved in secondary transport of BMW but also the large geographical distance covered for final disposal of the same, which could have adverse public health implications.

Treatment and Disposal

On-site Treatment

Treatment of Sharps

As per the Department of Health and Family Welfare, Government of West Bengal, needles and nozzles of used disposable syringes should be cut/destroyed with the help of needle cutters/destroyers and then disinfected by using disinfectants like 1% bleach solution (or sodium hypochlorite solution) for a sufficient contact time (at least 1 h) in a Sharps Decontamination Unit (SDU), consisting of a sieved bucket and blue bin. In addition to needles and other sharps like scalpels, blades, etc., should be treated similarly (Government of West Bengal 2003). The decontaminated sharps should be placed in a puncture-proof cardboard box, tied up securely and kept in a blue bag for final disposal. This standard set up by the government was followed partially by the hospitals under study.

All the eight hospitals were provided with needle cutters, but during regular visits to N.R.S, Medical College and Hospital, Sambhunath Pandit Hospital and Calcutta Medical College and Hospital it was seen that they were defunct. Observations revealed that the contaminated needles were not mutilated and thrown directly into the bleaching solution. These would in the long run pose grave public health hazard when picked by the ragpickers from the hospital vats. The decontaminated sharps were as per the rules, kept in cardboard boxes, but most often these were not sturdy and hence were always a great danger for the housekeeping staff and transporters.

Offsite Treatment

Sanitary Landfill

BMW after appropriate treatment can be disposed of in a secured landfill. It should have engineered facility for disposal of wastes designed and operated to minimise public health and environmental impacts. To minimise the adverse implications of large-scale open dumping, the Calcutta Municipal Corporation (CMC) on February 1, 1998, inaugurated its Rs. 20 lakhs medical waste plan. This is the first time that a civic body in the country has undertaken such an exercise, whereby a separate zone was demarcated to dump hazardous BMW. In order to relieve Dhapa from this insurmountable pressure, the state government set up a treatment plant at Howrah which started operation from April 01, 2004, and the environmental impact of several decades of indiscriminate dumping BMW at Dhapa can and will be felt by the community residing in its vicinity.

Occupational Safety Practices for Waste Handlers

Waste handlers comprising cleaners, sweepers, maintenance personnel, waste transporters and operators of BMW treatment equipment are the victims of irrational handling of highly infectious BMW. A comprehensive risk assessment of all activities involved in BMWM would facilitate the identification of suitable protection measures. These measures would prevent exposure to BMW or at least would keep the exposure within safe permissible limits.

Personal Protective Equipment (PPE)

PPE acts as a shield and ensures minimal contact with the contagious BMW. It includes gloves (heavy-duty rubber gloves), masks, gumboots and aprons, which have been categorically specified not only by the Ministry of Health and Family Planning, Government of West Bengal but also by the World Health Organisation. (Pruss et al. 1999). It would be the responsibility of the hospital authorities to ensure that the waste handlers use all the items listed under PPE, while handling hazardous BMW. While examining the waste management situation in each of the selected hospitals, these specifications were kept in mind. Seven out of the eight hospitals under the scanner did not abide by these standards in totality. The housekeeping staff of Bagha Jatin, N.R.S. Medical College & Hospital and School of Tropical

Medicine wore their uniforms and masks, but did not wear boots, which resulted in their exposure to thin and ruptured polythene waste bags, often dripping with blood and body fluids. High incidences of needle pricks were reported, which could be attributed to the ignorance of the waste handlers of the importance of PPE. Waste collectors at Sambhunath Pandit Hospital, N.R.S. Medical College & Hospital and Calcutta Medical College and Hospital did not wear the specified gloves and were vulnerable to infections. The health impact of this callousness and ignorance has been dealt in the following sections.

Emergency Response System

As per the WHO guidelines, a program of response should be established that prescribes action to be taken in the event of injury or exposure to hazardous substances. The program should include the following elements:

- immediate first aid measures, such as cleansing of wound and skin;
- an immediate report of the incident to a designated responsible person;
- retention, if possible, of the item involved in the incident;
- details of its source for identification of possible infection;
- medical surveillance;
- blood or other tests if indicated;
- recording of the incident;
- investigation of the incident, identification and implementation of remedial action to prevent similar incidents in the future (Pruss et al. 1999, p. 143).

This is the most neglected area and forms the weakest link of the entire management process. Instance of waste handlers being pricked by a needle jutting out from non-puncture-proof polythene was a regular feature. The presence of needles in waste bags questions the efficiency of not only the on-site treatment of sharps (needle cutters) but also the integral process of segregation. Similar callousness was seen on the part of waste transporters who were engaged in weighing waste bags collected from the wards and stored in the hospital vat. Contrary to the prescribed guidelines, they did not use the PPE and were exposed to ruptured polythene bags, as they exceeded their carrying capacity, overloaded with contagious BMW. Not only were the prescribed WHO guidelines violated, but there was violation of Labour Rights and Human Rights as well. The act of not keeping a track of the quantity of various categories of BMW, which hindered the auditing process and subsequently encouraged malpractices, can be attributed to one or all of the following reasons:

- the use of obsolete and defunct spring balance or weighing machine;
- overflowing and punctured waste bags which could not be hanged on the weighing machine for obtaining the actual weight;
- insincerity and callousness of the waste handlers, to weigh each of the bags individually.

Epidemiological Impact of Biomedical Waste

Risks for Healthcare Workers

The health hazards and risks involved with the handling of BMW were examined with reference to different segments of the societal structure.

Sharp Injuries

Healthcare workers are exposed to pathogens through contaminated needle sticks, sharps, or splash exposures. It is one of the greatest risks faced by the frontline healthcare worker. Every percutaneous needle stick and sharps injury carries a risk of infection, yet these exposures have often been considered 'part of the job'.

There is strong epidemiological evidence that the main concern of infectious BMW is the transmission of AIDS\HIV virus and more often, of Hepatitis B or C virus (HBV) through injuries caused by syringe needles contaminated by human blood. The groups at risk are healthcare workers, especially nurses, housekeeping staff and transporters. In places where scavenging or rag picking at disposal sites is common, people face a grave risk, but no data is available on incidences of injuries and infections in such situations. One case has been reported in the USA of a hospital housekeeper who developed staphylococcal bacteraemia and endocarditis after a needle injury (Pruss et al. 1999).

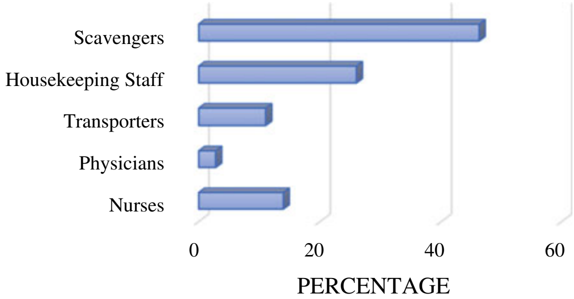
Unfortunately, there is paucity of data from developing countries. This is more in the case of uncontrolled liquid BMW discharges into the common sewage from most hospitals. One befitting example of this is the M. R. Bangur SD Hospital, Kolkata, where blood and body fluids from the Labour room were carried in buckets and dumped into the common drainage line. Budgets for personal protective equipment are inadequate. The housekeeping staff rarely wore masks, gloves and gumboots as they collected and transported reusable and disposables for decontamination, laundry and disposal bins. Thus, of immediate concern is the health threat of Class IV workers who are exposed to infectious BMW.

The workers at high risk of infection are transporters and those in charge of handling waste during treatment and disposal. They are involved in the daily collection, transportation and disposal of amputated body parts, blood-soaked dressings and syringes, without adequate PPE (Fig. 25.14). Despite separate collection, transportation and disposal of these infectious pathogens, all materials are infected after being mixed in soaring high temperatures and excessive humidity typical of Kolkata. On the basis of the questionnaire survey, it was found there was awareness of the fact that the handled waste is highly contaminated and potentially infectious. Many of the waste handlers complained of itching, rashes and lesions on their limbs as they seldom wore gloves and gumboots.

A total of 200 samples were interviewed across the selected hospitals and the findings revealed that the scavengers were the most affected by sharp injuries (46.23%)

Fig. 25.14 Dhapa landfill—Disposal of biomedical waste by worker without PPE

Fig. 25.15 Injuries from sharps sustained by health care workers



as they handled waste with naked hands, followed by 26% of housekeeping staff who did not pay heed to the importance of protective gear. Approximately 14% of the nurses who were in direct contact with sharps while drawing, injecting and handling specimens were at high risk followed by the transporters (Fig. 25.15). There is a concern among the medical staff about the risk of contracting infectious diseases in the hospitals. This concern is caused by the incidence of TB, HBV, HCV, HIV and meningitis in India. Except for guidelines covering radiological wastes, neither pre-service nor in-service training for physicians and matrons includes discrete modules on the management of infectious and other hazardous BMW.

Occupational Hazard

Every year, healthcare workers experience between 600,000 and 800,000 exposures to blood.

- Registered nurses working at the bedside sustain an overwhelming majority of these injuries.
- These exposures carry the risk of infection with HBV, HCV and HIV, the viruses that cause AIDS. Each of these viruses poses a different risk if a healthcare worker

is exposed. More than 20 other infections can be transmitted through needle sticks, including syphilis, malaria and herpes.
- At least 1000 healthcare workers are estimated to contract serious infections annually from needle stick and sharp injuries.

The victims are the nurses, housekeeping and maintenance personnel whose operational areas are characterised with large quantities of infectious hospital waste. The annual injury rates for these occupations vary from 10 to 20 per 1000 workers. Of all workers who come in contact with medical waste, sanitary services workers (e.g. refuse workers) report the highest rate of on-job injuries. Their overall injury rate of 180 per 1000 workers per year is more than double than that of the entire US work force combined (Occupational Safety and Health Administration 2001, p. 73). According to the National Institute of Occupational Safety and Health (NIOSH), the design of the device can increase the risk of injury. Specific features make certain devices like the following more dangerous:

- devices with hollow-bore needles;
- needle devices that need to be taken apart or manipulated by the healthcare worker-like blood-drawing devices that need to be detached after use;
- syringes that retain an exposed needle after use; needles that are attached to tubing-like butterflies—that can be difficult to place in sharps disposal containers (NIOSH 1999).

The highest risk of injury is from blood-filled hollow-bore needles. They accounted for 63% of the injuries from June 1995-July 1999. Ninety percent of the documented cases of healthcare workers who contracted HIV from needle stick injuries were handed hollow-bore and blood-filled needles (Bolyard et al. 1998). Percutaneous injuries were the most common and frequent among the healthcare workers, from needles and other sharps. As notified in the earlier section by the National Institute of Occupational Safety and Health (NIOSH), different categories have sharps that have varying degrees of harmful effect. The primary data revealed that 34% of the percutaneous injuries were caused by Hypodermic needles followed by glass (21%) and Winged-steel needle, which cause 14% of the injuries (Fig. 25.16). Though IV Stylets (8%), Suture (13%) and other sharps (8%) showed comparatively lesser incidence of injuries, their presence should not be neglected.

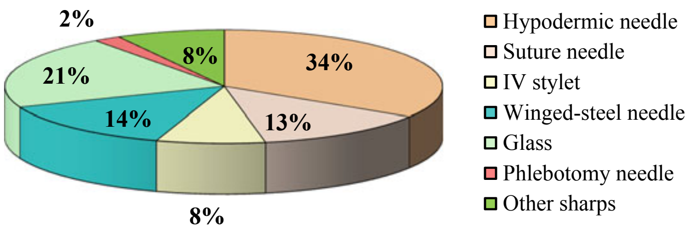


Fig. 25.16 Needles and medical equipment associated with percutaneous injuries

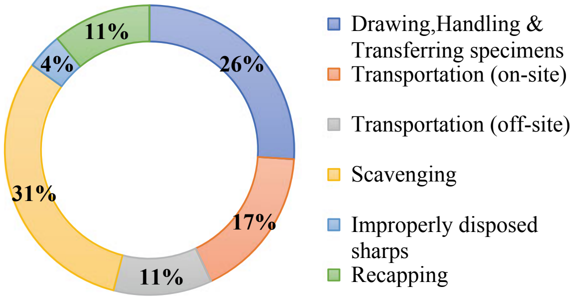


Fig. 25.17 Causes of percutaneous injuries from sharps

Nurses and housekeeping personnel were the vulnerable groups at risk of injuries. Highest rates of occupational injury among all workers who were exposed to BMW were reported by housekeeping staff and transporters. Though majority of work-related injuries among healthcare workers and refuse collectors were sprains caused by overexertion, a significant percentage reported cuts and punctures from discarded sharps. A number of causes of percutaneous injuries from sharps were identified. Physicians and nurses (26%) were injured while drawing, handling and transferring specimens. Since two-thirds of the BMW was scavenged and the ragpickers were ignorant of the adverse health hazards, this activity topped the list with 31% in terms of maximum sharp injuries (Fig. 25.17). On the other hand, it was found that as high as 11% injuries occurred during recapping clearly emphasising the dangers that lurk even in simple procedures.

Commercialisation and Recycling of Biomedical Waste

The Pricking Story

The modus operandi is simple. Some men in the guise of sweepers visit the wards and pick up syringes in connivance with the housekeeping staff. These are recycled and packed in clean jackets before being released again. They reappear in hospitals when doctors are forced to rely on medium-grade syringes at rush hours. During the survey, it was seen that sweepers of the Calcutta Medical College Hospital salvage almost 90 kgof BMW daily and sell them in local market. The sweepers store the mixed waste in the hospital backyard and sell them after segregating them item wise. Ragpickers on Central Avenue, outside the Calcutta Medical College and Hospital, were seen sorting the ampoules and syringes (Fig. 25.18). Each kilogram of blood bag fetches Rs. 6; disposable syringes are sold at Rs. 20 a kg. The unauthorised sale of infected waste is a source of additional income for the sweepers. The rate of syringes depends on their condition. Almost new looking syringes without scratches can be sold for as high as Rs. 50 a kg. On the other hand, second-grade syringes fetched Rs. 18 a kg (Table 25.3).

Fig. 25.18 Scavenger sorting pilfered items for resale—Calcutta Medical College and Hospital

Table 25.3 Commercialisation of biomedical waste

Salvageable items	Quantity	Selling rate (Rs.)	Total value (Rs.)
Blood bags	13.5 kg	6/kg	81.00
Saline bottles	426 pieces	2/piece	852.00
Surgical gloves	6.5 kg	2/kg	13.00
Syringes	2.5 kg	20/kg	50.00
Miscellaneous items[a]	67.50 kg	1/kg	67.50
Total	90 kg	–	1063.50

[a]Broken glass, rubber tubes, paper, etc.

Plastics and Glass

Plastics constitute a major chunk of BMW. The use of disposable plastics symbolises the initiative of the hospital to reduce infection and transmission of disease. There has been a major shift towards plastics within hospitals, be it syringes or blood and urine bags. In India, the market for medical disposables has grown from USD 2350 million (1979) to 4000 million (1986). The use of plastics is now growing at the rate of 6% per annum (Nazareth 2002). This growth is not reciprocated in terms of its treatment and disposal. There have been instances of resale and reuse of plastic items, which consequently leads to the spreading of nosocomial infection. The risks are transferred not only to the waste handlers but also patients and community at large. The extent of reuse of disposable syringes showed that at least two-thirds of patients were being administered with recycled syringes obtained from surgical waste bins. Plastic items in hospitals have a resale value which encourages rag pickers to first scavenge them and then sell them only to find their way back to the hospitals (Table 25.4). Scrap dealers who are in close association with N.R.S Medical College and Hospital and Calcutta Medical College and Hospital have huge stocks of plastic glucose bottles and glass bottles. Since these hospitals are not equipped with a shredder, plastics and

Table 25.4 The cost and resale value of plastics used in hospitals

Plastics in hospitals	Buying price (Rs.)	Selling price (Rs.)
Syringes	15–16	22
IV bottles	16–18	20
IV tubes	10–12	14
Catheters	16–20	24

glass find their way into the vats from where they are sneaked out by rag pickers. The glass bottles are sold to liquor shops, and the scavengers also sell them to the scarp dealers in lieu of vegetables, garlic and even money. There are sacks of contaminated surgical gloves and IV bottles in shops along Central Avenue and Golf Club Road, which have found their way only a few yards away from Calcutta Medical College and Hospital and M. R. Bangur Hospital. Ragpickers collect BMW from the hospital daily and sell them to scarp dealers. They procure gloves and used syringes from the vat of Calcutta Medical College and Hospital before they are transported for final disposal. There have been instances where the transporters intentionally leave these for the rag pickers who would earn a meagre living from selling it.

Dressings and Gloves

Bandages and blood and pus-soiled cotton/dressings reach the main garbage bin. But before they are collected by the conservancy staff for final treatment and disposal, they are siphoned away by the ragpickers.

The results from shadowing exercises revealed that the bandages are washed, and the soiled portions were removed by naked hands. This in turn was used for making blankets, mattresses and earbuds (Fig. 25.19). Gloves which are discarded in large quantities but not documented during the waste audit were recycled in an unauthorised manner. The survey findings revealed rampant siphoning of gloves. These were washed and resold along one of Kolkata's best-known thorough way—the Chowringhee Road, considered to be the Central Business District of Kolkata (Fig. 25.20). These were procured predominantly by salons, who use them for hair and skin treatment, exposing the common man to risks of nosocomial infection.

The Placenta Story

The trade of human organs has from time immemorial involved in numerous controversies. Kidney, liver and heart have always been the main organs of transplant. But the importance of the placenta has today reached magnified proportions. The inherent quality of the placenta obtained from the firstborn is that it has wound-healing properties. It is due to this characteristic utility that famous medical companies like Albert David Limited use it to manufacture drugs. Thus, due to its high demand, the placenta

Fig. 25.19 Plasters dumped outside the Orthopaedics ward N.R.S. Medical College and Hospital

Fig. 25.20 Scavenged surgical gloves resold illegally

business has established strong roots. A strong nexus between the hospital administration, the Class IV workers and the companies has facilitated the availability of placenta not only of the firstborn but also of subsequent births. As per the Notification issued by the Ministry of Environment, Forests and Climate Change, Government of India, dated 28 March, 2016, in Schedule I of the Gazette of India, human anatomical waste, like placenta, should be disposed by incineration (Government of India 2016). But due to the lack of an effective BMWM, this highly contaminated pathological waste was either dumped in the open vats in the backyard of hospitals or is being sold through unauthorised channels.

Conclusion

The evidence from this study reveals glaring loopholes throughout the waste chain. The study indicates several challenges like ignorance, lack of transparency, gaps in accountability and financial constraints that hinder with the management of BMW.

The findings suggest that 90% of the hospitals were aware of segregation at source, but only 35–40% of them, followed the prescribed guidelines in totality. This led to mixing of infectious waste with the general waste. 50% of the hospitals generated 250–500 g of BMW/bed/day in accordance with the CPCB estimates. The hospitals with greater number of beds, reported less than 25% of these estimates, indicating a lacunae in the segregation process. Segregation plays a pivotal role; hence, training modules specifically tailored for the healthcare staff would ensure accountability and methodological handling of BMW. A Waste Management Cell should be created which could identify and document job-related exposures and offer appropriate post-exposure diagnosis. 56% of the respondents were not aware of either the authority or the legislation associated with BMWM. The economic and environmental costs of BMW are substantial. Inadequate strategies and behind the scenes nexus must be tackled before the risk escalates to gigantic proportions. One of the major findings revealed that the contaminated needles were not mutilated and were disposed directly in waste bags. More than 45% of ragpickers were victims of sharp injuries. There is a need to acknowledge the struggle of ragpickers and encourage hospital authorities, governments and policymakers to engage in a constructive dialogue. Given the disparity between available resources and the magnitude of the problem at hand, it is imperative that research and quality assurance initiatives are undertaken for ameliorating medical care deficiencies. The need of the hour is to formulate proactive policies that would go beyond regulatory compliance requirements. Advocacy for sustainable BMW management would formulate strategies which would promote a resilient hospital ecosystem and maintain the delicate balance of environmental health and social justice.

References

Almuneef M, Memish ZA (2003) Effective medical waste management: it can be done. Am J Infect Control 31(3):188–192

Bolyard EA, Tablan OC, Williams WW, Pearson ML, Shapiro CN Deitchman SD (1998) Guidelines for infection control in health care personnel, 1998. In: Infection control and hospital epidemiology, hospital infection control practices advisory committee, vol 19, no 6, pp 407–463. https://doi.org/10.1086/647840

Census of India (2021) https://censusofindia2021.com/west-bengal-population-2021-census-data/

Chartier Y (2014) Safe management of wastes from health-care activities. World Health Organization

Dutt MK (1973) The diffusion and ecology of cholera in India. Geographical Review of India 35(3), Calcutta, India

Government of India (1998) Ministry of Environment and Forests Gazette notification No 460 dated July 27, New Delhi, pp 10–20

Government of India (2016) Ministry of Environment, Forests and Climate Change Gazette notification dated 28 March 2016, New Delhi

Government of West Bengal (2018) Directory of medical institutions in West Bengal, State Bureau of Health Intelligence Directorate of Health Services, Kolkata

Government of West Bengal (2003) Training module on Health care waste management. West Bengal health systems development project (Department of Health and Family Welfare), Government of West Bengal, Kolkata

Maclean RW (1996) Environmental audit—what it is and how to organise it. Waste audit and pollution prevention techniques. National Productivity Council, Chicago, USA

Macnamara FN (1980) Climate and medical topography in relation to the disease distribution of the Himalyan and Sub Himalayan District of British India. Longmans Green and Co., London, p 11

Nazareth S (2002) Transferring life or death? A factsheet on plastics in health care, hospital waste time to act. Srishti, New Delhi, p 8

National Institute of Occupational Safety and Health (1999) Preventing needle stick injuries in health care settings. Pub. no. 2000–108

Occupational Safety and Health Administration (2001) Enforcement procedures for the occupational exposure to blood borne pathogens. Office of health compliance assistance, U.S. Department of Labour, Washington D.C., USA, p 73

Plianbangchang S (2005) A report on alternative treatment and non-burn disposal practices; safe management of bio-medical sharps waste in India. World Health Organisation, Geneva

Prasad KSSVV (2000) Environmental audit—a tool for solid waste management. In: Jana B, Banerjee B, Guterstam B, Heeb J (eds) Water recycling and resource management in the developing world—ecological engineering approach. India and International Ecological Engineering Society, Wolfusen, Switzerland, p 346

Pruss A, Giroult E, Rushbrook P (1999) Safe management of wastes from health-care activities. World Health Organisation, Geneva, p 143

Chapter 26
Analysing the Institutional Framework for Climate Resilient Metropolitan Regions from the Global North and Global South

Nikita Ranjan, Arindam Biswas, and Markus Neppl

Abstract Climate change and an increasingly urban population around the globe are impacting urban areas, making climatic shocks and stresses explicitly evident. Despite these threats to the urban fabric, metropolitan areas worldwide are the drivers of economic and cultural growth. The resilience of cities and even their associated region is strongly impacted by the planning and governance of the city. The spatial scale of metropolitan regions is vital in bringing climate resilience to the larger region besides the city itself. Also, climate change has widely varying effects on different socio-economic systems and populations. This chapter explores these differences through a comparative study of the metropolitan regions, the Hamburg Metropolitan Region (HMR) and the Surat city region. Although the climatic hazards in the two regions are comparable, their institutional systems and resilience-building strategies differ significantly. The chapter presents a comparative study of their institutional setup for resilience-building, outlining the varying adaptation approaches between developing and developed countries. The theoretical premise for the comparison is built on the existing literature on climate resilience for urban systems and tools/approaches for assessing institutional resilience-building capacities. The reciprocal understanding from the comparison highlight potential solutions to the gaps in climate change adaptation and contributes to developing an in-depth understanding of climate adaptation action in local contexts.

Keywords Urban resilience · Climate resilience · Urban institutions · Metropolitan governance · Climate governance

N. Ranjan (✉) · A. Biswas
Department of Architecture and Planning, Indian Institute of Technology Roorkee, Roorkee, Uttarakhand 247667, India
e-mail: nikita_r@ar.iitr.ac.in

A. Biswas
e-mail: arindam.biswas@ar.iitr.ac.in

M. Neppl
Department of Architecture, Karlsruhe Institute of Technology, 76131 Karlsruhe, Baden-Württemberg, Germany
e-mail: markus.neppl@kit.edu

U. Chatterjee et al. (eds.), *Urban Commons, Future Smart Cities and Sustainability*, Springer Geography, https://doi.org/10.1007/978-3-031-24767-5_26

Introduction

Climate change, which has affected every country, is a pressing reality for the world. It has evoked extensive research to understand its impacts on various systemic structures of the natural and man-made environment. Almost 60% of the world's population is expected to live in urban areas by 2030, which will rise to nearly 70% by 2050 (United Nations 2014). Urban areas are not only predicted to house the majority of the world's population but also to form the centre of economic and socio-cultural activities. The extent and impact of shocks and stresses in urban regions are growing with the increasing population growth. The metropolitan areas around the world are becoming the drivers of economic and cultural growth in spite of these constant threats. Thus, metropolitan areas play an important part in bringing climate resilience to cities and their hinterlands. The way the cities are planned, financed, developed, built, governed and managed directly impacts the sustainability and resilience within and beyond the city boundaries (United Nations 2017). If planned and managed well, urbanisation can be a powerful tool for building climate resilience. Building resilience against climate change not only requires significant adjustments in the interaction of different sectors, regions and populations but also in the interaction of various levels of governance (Nachbaur et al. 2017). The concept of resilience and the importance of integrated governance have emerged as prominent policy narratives to enable the understanding of joint planning, implementation, monitoring and tracking of an integrated climate change action at the local and regional levels (ICLEI 2018; United Nations 2017). Hundreds of local and regional governments called for stronger linkages between urban and climate policy in the Bonn-Fiji commitment issued at COP23 (ICLEI 2017; Revi et al. 2014).

Climate change is a natural phenomenon impacting large geographical regions without much heed to man-made spatial delineations. This makes it even more important to have a holistic view of the cities along with their associated hinterlands for addressing climate change on the ecosystem level. Cities depend on resources and ecological services from distant ecosystems and are affected by both the health and availability of these ecosystems. In a true sense, cities are not independent entities (Wackernagel et al. 2006). Cities and their surrounding hinterlands are closely knitted in spatial and functional interdependency of resources and functions (Fig. 26.1). A regional approach towards coordinated development is not only valuable for the resource sharing benefits but also for collaboration with the peri-urban and rural areas surrounding the metropolitan core. A city-centred approach often misses critical risk-reducing opportunities for such ecosystems spanning larger areas. Therefore, climate change adaptation planning at a regional level offers the opportunity to access required resources while addressing the entirety of the ecological and social systems that are at risk (Hammett 2016).

The prevailing knowledge about the effects of climate change has also indicated that the impacts of climate change have not been uniform. They have affected different countries, socio-economic systems, ecosystems and populations in different ways and to widely varying degrees. This chapter presents a comparative study of two specific

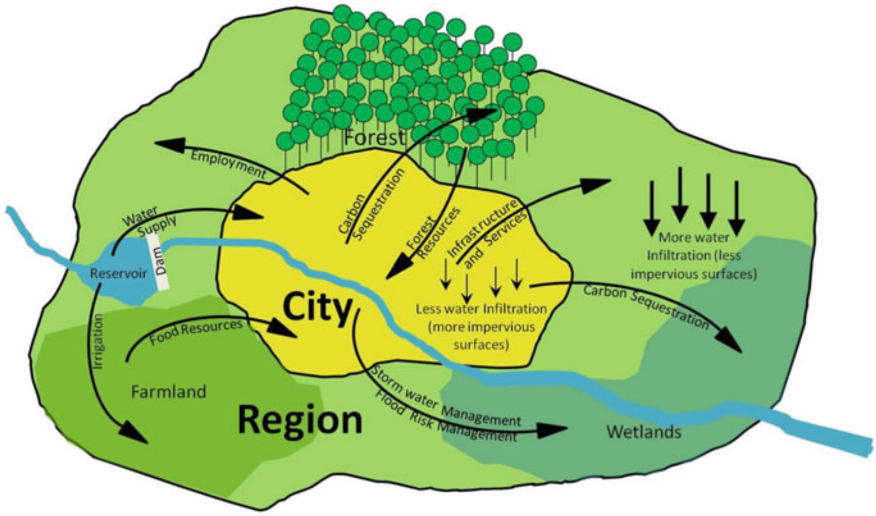


Fig. 26.1 Dependence of city and the region on each other. *Source* Authors

city regions—the Hamburg Metropolitan Region (HMR) and the city region of Surat (the city region of Surat corresponds with the limits of the Surat Urban Development Authority). These regions, while facing similar climatic risks, have varying levels of vulnerability and even have a varying institutional framework to build resilience. The reasons for selecting these two regions are their comparability in area, population, topography, climatic risks, stresses and the resilience initiatives taken by them (Refer to Table 26.1). Comparing the institutional structure for climate change adaptation in these regions provides a perspective on varying adaptation between developing and developed countries. This comparison also helps in finding solutions to gaps in climatic adaptation in regions based on the reciprocal understanding of the two regions and provides an in-depth understanding of the importance of climate adaptation actions according to the local contexts.

This chapter aims to establish the institutional settings required to make a region resilient to climatic risks based on the comparative study of the gaps and strengths of both institutional frameworks. The main research questions addressed in this chapter are the following:

i. What are the key dimensions of institutional capacity for assessing the gaps and strengths in the institutional framework crucial for augmenting climate resilience in cities and regions?
ii. How do the institutional framework and the institutions' capacity shape climate resilience planning in the metropolitan regions of Surat and Hamburg?
iii. What are the gap areas in the current institutional arrangements in both regions?
iv. What are the strengths and good practices in both institutional arrangements that can be adopted by other city regions to build their resilience to climate risks?

Table 26.1 Rudimentary comparison of the city regions of the study areas

City and region	Surat		Hamburg	
	Surat city and region (corresponding to SUDA's limits)		Hamburg city and Hamburg Metropolitan region	
Area (km^2)	City: 326.5	Region: 715	City: 755.22	Region: 28,500
Population (million)	City: 4.46	Region: 4.8	City: 1.8	Region: 5.3
Risks and stresses	Drought, sea-level rise, coastal erosion and river flooding		Flooding, altered rainfall patterns, rising temperatures, heat waves, dry periods, Sea-level rise, storm surges and heavy precipitation	
Topography	Surat city is located on the banks of the Tapti River. Surat falls under coastal plains, with some parts of the region under alluvial plains		Hamburg is located in a sheltered natural harbour. And located at the banks of river Elbe at its confluence with the Alster and Bille. Hamburg metropolitan region is a part of the Northern German lowlands. The topography is comprised of flat, fertile marshes, sandy and wavy Geest areas interspersed with lakes	

Source Based on SUDA (2016), Regional Councils of Baden Wurttemberg (2016), Metropolregion Hamburg (2017)

The chapter is structured in seven sections. Section "Methodology" presents the methodology of the research undertaken for this study. The research builds upon a review of existing literature about climate resilience for urban systems and the suitable tools and approaches for the identification and assessment of the institutional capacity for resilience planning. The findings of this literature review are presented in Sect. "Literature Review". The metropolitan regions selected for the comparative study are introduced in Sect. "Study Areas". These metropolitan regions are then comparatively assessed for climatic vulnerability and institutional capacities for developing climate resilience. The key points of this analysis are summarised in Sects. "Analysis and Findings I" and "Analysis and Findings II". Section "Conclusion" concludes the chapter with key inferences from this analysis and indicates the further scope of this research.

Methodology

The study starts with a comprehensive review of the concept of resilience and its use in the context of urban areas and climate change adaptation. This chapter builds on the comparative study of two city regions. The study refers to the secondary data collected from published electronic sources, books, journal articles, government records, websites and census data. The secondary data consists of cities and regions, regional delineation, climatic risks and vulnerabilities, governance structure and institutional dynamics. Data about the institutional framework is collected from the visible evidence of institutional arrangements, which includes:

i. policy and legislative framework;
ii. policy instruments like urban plan documents, standards, incentives/disincentives, sanctions, communications initiatives and monitoring and evaluation frameworks;
iii. institutional hierarchy and organisational setup; and
iv. coordination arrangements between different institutions like multi-actor collaboration and networks, policy for alignment of different sectors and governance hierarchy, knowledge-sharing networks and participation mechanisms.

At first, this data is used for comparing the risks and vulnerabilities, regional delineation and the existing institutional framework to facilitate climate adaptation action in the metropolitan regions. The key sectors for climate change adaptation, associated institutions and relevant stakeholders are identified for the regions. Next, the capacities of the institutional frameworks to facilitate climate change adaptation efforts are assessed for both regions. This assessment is done by evaluating the institutional capacities against eight key components of desired institutional capacity (Fig. 26.2).

These components are used to identify and assess the institutional arrangements and capacities for climate change adaptation and have been identified based on a review of relevant literature. This assessment helps to determine the key institutional capacities required for an effective regional climate change adaptation. The strategic interventions aiming to mitigate institutional gaps of the studied regions also create a case in point for future references.

Literature Review

The metropolitan region is a constantly changing, complex and adaptive socio-ecological system (people and nature as interdependent systems) whose resilience represents the ability of the system to absorb, recover and prepare for future shocks (Folke et al. 2010; OECD 2018). Thus, the vulnerability of any urban system to the impacts of climate change is not only defined by the biophysical conditions of the urban system but also by the socio-political and institutional factors (Agrawal 2008). It is essential to study and analyse the institutional setup in the metropolitan region to comprehend the resilience of human settlements. The region's economic, technological, infrastructural and innovative capacities are essential components for building the region's ability to adapt to any threat. The capacities of the institutional arrangement for regulating and planning all these components are equally important. Numerous studies have indicated that institutional arrangements such as education and innovation networks, social networks and effective governance practices are

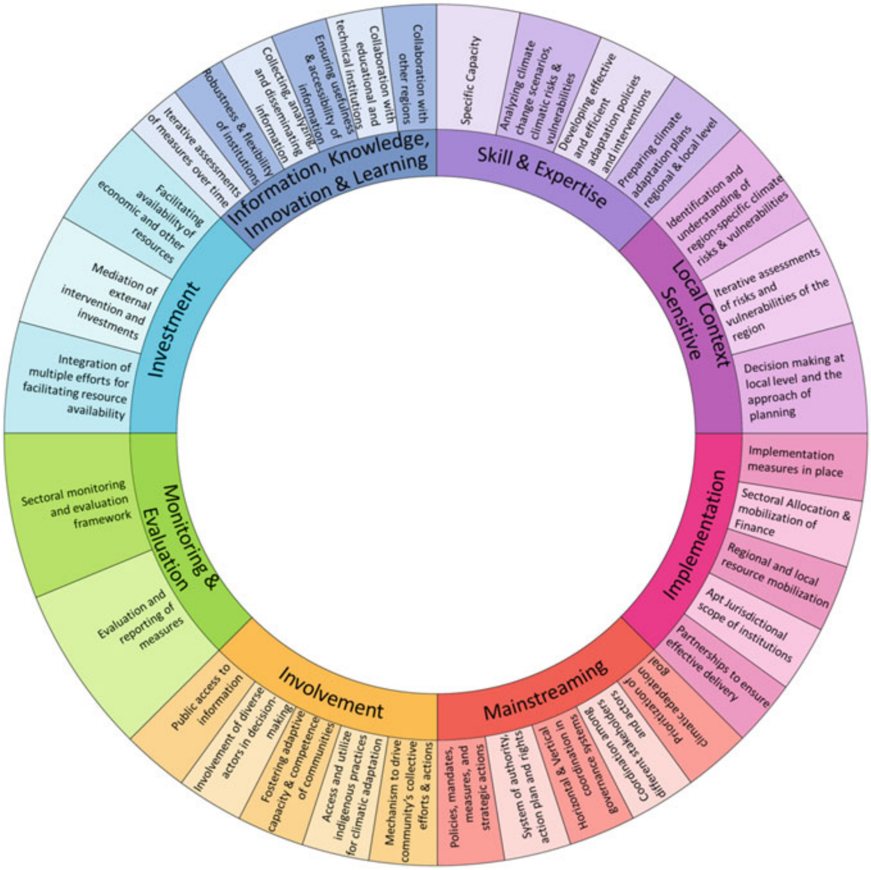


Fig. 26.2 Key components for the assessment of institutional capacity for developing resilience to climate change. *Source* Authors

significant contributors to the development of resilience in urban systems (Tanner et al. 2009; UNFCCC 2014; Dixit et al. 2011; FAO 2018; United Nations 2019).

Further literature review determines the suitable approaches and methodology for the identification and assessment of the institutional arrangement. This literature review also recognises that urban resilience is the capacity and ability of the cities and their socio-ecological systems to adapt to uncertainty and change, recover quickly from shocks and stresses and maintain their functions and structures (Ernstson et al. 2010; Campanella 2006; Ahern 2011; Leichenko 2011; Liao 2012; Brown et al. 2012; Lhomme et al. 2012; Wagner and Breil 2013; Romero-Lankao and MGnatz 2013; Pickett et al. 2004). The key components that influence the institutional capacity for developing resilience to climate change in the region were identified based on the inferences from this literature. These components (Fig. 26.2) are:

i. mainstreaming climate change adaptation into institutional strategies and policies at different levels of governance to facilitate adaptation to climate change;
ii. implementation and effectiveness of climate adaptation solutions;
iii. sensitivity to local risks, vulnerability, socio-economic situations, development goals of the region, funding and other constraints for enabling adaptation actions;
iv. technical skills and functional expertise of individuals, communities and institutional arrangements for building climate resilience;
v. information management and knowledge exchange among different institutions, regions and stakeholders to make the required information on gaps, challenges, solutions, pathways and techniques to promote learning;
vi. institutional arrangements' effort in driving investments for climate change adaptation;
vii. monitoring and evaluation of climate change adaptation efforts; and
viii. involvement of diverse stakeholders.

Study Areas

Metropolitan regions in Germany vary in their official status, organisation, budget and the extent of strategic cooperation between participating organisations and stakeholders. Seven out of eleven metropolitan regions, including the HMR, have a legal mandate conferred through a state treaty (OECD 2017). HMR is the second largest metropolitan region in Germany. The total population of the region is almost 5.4 million. It contains the free and Hanseatic[1] city of Hamburg as its urban centre with parts of three surrounding states—Schleswig–Holstein, Mecklenburg-Western Pomerania and Lower Saxony (Fig. 26.3). The metropolitan region houses 20 counties and above 1100 municipalities.

In India, the metropolitan region or city region is analogous to several other terms, such as urban agglomeration, metropolitan area, greater urban area. The Indian census describes the urban agglomeration as 'an area comprising a core city, other contiguous municipalities and urban outgrowths' and even provides formal criteria for their delineation. However, the method of delineating metropolitan regions in India consists of aggregating even bigger areas, including rural areas. Many such rural areas adjacent to urban areas are urbanising and encompassing a significant part of the metropolitan region (Sivaramakrishnan and Maiti 2009). The 74th Constitutional amendment act (74th CAA) has prudently introduced the concept of metropolitan governance with independent decentralised local decision-making authorities. The states earmark metropolitan regions based on the fulfilment of the definition outlined in the 74th CAA (Biswas et al. 2019). A metropolitan region consists of at least one municipal

[1] The Hanseatic League (also known as Hansa, Hanse, 1356–1862 CE) was a federation of North German towns and cities formed in the twelfth century CE to facilitate trade and protect mutual interests.

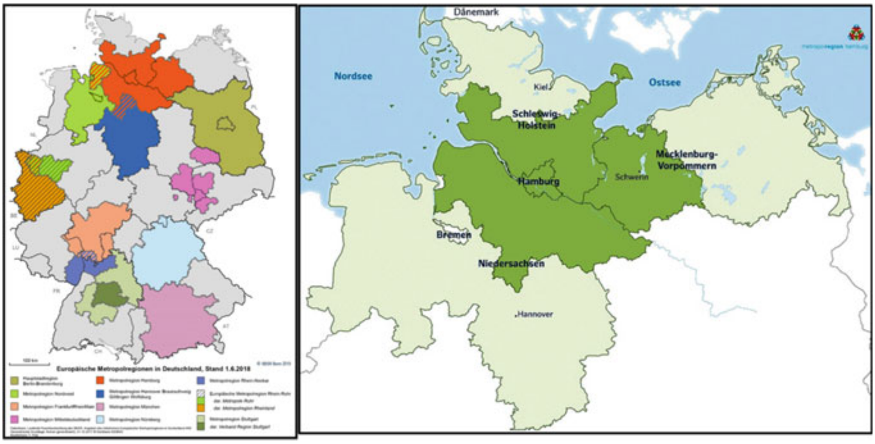


Fig. 26.3 (Left) Metropolitan Regions in Germany in 2018. *Source* OECD (2019), adapted from the Federal Institute for Research on Building, Urban Affairs and Spatial Development; (Right) Hamburg Metropolitan Region. *Source* OECD (2019)

corporation and several municipalities and city panchayats. The metropolitan region also consists of several village panchayats, which are the smallest administrative unit of India's rural governance (Biswas 2020). These regions as a whole do not have legitimacy as a political entity but are made up of either whole or parts of several other spatial and political entities. The governance system for metropolitan regions in India has evolved to meet specific needs for delivering infrastructure and services at a metropolitan level (Gandhi and Pethe 2017).

Surat is located in the western state of Gujarat in India. The city is situated on the banks of the river Tapi at its confluence with the Gulf of Khambhat. The city has been an important historic centre for trade and manufacturing. It is one of the fastest-growing cities in India. Its area has expanded multi-fold since the 1960s (Fig. 26.4). The population of Surat has also increased very rapidly to become the eighth largest city in India (Census of India 2011).

The Surat Urban Development Authority (SUDA) was constituted in 1978 for the development of the Surat metropolitan region. The Surat Municipal Corporation (SMC) is the principal city of the metropolitan region. SUDA's jurisdiction area constitutes Surat municipal area, several census towns, Industrial Notified Areas (INAs), municipalities and outgrowths (SUDA 2015).

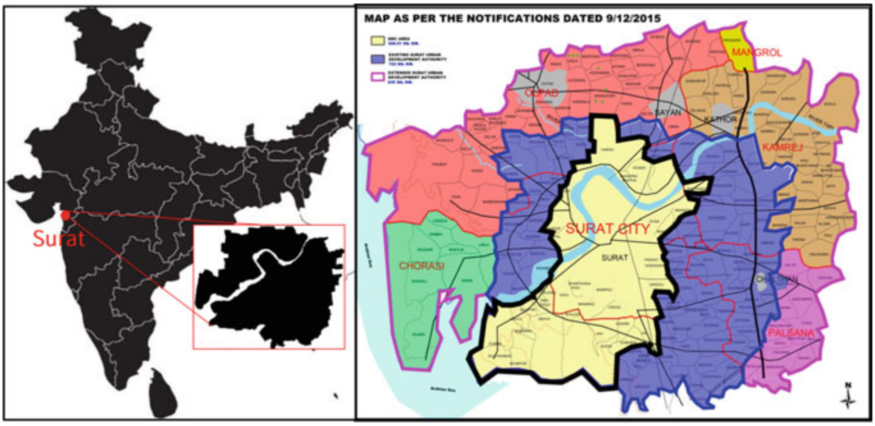


Fig. 26.4 Area under the jurisdiction of SUDA considered as Surat's city region for the purpose of this study. *Source* SUDA (2015)

Analysis and Findings I

Regional Delineation and Associated Governance Framework

The organisational structure of regional planning directly affects the territorial definition of planning regions and therefore affects the organisation of governance systems and associated institutions. Thus, it is essential to look into the regional delineation of metropolitan regions and how it affects the resilience planning capacity of the institutional systems.

Metropolitan regions of Germany do not necessarily constitute a distinct tier of government in the German federal system; instead, they are a form of regional alliance between the regional and local authorities. They are defined by the standing conference of ministers responsible for spatial planning (Ministerkonferenz für Raumordnung), which is a joint committee of federal ministers and ministers from individual federal states. These metropolitan regions form the Association of European Metropolitan Regions in Germany (Initiativkreis Europäische Metropolregionen in Deutschland) for networking at the national level and with the other European regions.

Regional planning in Germany coordinates planning matters of the areas beyond the municipal boundaries. These plans drive the systematic alignment between top-down planning at the federal and state level and bottom-up planning at the local level (German Federal Ministry for Regional Planning, Building and Urban Development 1995; OECD 2017). In recent years, Germany has also started using supplemental spatial policy and strategies apart from formal laws and plans. These supplemental procedures are voluntary and informal in nature and act as steering instruments of spatial planning at the regional level.

The regional governance in HMR is organised differently from the remaining metropolitan regions in Germany. The HMR does not have any legal recognition but has a coordination mechanism between the key stakeholders of the region. It is governed by a central governing body composed of the representatives of stakeholders and determined by a general assembly. Hamburg is both a municipality and a city-state. Both these administrative levels are the same for Hamburg. The Hamburg municipal and state administration is administered by the Hamburg State Parliament (Bürgerschaft). The land use plan replaces the regional plan in the case of Hamburg. In the Lower Saxony part of the HMR, the districts are responsible for regional planning, while in Schleswig–Holstein, the Ministry of the Interior (a state government organisation) is assigned the responsibility of regional planning. The districts of Mecklenburg-Western Pomerania belonging to the HMR are accounted for in the West Mecklenburg planning region in the regional spatial development concept. The members of the HMR have defined guidelines, goals and measures for joint regional development in a joint regional development concept (Regionalen Entwicklungskonzept [REK 2000]). However, the REK is informal in nature. Its statements and procedures are subject to voluntary adoption in the regional and site planning by the states. The strategic framework for action of the Hamburg Metropolitan Region (Strategischer Handlungsrahmen), adopted in 2010, has been updated regularly. It forms the basis for cross-border cooperation in the region. HMR office does not have any predisposed or mandated powers or authority as it is not a separate tier of government. It serves as a coordination organisation to promote dialogue and build unanimity for regional decisions among its stakeholders. The relevant stakeholders are (Fig. 26.5):

a. four federal states: Hamburg, Lower Saxony, Mecklenburg-Western-Pomerania and Schleswig–Holstein;
b. seventeen counties;
c. three county-free cities;
d. seven chambers of commerce and industry;
e. three chambers of crafts;
f. the United Business Associations of Hamburg and Schleswig–Holstein; and
g. the federation of German trade unions, district north.

In India, independent governing institutions (usually a separate metropolitan area development authority) administer all cities within a metropolitan region. Governance of large cities involves diverse institutional actors, both public (municipal corporations, parastatal agencies, state and central governments and the judiciary) and private institutions (corporate, the private companies and organised civil society). The development authority is responsible for the preparation and implementation of development plans for the city and metropolitan areas, local area plans for the neighbourhood and special areas. A metropolitan region is under the direct or delegated jurisdiction of the state. At the local level, independent institutions (ULBs and village panchayats) govern cities and villages within a metropolitan area. The ULBs depend on the metropolitan development authority for technical support, knowledge and

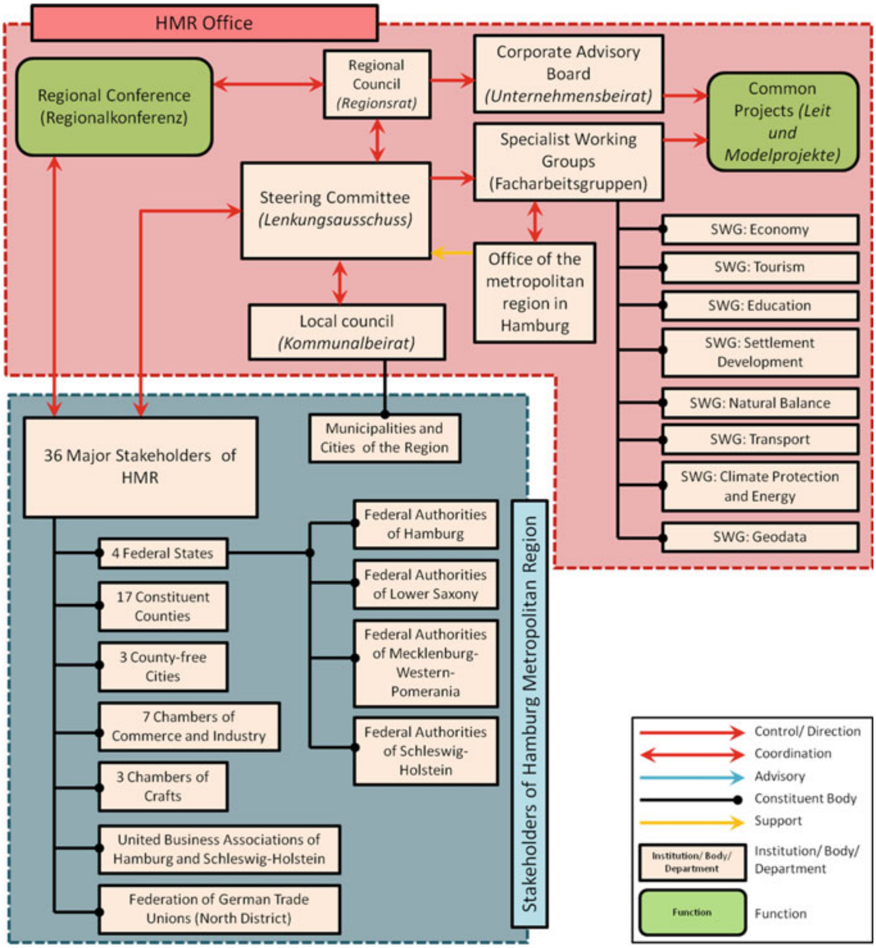


Fig. 26.5 Organisational structure of HMR and coordinating institutions. *Source* Authors based on Hamburg Senate Chancellery (2019)

policymaking. The role of regional planning and preparation of regional development plans has even been delegated to the municipalities in the case of some Indian cities (Biswas et al. 2019). Apart from these institutions, agencies like Improvement Trusts and Housing Boards also function at the local level. They perform the task of developing special areas (for example, specific housing colonies) in the city, in compliance with the city's development authority, in the areas or land pockets which have already been earmarked by the development authority (Mahadevia et al. 2009).

In the specific case of the Surat city region, the task of regional planning and governance is delegated to two organisations—Surat Municipal Corporation, which administers Surat city and the Surat Urban Development Authority (SUDA). They oversee the development of the entire region under the purview of the state government. While HMR and Surat do not have any political competencies or form a separate tier of governance, their governance and institutional framework for regional planning vary significantly. For HMR, regional planning is a collaborative process aimed at building unanimity for regional decision-making among its stakeholders. For the Surat city region, SUDA is tasked with preparing "development plan and "town planning schemes". Other ULBs of the region are tasked with performing the municipal functions in their jurisdiction and provide a very limited contribution to the regional planning and governance. In addition to these, the parastatals are tasked with other regional planning functions.

Climatic Risks and Vulnerabilities

Both these regions are going to experience similar climatic variations like sea-level rise, temperature rise and altered precipitation patterns in the future. They face similar risks like coastal erosion, storm surge, flooding, urban heat islands, vulnerable water resources, susceptible coastal ecosystems, jeopardised economic activities and threatened public health and welfare. However, the intensity of climatic risks, stresses and vulnerability of the socio-ecological systems in both regions vary significantly. According to the Global Climate Risk Index (CRI), India ranked as the 6th most vulnerable (to climate change impacts) country in the world in 2016 and the 12th most vulnerable country between 1997 and 2016. However, Germany only ranked as the 42nd most vulnerable country in the world in 2016. Earlier, from 1997 through 2016, Germany ranked 23rd (Eckstein et al. 2017).

The only significant direct impact of the climatic risks and stresses on the public health and welfare in HMR occurs from extreme events like flooding or storms. Agriculture, forestry, fishing and tourism are some of the economic sectors likely to be affected by climatic risks. Incidentally, the HMR is equipped with robust infrastructure systems to mitigate extreme threats from climate change-induced risks. Besides, the overarching policies of the European Union (EU), Germany and the federal states are focused on long-term plans and strategies for CO_2 reduction and adaptation of renewable energy sources. Following these overarching goals, the local bodies drive the region-specific climatie change adaptation to region-specific climatic risks.

The intensity of the climatic risks and stresses on the Surat metropolitan region is greater in comparison to HMR. In Surat, the percentage of workers dependent on the primary, secondary and tertiary sectors is 0.28%, 66.10% and 33.63%, respectively. A large number of people are dependent on natural resources for livelihood and basic services. Climate change is particularly affecting the agriculture, water and forestry of the Surat Metropolitan Region. Both the primary and secondary sectors in the region are threatened by the impacts of climate change and its prevailing stresses. Surat metropolitan region has been struggling with rapid urban growth and expansion since the 1960s. The city has grown unchecked beyond its boundaries, resulting in a spillover of the population in its periphery. This has affected the accessibility to affordable housing in the region. Migration has been a major contributor to population growth in the city. A large section of this migrant population is unskilled labour employed in the informal sector. This population often ends up in informal and slum housing. The number of slums has increased since the extension of the city limits (Taru Leading Edge 2017). These slums also tend to situate near tidal creeks and drainage channels for access to water resources. This not only makes them more vulnerable to extreme climatic events like floods and storm surges but also creates congestion in the drainage system of the city, thus further intensifying the impact of these extreme events. Unhealthy living conditions coupled with climate change are also expected to increase the spread of diseases in the city. The pattern of climate change adaptation planning in Surat is more focused on achieving short-term goals and tackling the problems at present.

Analysis and Findings II

The review of the institutional framework and capacities for climate resilience of HMR and Surat Metropolitan Region in different thematic areas (see Fig. 26.2) produces the following observations.

Mainstreaming of Climate Adaptation

In Germany, the region is generally perceived as a suitable decision-making level to adapt to climate change outcomes. The ‘Strategischer Handlungsrahmen’ (strategic framework) containing the overall goals and measures form the base of climate adaptation action in HMR. Hamburg also has a draft climate protection law under the process of resolution. The national and international climate adaptation policies in Germany are target-oriented. The regional and local level institutions are entrusted with the spatial constraint of implementation and realisation of these targets. The roles and responsibilities of different authorities for spatial planning are clearly defined by the governance structure of Germany and the cooperation agreement of HMR, and the joint regional development concept (REK 2000). The Climate Control Centre, along with the Authority for Environment and Energy, is responsible for coordinating the fundamental issues of climate policy at the local, state, federal and EU levels, as well as in the HMR. The REK and the ‘Strategischer Handlungsrahmen’ reflect the prioritisation of climate adaptation goals. The international, national and state-level climatic goals are incorporated into the regional development policies and objectives of the HMR. Scrupulous climatic goals by the EU and Germany, legal frameworks and obligations for the regional and local authorities ensure consistency in climate change adaptation efforts in HMR. Consistency in efforts from different administrative levels and sectors is ensured by a robust and comprehensive framework for monitoring climate change adaptation.

For India, the commitment to the United Nations Framework Convention on Climate Change (UNFCCC) is the guiding policy framework at the global level. At the national level, the coordinating entity for climate change is the Prime Minister's Council on Climate Change (PMCCC), and the coordinating policy document is the National Action Plan on Climate Change (NAPCC). No mandate or policy document specifically addresses climate change adaptation at the regional level of the Surat Metropolitan Region. Surat's resilience strategy forms the basic framework for climate adaptation action in the city of Surat. This strategy document is aligned with the existing NAPCC, whose eight national missions act as overarching climate change goals for the country. Programs and actions are enumerated under the NAPCC to be implemented at different levels of governance. Gujarat's State Action Plan on Climate Change (SAPCC), which is aligned with the NAPCC, also forms the policy framework for this strategy. The Surat Resilience Strategy 2017 has aligned the institutions and the related programs, schemes, or plan documents with each initiative proposed in the strategy. However, the role and authority of various institutions in carrying out the tasks of this strategy are not clearly defined, which leads to ambiguity in the system of authority. The initiative of SMC for creating a resilience strategy is an indication of the prioritisation of climate adaptation goals. However, Surat lacks any binding legal framework ensuring climate adaptation in the city or the region.

Implementation of Climate Adaptation Solutions

In HMR, the implementation measures for various programs, including CO_2 reduction, are in place. The details of their implementation status, funding and effectiveness are recorded and communicated transparently. The implementation of various programs and schemes in HMR is done cooperatively by institutions from different levels and sectors. The sectoral allocation of funds for implementation is regulated by the policy framework at different levels. The budget of HMR is obtained from the federal states, private sector stakeholders and the EU programs. The HMR office, along with the Climate Control Centre, drives the cooperation arrangement between various stakeholders of HMR, ensuring effective and efficient implementation of all measures. Several stakeholder clusters and partnerships are also there for collective climate adaptation action in HMR.

The measures planned in the Asian Cities Climate Change Resilience Network (ACCCRN) phase I and II have been implemented in Surat. However, information about the newly introduced climate adaptation actions is not available. Sectoral allocation of finance at the national level is done according to the different missions of the NAPCC. The Surat Municipal Corporation (SMC) is the key institution for implementing climate action in Surat and is known for its municipal self-sufficiency in financing these measures. SMC and Surat Climate Change Trust (SCCT) have also partnered with several stakeholders to develop and implement a strategic plan and targeted initiatives for resilience in Surat.

Sensitivity to the Local Context

Extensive studies for the climate change parameters, scenarios, risks and vulnerabilities for HMR and Northern Germany have been conducted. These assessments are also iterative in nature. Numerous institutions from different levels of governance located in different parts of the country and belonging to different sectors are involved in these assessments. The decision-making for the region is done by the regional and local authorities in compliance with the higher legal frameworks.

Analysis of climatic data for Surat is done in the ACCCRN phase II by procuring climate data (past and future) from IMD and other international institutions. This data has been taken from large-scale general circulation models. Assessment of vulnerabilities for the city has also been done in the ACCCRN phase II for the households of Surat based on relevant thematic areas. The climate adaptation decision-making for Surat is done on the local level and aligned to the policy framework at higher levels, with contributions from institutions from different levels of governance.

Skill and Expertise

HMR has access to Europe's best infrastructure for climatic research. Research clusters like Cluster of Excellence Integrated Climate System Analysis and Prediction (CliSAP), KlimaCampus and Klimawandel in Regionen Zukunftsfähig Gestalten-Nord (KLIMZUG-NORD) bring institutions from research, technical and administrative backgrounds together to analyse climate change scenarios, climatic risks and vulnerabilities for HMR. Inter-disciplinary research events and conferences for the regular exchange of ideas between experts aid in the formation of effective and efficient adaptation policies and interventions. These are organised and supported by local and regional stakeholders. HMR has also developed its capacity for local area-specific climatic risk management on the local level. HMR has specific risk monitoring systems based on local climatic information monitoring. They also have early warning systems, flood-resistant infrastructure, provisions for the protection of private property, and disaster management and risk mitigation strategies. Besides, they have also developed comprehensive climate change scenarios for the region and established provisions for energy use optimisation.

SMC has collaborated with ACCCRN and Taru Leading Edge Private Limited to assess the climate variability of Surat. Surat also harnessed the opportunity to gain essential learning and experience in developing effective and efficient adaptation policies and interventions for reliance through the 100RC program. SMC also undertook consultations with several institutions to gain crucial insight into effective policy and intervention design. Surat has successfully prepared a city-level resilience strategy with well-defined goals and initiatives. In terms of specific capacity for risk management, Surat has developed early warning systems, disaster management provisions and risk mitigation strategies. Scenario development for flooding in the city of Surat has also been done. Waste management systems in the city have been planned to cope with urban flooding. The addition of flood protection measures like raised plinths in houses have only been done by the residents of flood-prone areas, but no other targeted infrastructure for flood protection has been installed.

Information Management, Knowledge Exchange, Learning and Innovation

Networking between various educational, technical, research and administrative institutions through research groups and excellence clusters has facilitated pathways for the exchange and effective dissemination of relevant knowledge, data and information for HMR. HMR also collaborated with institutions from different parts of the region, enabling the collection of relevant data. Metropolregion Hamburg Zensus 2011 is an important step in collecting demographic data of HMR. Collaborative research has also been done to develop the expertise required for effective communication of climate change risks, adaptation pathways, adaptation goals and objectives to different actors and stakeholders in the region. Pathways for formal communication climate plans, updates and action plans for climate change adaptation to the citizens are in place in states of HMR. Several other mechanisms, like free advisory services, information websites and social media pathways for making the relevant information accessible to the stakeholders, are also in place. The involvement of institutions with expertise in media and communication enables effective dissemination of relevant information and awareness to every stakeholder. HMR and the constituent states are also a part of networks such as the Covenant of Mayors, the Climate Alliance and METREX (Network of European Metropolitan Regions and Areas), which facilitates exchanges with other cities of the EU and the world. HMR has periodically augmented and developed the adaptation action induced by constant monitoring and feedback. Iterative evaluation of the climate plans and conception of new climate action plans shows the flexible nature of climate adaptation in HMR.

SMC has also developed basic information storage, management and dissemination system. It has also undertaken capacity-building exercises to train its staff for the same. SMC also collaborated with various educational, technical, research and administrative institutions for the formation of its resilience strategy. It also had an important exchange of experiences and learning from cities around Asia and the world by being a part of the ACCCRN and 100RC programs. The involvement of diverse institutions on different levels of governance and from different sectors also ensures the flexibility and robustness of the institutional arrangement in both HMR and Surat.

Investment

HMR has sufficiently facilitated economic and non-economic resources for climate adaptation in the region. The resources have been made available by the integration of multiple efforts and mediation of several internal and external interventions. This integration and mediation have been done by the collaborative efforts of different stakeholders in the region. The availability of financial resources and consultation has also been provisioned with the help of banks and other partnership clusters. Funding pathways for local governance bodies for funding local initiatives are also in place.

SMC has been exemplary in its practice of municipal self-sufficiency and mediation of finance for projects. SMC has initiated facilitating the availability of all the required knowledge, information and expertise required for the preparation of the resilience strategy. SMC has also integrated national and state-level programs and schemes for facilitating economic and other resources. Surat, along with the State of Gujarat, has also made efforts in the past for mediation of external interventions.

Monitoring and Evaluation

In Germany, monitoring of climate adaptation action is done on several levels, and the results are communicated through progress reports. The framework is designed to monitor both sector-specific and comprehensive climate change variability and adaptation action in the region. A monitoring system (ROPLAMO) monitors land use plans, written records and graphical elements of state and regional plans, allowing for a nationwide overview of the binding statements regarding regional planning laws and learning through the exchange.

At the national level, the commitment to UNFCCC communication forms an important monitoring framework in India. The impact assessments carried out for the National Communication (NATCOM) are mostly sector-specific and don't explicitly explore the inter-sectoral linkages and adaptation concerns. Although the resilience strategy suggests monitoring various resources and other resilience constraints for climate change adaptation, no monitoring mechanism for the implementation and effectiveness of the city resilience strategy is in place.

Involvement of Diverse Stakeholders

The regional development goals of HMR reflect their priority for regional cooperation and facilitation of public awareness and communication of HMR's climate adaptation strategies. Several measures and pathways for the same are in place in HMR. EU has also obliged its member states to report their progress in achieving the climatic goals to their citizens. There are also pathways for accessing information about climate change, risks and adaptation efforts in HMR. The federal states and counties of the state also have both formal and informal pathways of communication of climate change information. The program 'Climate adaptation made easy' also provides advisory services, lectures and practical examples along with a broad range of information and advice to encourage all stakeholders to participate in stakeholder-led climate action.

The HMR and Hamburg city developed a 'Climate-friendly Society' in HMR. Festivals, events, guides and integrating climate protection into Hamburg's educational landscape are some of these initiatives. The website 'moinzukunft' and the hashtag '#moinzukunft' have been created to communicate the climate plan to the citizens and awareness across social networks. Membership programs like the Hamburg environmental partnership and networks for heating and cooling are methods of leveraging social capital to form communication and collaboration networks for targeted climate protection in the city.

The identification of relevant stakeholders and their involvement was key to the development process of the Surat resilience strategy. These stakeholders were identified as seven discovery groups which included planners, municipal engineers, academicians, researchers, entrepreneurs/businessmen, builders' associations, water resource managers, public health practitioners and energy/gas suppliers. Several initiatives for public awareness about climate change adaptation and resilience have been designed in the Surat city resilience strategy. These events, however, only focus on the city population (as the strategy is a city-specific strategy) and do not address the population from the whole region (villages and towns in the SUDA area except the city). Also, all these events are short to medium-term initiatives (2017–2020), but details about their implementation are not available. This makes it difficult to comment on their effectiveness.

ACCCRN assessed Surat's vulnerability and found strong community networks (Taru Leading Edge 2010). However, higher social capacity was observed in the middle and higher-income groups as compared to the lower-income groups and slum dwellers, which dominantly include migrants from other states. The resilience strategy has also planned initiatives for awareness through social gatherings and educational institutions.

Conclusion

Both Hamburg and Surat have shown a proactive attitude in climate resilience planning. They are a source of learning for the cities in developing and developed countries. The comparative study of both regions shows both similarities and disparities in vulnerability and adaptation.

HMR has made strong strides towards mainstreaming climate change. It has not only created a policy framework but also ensured the prioritisation of climatic goals and consistency in adaptation efforts through target-oriented goals, binding legal frameworks and a strong monitoring framework. HMR has been successfully implementing its planned climate action measures through a combination of cooperated efforts from the involved institutions, appropriate sectoral allocation of funds and proper mobilisation of funds at various levels (including the regional and local levels). They have contextualised adaptation action sensitive to local settings. As a developed region, HMR can access state-of-the-art infrastructure and expertise to analyse climate change scenarios, risks and vulnerabilities to prepare climate action plans. Additionally, HMR has also facilitated the efficient exchange of key information and expertise among different institutions, regions and stakeholders, facilitating policy learning and institutional innovation. These efforts, coupled with the mild impacts of climate change, have enabled HMR to develop resilience. HMR is now working towards developing resilience for future climatic impacts and reducing its contribution to global emissions.

While facing similar climatic risks, the vulnerability of Surat's city region is not the same. The intensity of the climatic risks and stresses is greater for Surat due to persistent stresses like lack of affordable housing, poverty, inequity, ageing infrastructure, and water and air pollution. Surat builds upon the national and state-level climatic action plans for developing a city-level resilience strategy. However, little effort has been made for the integration of the city region into the resilience strategy. The absence of binding legal frameworks, target-oriented goals, monitoring mechanisms and clearly defined responsibilities of institutions make the adaptation efforts less than consistent. Surat has implemented several of its climate adaptation measures in collaboration with the ACCCRN. Several more initiatives are planned for further implementation in the city aligned with the NAPCC and SAPCC. However, the outcome of this alignment for coordinating and facilitating implementation is unclear. The region-specific climatic risk study for Surat is not very extensive and builds majorly upon downscaled climatic data from large-scale circulation models. ACCCRN's risk and vulnerability assessment for Surat focuses primarily on the city and not the city region. The role of the local bodies of the peripheral areas of the city region in the decision-making process remains limited. Both these factors lead to significant gaps in the local-context-sensitivity climate adaptation action in Surat's city region. The study infers that prompt efforts are required to restructure policies and the techno-legal framework to develop appropriate infrastructure and resources for building climate resilience. Better integration of the region into the existing institutional framework is also crucial for the holistic development of both the city and the region. Surat has been a beacon to other cities in India, owing to its proactive resilience development initiatives at the municipal level. However, it has yet to prepare itself for the threats of emerging disasters in the future.

The institutional systems and the frameworks of policies and strategies play a crucial role in driving climate adaptation action. Climate resilience planning for city regions is still at the initial stages and requires a copious amount of research and development. This study presents a detailed analysis of the key factors that shape the resilience-building capacities of metropolitan regions. It also highlights the areas of Surat's institutional framework which require interventions to develop better capacities for climate change. Further research endeavours should be organised to explore ways for the better integration of the metropolitan region into climate change adaptation planning. Research is also required for the development of better networks among stakeholders, research institutions and businesses for Indian city regions to facilitate efficient knowledge transfer, policy learning and resource mobilisation.

Acknowledgements We thank the Ministry of Human Resource and Development (MHRD), Government of India and the German Academic Exchange Service (DAAD) for funding this chapter's research work. Author 1 was awarded the Graduate Aptitude Test in Engineering (GATE) fellowship by the MHRD and the Combined Study and Practice Stays for Engineers from Developing Countries (KOSPIE) fellowship (Ref. No. 91755151) by DAAD to carry out the research activities in India and Germany.

References

Agrawal A (2008) The role of local institutions in adaptation to climate change. In: World bank group open knowledge repository. World Bank Publishing, Washington, DC. Retrieved from https://openknowledge.worldbank.org/handle/10986/28274

Ahern J (2011) From fail-safe to safe-to-fail: sustainability and resilience in the new urban world. Landsc Urban Plan 100(4):341–343. https://doi.org/10.1016/j.landurbplan.2011.02.021

Biswas A (2020) Establishing metropolitan governance and local governance simultaneously: lesson from India's 74th Constitutional amendment act. J Urban Manage 9(3):316–330. https://doi.org/10.1016/j.jum.2020.06.002

Biswas A, Kidokoro T, Seta F (2019) Metropolitan governance and local decentralisation in India: case of Chennai and Kolkata metropolitan regions. Asia-Pacific J Reg Sci 3:675–696. https://doi.org/10.1007/s41685-019-00115-w

Brown A, Dayal A, Rio CR (2012) From practice to theory: emerging lessons from Asia for building urban climate change resilience. Environ Urbanization 24(2):531–556. https://doi.org/10.1177/0956247812456490

Campanella TJ (2006) Urban resilience and the recovery of New Orleans. J Am Plann Assoc 72(2):141–146. https://doi.org/10.1080/01944360608976734

Census of India (2011) Surat urban region. Retrieved 14 Apr 2020, from Census 2011. https://www.census2011.co.in/census/metropolitan/276-surat.html

Coaffee J (2013) Towards next-generation urban resilience in planning practice: from securitization to integrated place making. Plan Pract Res 28(3):323–339. https://doi.org/10.1080/02697459.2013.787693

Dixit A, McGray H, Gonzales J, Desmond M (2011) Ready or not: assessing institutional aspects of national capacity for climate change adaptation. World Resources Institute, Washington DC. Retrieved 15 June 2022, from https://files.wri.org/d8/s3fs-public/pdf/ready_or_not.pdf

Eckstein D, Künzel V, Schäfer L (2017, November) Global climate risk index 2018: who suffers most from extreme weather events? Weather-related loss events in 2016 and 1997 to 2016. Germanwatch e.V., Bonn. Retrieved 21 June 2020, from https://germanwatch.org/sites/germanwatch.org/files/publication/20432.pdf

Ernstson H, Leeuw SE, Redman CL, Meffert DJ, Davis G, Alfsen C, Elmqvist T (2010) Urban transitions: on urban resilience and human-dominated ecosystems. Ambio 39(8):531–545. https://doi.org/10.1007/s13280-010-0081-9

FAO (2018, March) Institutional capacity assessment approach for national adaptation planning in the agriculture sectors. Retrieved from https://www.fao.org/in-action/naps/resources/detail/en/c/1110835/

Folke C, Carpenter SR, Walker B, Scheffer M, Chapin T, Rockström J (2010) Resilience thinking: integrating resilience, adaptability and transformability. Ecol Soc 15(4). Retrieved from https://www.ecologyandsociety.org/vol15/iss4/art20/

Gandhi S, Pethe A (2017) Emerging challenges of metropolitan governance in India. Econ Polit Weekly 52(27). Retrieved from https://www.epw.in/journal/2017/27/special-articles/emerging-challenges-metropolitan-governance-india.html

German Federal Ministry for Regional Planning, Building and Urban Development (1995, March 8) Raumordnungspolitischer Handlungsrahmen: Beschluß der Ministerkonferenz für Raumordnung. Düsseldorf. Retrieved from https://www.econbiz.de/Record/raumordnungspolitischer-handlungsrahmen-beschlu%C3%9F-der-ministerkonferenz-f%C3%BCr-raumordnung-in-d%C3%BCsseldorf-am-8-m%C3%A4rz-1995/10000927361

Hamburg Senate Chancellery (2019) The authorities of the Free and Hanseatic City of Hamburg. Retrieved April 2020, from www.hamburg.de:https://www.hamburg.de/behoerden/3733948/fachbehoerden/

Hammett L (2016) Thinking beyond the city: regional climate adaptation planning and habitat III. Retrieved 01 July 2019, from environment.yale.edu: https://environment.yale.edu/blog/2016/06/thinking-beyond-the-city-regional-climate-adaptation-planning-and-habitat-iii/

Henstra D (2012) Toward the climate-resilient city: extreme weather and urban climate adaptation policies in two Canadian provinces. J Comp Policy Anal Res Prac 14(2):175–194. https://doi.org/10.1080/13876988.2012.665215

ICLEI (2017, November) The Bonn-Fiji commitment of local and regional leaders to deliver the paris agreement at all levels. The Bonn-Fiji Commitment. citiesandregions.org. Retrieved 30 Jan 2019, from https://www.cities-and-regions.org/wp-content/uploads/2017/11/bonn-fiji-commitment-of-local-and-regional-leaders.pdf

ICLEI (2018, April) Multi-level governance to enhance integrated climate action: good practices inspiring Talanoa dialogues. In: 9th global forum on urban resilience and adaptation. Bonn, Germany: resilient.cities@iclei.org

Leichenko R (2011) Climate change and urban resilience. Curr Opin Environ Sustain 3(3):164–168. https://doi.org/10.1016/j.cosust.2010.12.014

Lhomme S, Serre D, Diab Y, Laganier R (2012) Urban technical networks resilience assessment. Taylor & Francis Group , CRC Press. Retrieved from https://www.taylorfrancis.com/chapters/edit/10.1201/b12994-18/urban-technical-networks-resilience-assessment-lhomme-serre-diab-laganier

Liao K-H (2012) A theory on urban resilience to floods—a basis for alternative planning practices. Ecol Soc 17(4). https://doi.org/10.5751/ES-05231-170448

Mahadevia D, Joshi R, Sharma R (2009, December) Integrating the urban poor in planning and governance systems, India. Centre for Urban Equity, An NRC for Ministry of Housing and Urban Poverty Alleviation, Government of India, CEPT University. Retrieved from https://cept.ac.in/UserFiles/File/CUE/Working%20Papers/Revised%20New/03CUEWP3_Integrating%20the%20Urban%20Poor%20in%20Planning%20and%20Governance%20Systems%2C%20India.pdf

Metropolregion Hamburg (2017) Spatial development in the metropolitan region of Hamburg. Retrieved 1 Dec 2019, from metropolregion.hamburg.de: https://metropolregion.hamburg.de/raumentwicklung/allgemeines/

Nachbaur J, Feygina I, Lipkowitz E, Karwat D (2017) Climate change resilience: governance and reforms. Consortium for Science, Policy and Outcomes at Arizona State University. Retrieved 15 July 2022, from https://cspo.org/wp-content/uploads/2017/01/Resilience-Governance-Reforms-Report-With-Logos.pdf

Nair KS (2009) An assessment of the impact of climate change on the megacities of India and of the current policies and strategies to meet associated challenges. Fifth Urban Research Symposium. Retrieved from http://www.indiaenvironmentportal.org.in/files/climatechange-urbansymposiumNair.pdf

OECD (2017) The governance of land use: country fact sheet Germany. Retrieved 28 Jan 2019, from oecd.org: https://www.oecd.org/regional/regional-policy/land-use-Germany.pdf

OECD (2018) Resilient cities. Retrieved 28 Jan 2019, from oecd.org: https://www.oecd.org/cfe/regionaldevelopment/resilient-cities.htm

OECD (2019) OECD territorial reviews: Hamburg Metropolitan Region, Germany. OECD Publishing, Paris. Retrieved from https://www.oecd.org/cfe/cities/Hamburg-Policy-Highlights.pdf

Pickett S, Cadenasso M, Grove J (2004) Resilient cities: meaning, models, and metaphor for integrating the ecological, socio-economic, and planning realms. Landsc Urban Plan 69(4):369–384. https://doi.org/10.1016/j.landurbplan.2003.10.035

Regional Councils of Baden Wurttemberg (2016) The administrative district Karlsruhe. Retrieved 01 Dec 2019, from https://rp.baden-wuerttemberg.de/rpk/wir/Seiten/Regierungsbezirk.aspx

Revi A, Satterthwaite D, Aragón-Durand F, Corfee-Morlot J, Kiunsi R, Pelling M, Roberts D (2014) Urban areas. In: Climate change 2014: impacts, adaptation, and vulnerability. Part A: global and sectoral aspects. Contribution of working group II to the fifth assessment report of the intergovernmental panel on climate change. Cambridge University Press, Cambridge, United Kingdom and New York, USA, pp 535–612. Retrieved 15 July 2022, from https://www.ipcc.ch/site/assets/uploads/2018/02/WGIIAR5-Chap8_FINAL.pdf

Romero-Lankao P, MGnatz D (2013) Exploring urban transformations in Latin America. Curr Opin Environ Sustain 5(3–4):358–367. https://doi.org/10.1016/j.cosust.2013.07.008

Sivaramakrishnan K, Maiti A (2009, January) Metroplitan governance in India: an overview of selected cities. Centre for Policy Research, Delhi

SUDA (2015, December 09) SUDA authority map. Retrieved 14 Apr 2020, from https://www.sudaonline.org/suda-authority-map/

SUDA (2016, May 10) Development Plan 2035. Retrieved 28 Aug 2019, from https://www.sudaonline.org/wp-content/uploads/2016/05/Full-page-photo.pdf

Tanner T, Mitchell T, Polack E, Guenther B (2009, May 13) Urban governance for adaptation: assessing climate change resilience in ten Asian cities. IDS Working Papers. https://doi.org/10.1111/j.2040-0209.2009.00315_2.x

Taru Leading Edge (2010) Asian city climate change resilience network: India chapter, phase 2: city vulnerability assessment report Indore and Surat. Vulnerability Assessment Report submited to The Rockefeller Foundation, Gurgaon & Gandhinagar. Gurgaon & Gandhinagar. Retrieved from https://www.ctc-n.org/sites/www.ctc-n.org/files/resources/indore_surat_vulnerability_and_risk_assessment_report.pdf

Taru Leading Edge (2017) Surat resilience strategy. Retrieved from https://resilientcitiesnetwork.org/downloadable_resources/Network/Surat-Resilience-Strategy-English.pdf

The World Bank (2018) South Asia's hotspots: the impact of temperature and precipitation changes on living standards. World Bank Publications, Washington DC. Retrieved 15 July 2022, from https://openknowledge.worldbank.org/bitstream/handle/10986/28723/9781464811555.pdf?sequence=5&isAllowe

UNFCCC (2014) Institutional arrangements for national adaptation planning and implementation. Adaptation Comitteee. UNFCCC. Retrieved 15 July 2022, from https://unfccc.int/files/adaptation/application/pdf/adaption_commitee_publication_-_web_high.pdf

United Nations (2014) Urbanization and sustainable development: towards a new united nations urban agenda. Retrieved 15 July 2022, from habnet.unhabitat.org: https://habnet.unhabitat.org/sites/default/files/oo/urbanization-and-sustainable-development.pdf

United Nations (2017) New urban agenda. e United nations conference on housing and sustainable urban development (Habitat III). Retrieved 15 July 2022, from https://habitat3.org/wp-content/uploads/NUA-English.pdf

United Nations (2019) Climate and disaster resilience. UNDP. Retrieved 05 May 2019, from https://www.undp.org/content/undp/en/home/climate-and-disaster-resilience.html

Wackernagel M, Kitzes J, Moran D, Goldfinger S, Thomas M (2006) The Ecological Footprint of cities and regions: comparing resource availability with resource demand. Environ Urbanization 18(1):103–112. https://doi.org/10.1177/0956247806063978

Wagner I, Breil P (2013) The role of ecohydrology in creating more resilient cities. Ecohydrol Hydrobiol 13(2):113–134. https://doi.org/10.1016/j.ecohyd.2013.06.002

Chapter 27
Comparative Urban Waste Management in Developing Countries—Case Studies of Nairobi and Johannesburg Cities of Africa

Joan Nyika and Megersa Dinka

Abstract Municipal waste management is growing to be the world's greatest environmental issue. In this chapter, urban waste management was linked to sustainable development in the cities of Johannesburg and Nairobi. Using a comparative analysis of academic literature, the chapter explored the solid waste management practices and policies the cities have implemented over time. In addition, the chapter made suggestions on the improvements that can be taken up to enhance sound solid waste management and ultimately, sustainable urban and environmental management. The results of the two case studies showed that municipal waste storage is rudimentary while waste collection and transportation to disposal areas are the most visible aspect of waste management. Nairobi City lacked an engineered landfill facility while Johannesburg had four landfills. The local governments oversaw the provision of waste services. Environmental concerns due to mismanagement of the waste were pointed out in both case studies with waste pickers having direct exposure as they search for recyclables. A policy-action gap was evident due to non-cooperation of waste regulatory agencies and poor enforcement of laws hence their poor uptake. To enhance sustainable waste management in the cities the study recommended for a change of attitude toward waste recovery and a circular economy, cooperation of stakeholders and regulatory agencies, enforcement of waste management laws and improved infrastructure to deal with the growing demand for waste services. This is possible through public–private partnerships, action-based planning and local participation in waste management undertakings.

Keywords Africa · Cities · Johannesburg · Municipal waste management · Nairobi · Environmental sustainability · Urbanisation

J. Nyika (✉) · M. Dinka
Department of Civil Engineering Science, University of Johannesburg, APK Campus 2006, Johannesburg, South Africa
e-mail: joashmada2011@gmail.com

M. Dinka
e-mail: mdinka@uj.ac.za

U. Chatterjee et al. (eds.), *Urban Commons, Future Smart Cities and Sustainability*, Springer Geography, https://doi.org/10.1007/978-3-031-24767-5_27

Introduction

Waste generation in an era of rising population, industrialisation and urbanisation has become an inevitable practice. The population of urban Africa is expected to rise from 395 million in 2010 to 1.339 billion in 2050 (Guneralp et al. 2017). With urban sprawl, environmental degradation is orchestrated by industrial and domestic activities in urban areas that result to production of wastewater and solid waste (Guneralp et al. 2017). According to Gutberlet (2017), the unavoidable production of urban waste has been prompted by the diverse nature of the waste content and the changes in consumption patterns that favour more generation and hence the need to device waste minimisation techniques as a countermeasure to the trend. The management of urban waste is a basic component in restoring environmental order, which is one of the components of sustainable development. To emphasise this opinion, Tausova et al. (2020) noted that urban or municipal waste management is not only key in restoring human health but also in protecting socio-economic interests and environments, which are key to realising sustainable development. Additionally, scientific and sound management of urban waste promotes smart and green cities. Urban centres with green economies and that are deemed to be smart value waste management because it protects their ecosystems in addition to enabling climate change adaptation (Mingaleva et al. 2020).

In sub-Saharan African (SSA) cities, urban waste management is becoming increasingly arduous as urbanisation trends increase and populations rise (Oteng-Ababio et al. 2013). Trends favouring generation of large quantities of wastes have instigated a demand for improved waste management services (Nyika et al. 2019) though the delivery of the services by municipal authorities and private sector contractors is inadequate and overwhelming. Inadequacy in delivering waste services is associated with high demand that induces financial, technical and institutional constraints at local and national governments as well as in private sectors (Nyika and Onyari 2021). In these African cities, waste management is characterised by inadequate collection among poor city dwellers, open dumping and burning of waste heaps and a population with complacency and little awareness of scientific waste management habits (Debrah et al. 2021). Consequently, the human health and environmental soundness of the regions is under threat. Although in recent times, awareness on scientific waste management in urban centres is increasing through collaborations of the private sector, NGOs and community-based organisations the urgency in managing the rising demand for waste services in African cities remains unresolved. In sharing the same sentiments, Aryampa et al. (2019) highlighted that Africa's inadequacy to manage solid waste is an impediment to achieving Sustainable Development Goals. This is because mismanagement or unscientific waste management (1) predisposes populations to illnesses associated with atmospheric, land and water pollution, (2) slows down sustainable water resources management and (3) increases adverse environmental effects in cities resulting from its impacts. Additionally, policy makers, local and national governments show lax in their political willingness to change the apparent waste mismanagement in African cities, which worsens the situation. In the light of these challenges, this chapter links urban waste management to sustainable development in two African cities. The particular focus in this case is waste management for sustainable environmental management. Using a comparative analysis based on academic literature conducted by research institutions and regulatory agencies, this chapter will focus on the solid waste management practices and policies the cities have implemented over time. Additionally, the chapter will make suggestions on the improvements that can be taken up to enhance scientific solid waste management and ultimately, sustainable environmental management.

Basic Principles of Sustainable Cities and Rationale for the Study

Economic growth influences change in urban development and dynamisms. The predisposition of urbanisation in the contemporary world is on an upward trend. According to Zhang (2016), in 1800 only 2% of the population lived in cities. The number since rose to 15% in 1900 and 54% in 2014. It is further expected that more than 70% of the world populace will live in urban areas by the 1950s (Zhang 2016). The escalating urbanisation trend is a challenge that demands adequate resource allocation and planning to the cities and their improved management for dwelling communities to grow ecologically, socially and economically sustainable (United Nations Human Settlements Program (UN-Habitat) 2020).

The urban landscape has changed significantly as a result of economic development (Park et al. 2017). In transitional economies and developing nations that are rapidly urbanising as a result of economic growth, the consequences of environmental degradation are dire due to reduced green spaces, expanded impervious surfaces, high vulnerability to extreme climate and pollution of land, atmospheric and water resources (Chen et al. 2016). Reduced open areas and expanded infrastructure in the cities culminate to disrupted ecosystems, and therefore, cities require a reorganisation towards green infrastructure (Mesjasz-Lech 2014). Characteristics of such green infrastructure include the presence of urban agricultural spaces, undeveloped ridges, urban drainage lines connected to riparian zones, public and private parks/gardens and trees (Parker and Zingoni 2019; Ying et al. 2021). In addition to environmental benefits, urban green infrastructure has social and economic benefits, which stem from various ecosystem services defined by Jansson (2013) and shown in Table 27.1. The ecosystem services facilitate life improvement sustainably. Urbanisation enhances the social conditions of city communities (Fan et al. 2019) but is also attributable to social stratifications and disparities of the poor and the rich as well as migrants and residents (Chen et al. 2016).

In the sustainable development debate, urbanisation is a key component and in particular, city planning and development intelligently. By enhancing sustainable development, city ecosystems grow and the lives of urban dwellers are improved

Table 27.1 Environmental, economic and social functions of urban ecosystems (Jansson 2013)

Function type	Description
Informative	Such functions enhance knowledge through education, research, culture enrichment in addition to aesthetic value enhancement
Productive	The functions provide resources in the form of energy, fertiliser, food, medicine, oxygen and water
Habitat-based	The functions provide spaces for recreation, tourism and cultivation
Regulatory	The functions serve to balance life support systems of the biosphere on earth. This is by the cycling of nutrients, natural air and water purification, regulation of environmental flows, biological diversity maintenance and control of soil erosion

(Fan et al. 2019). In the pursuit, cities struggle to balance between their dense populace, being energy secure and building green infrastructure useful for ecosystem and biodiversity improvement in such environs (Zhang 2016; Nyika and Onyari 2021). Guneralp et al. (2017) noted that urbanisation in Africa is challenging due to lack of basic services, poor planning, poor governing and infrastructure due to the pressures of the growing population. In a bid to enhance urban development cultured towards sustainable development, UN-Habitat set up the Sustainable Urban Development Network (SUDNet) whose role is to pursue interdisciplinary and multilateral actions to improve cities (Shaalan 2013).

Various studies try to demystify the meaning of sustainable development in cities though not in a clear-cut approach (Mesjasz-Lech 2014). Vojnovic and Darden define urban sustainable development as ‘the social, economic and physical organisation of urban population in ways that accommodate the needs of current and future generations, while preserving the natural environment and its ecological systems over time’ (2013, p. 88). In another viewpoint, sustainability of an urban area is defined as ‘… a practice that uses resources efficiently and improves the quality of life in an excellent environment within the constraints of our earth’ (Shen et al. 2012, p. 33). Haas and Troglio (2013) distinguish the three pillars of sustainable development while defining the aspects in cities. In their view, the authors define environmental sustainability as having low carbon lifestyles and more ecological awareness in cities. Social sustainability is defined as an appropriate mix of dwellings, recreational and green spaces and provision of amenities while economic sustainability refers to growth in business opportunities and activities that offer employment to city dwellers with the aim of improving their socio-economic wellbeing. Wang and Liu (2016) as well as Myers (2017) also theorised a sustainable city as one whose form is designed scientifically to suit socio-economic development and environmental conditions aimed at improved governance, optimised functions internally and externally and with dynamic equilibrium in environmental safety, social equity, risk management and economic growth. Trindade et al. (2017) also pointed out that sustainable consumption is one off the pillars of urban sustainability since it prevents waste generation amid depleting resources. As such, excessive consumption in cities is commensurate to the municipal waste produced. In cognition of the trend, it is imperative to implement waste management actions and plans aimed at reduced consumption and wasting for the development of sustainable cities as Mesjasz-Lech (2014) emphasised. Such advances as aimed in chapter will not only improve waste management in African cities but it will bring overall transformation to the politics of cities in the continent that hinder sustainable environmental management in such regions. Myers (2017) had similar views suggesting that African cities have been operating in a vacuum characterised with perennial environmental and governance problems and cultural politics that are counterproductive. The trend has to be reversed through proper restrategising and cooperative governance involving all waste management stakeholders.

Materials and Methods

In order to assay solid waste management practices and policies in African cities, two countries; Kenya and South Africa were selected and their cities, Nairobi and Johannesburg evaluated, respectively. The two were chosen due to their appropriateness in investigating the governing structures, lead approaches and policy outcomes relevant to waste management and emergent globally. In this study, academic literature and information from various regulatory authorities were evaluated for understanding of each case study. Additionally, industry reports, quantitative results and political documents were evaluated for more insight. The results of the evaluation were theoretically described and used to make recommendations on measures to take up to achieve sustainable waste management in African cities.

Results and Discussion

Urban Waste Management as an Element of Sustainable Cities

Towns are the backdrop of economic activities in both developing and developed countries. The activities in the cities subsequently lead to waste generation due to high flow of goods and services. According to Wowrzeczka (2021), waste generation in cities depends on the size of city, its spatial structure and organisation, wealth of the people and their distribution density, technology applied and regional climate. Varied literature classified waste generated in cities using specific criteria. Based on origin, waste is either municipal or industrial (Nyika and Onyari 2021). Municipal waste includes that generated at households and excludes non-toxic wastes generated from other activities but with similar composition as well as exploited vehicles.

Misuse and/or overuse of resources as well as inefficiency in city community functioning is affiliated with increased waste generation in towns. According to Liu et al. (2019), the emergence of new towns as a result of growing economies especially in developing countries results to resource consumption patterns that encourage solid waste generation. In another scenario, Zaman and Lehmann (2013) highlighted that urban space occupies only 2% of the global space but consumes 75% of resources in addition to generating more than 70% of all global solid waste. Waste generation is also linked to reducing land and water resources in that it encourages water consumption, has negative effects on the environment and creates additional costs to treat and manage wastes. Abdel-Shafy and Mansour (2018) emphasised that cities are large natural resources consumers hence result to waste generation. The authors add that waste generation is one of the greatest environmental issues of modern day and its treatment requires financial, legal, social and technological inputs that are additional costs. With these impacts of waste generation, there is need to create environmental awareness to citizens and entrepreneurs in cities to control and reverse the apparent situation. As highlighted by Debrah et al. (2021), raising awareness includes educating individuals on waste avoidance, reduction, valorisation and reuse as well as practical implementations of such undertakings. From the urgent appeal to reduce waste generation and manage it scientifically in our cities, Zaman and Lehmann (2013) proposed the zero-waste city concept that outlines the strategies of transforming the current situation to zero-waste cities. The concept has six tenets which include:

(1) Enhanced awareness, research and education on current solid waste generation and management trends
(2) Revamping the waste infrastructure through improved technology
(3) Enhancing recycling and recovery trends that encourage waste reduction, repair and reuse
(4) Adoption of sustainable behaviour and consumption patterns to reduce the use of resources
(5) Transformation of industrial designs and practices to enable cleaner production, producer responsibility and cradle-to-cradle operations and practices
(6) Stringent adherence to waste laws and regulations to reduce landfill and incineration trends, which have negative environmental impacts.

In the zero-waste concept, creating awareness through education and behaviour modifications are the long-term strategies while enforced legislation uptake and industrial redesigning are short-term plans to its realisation (Mesjasz-Lech 2014).

In many developing economies of Africa, the environmental soundness and health of residents are on a declining trend due to crippled ineffective municipal waste management systems. According to Godfrey et al. (2019), waste volumes generated in African countries are lesser than those of developed countries but their mismanagement results to environmental and human health issues. Bello et al. (2016), Nyika et al. (2019) also added that waste management in Africa is characterised by indiscriminate dumping of wastes in land and water resources worsening the already existent sanitation crises in the region. Most management approaches prefer landfilling to other alternatives due to its perceived cost-effectiveness in cleansing waste (Nyika and Dinka 2022). However, the practice is costly, takes up a lot of space, which is limited and is not acceptable socially unless its meet strict administrative and legal requirements. Landfilled waste is hazardous in that it generates greenhouse gases such as methane and produces leachate, which is toxic to land and water resources (Nyika et al. 2022). Therefore, waste prevention is not possible but its recovery is a preferred management approach. With recovery the benefits of waste recycling, reuse and valorisation are evident and reduced disposal is realised (Zhang et al. 2014). Cities whose economic growth is higher and are well-organised had higher waste recovery potential compared to low-income ones. The explanation for this trend according to Miyata et al. (2013) is that higher-income cities generate more waste but input more financial and technological expenditure to treat and recover it over time. Public investment is therefore imperative to promote sustainable waste management and development in cities. This is because the management of municipal waste plays a crucial role in economic, environmental and social management of cities and is therefore an aspect of sustainable development.

State of Waste Management in Nairobi City

Nairobi City (Fig. 27.1) has a population of more than 4.4 million people and is the largest city in Kenya. Increased rural–urban migration, growth in industrialisation and economic development have prompted a steady rise in population and an exponential growth in generation of municipal waste whose management is under the Nairobi County government (Ogutu 2019). Municipal waste management in the region is a menace since generation levels have surpassed the management capacity. According to the World Bank (2021), the city generates 2400 tonnes of municipal waste daily and out of this 20% is plastic and 45% is reused and/or recycled. By 2030, this generation rate could increase by 35% if improved management is not adopted as forecasted by Musyoka (2019). The city waste management system is therefore characterised by uncontrolled dumping, lack of a solid infrastructure, uncoordinated and unregulated intervention of the private sector and low coverage of waste services (Ogutu et al. 2020). Increased waste generation in the form of organic, inorganic and plastic wastes in the city attributable to lifestyle modifications have further overwhelmed the system (UNEP 2016). The policies guiding waste management in the city and the practices adopted are detailed in the following section.

Municipal Waste Management Policies and Practices in Nairobi City

The policies that guide solid waste management in Nairobi City can be categorised into two: (1) sector-specific and (2) issue-specific policies (Halegu et al. 2017). The latter are policies defined by the Environmental Management and Coordination Act (EMCA) of 1999 while the former, are general policies that indirectly affect waste generation and management. The policies are summarised in Tables 27.2 and 27.3, respectively. Implementation and enforcement of these laws are done in collaboration of many agencies including the national government, ministries of health

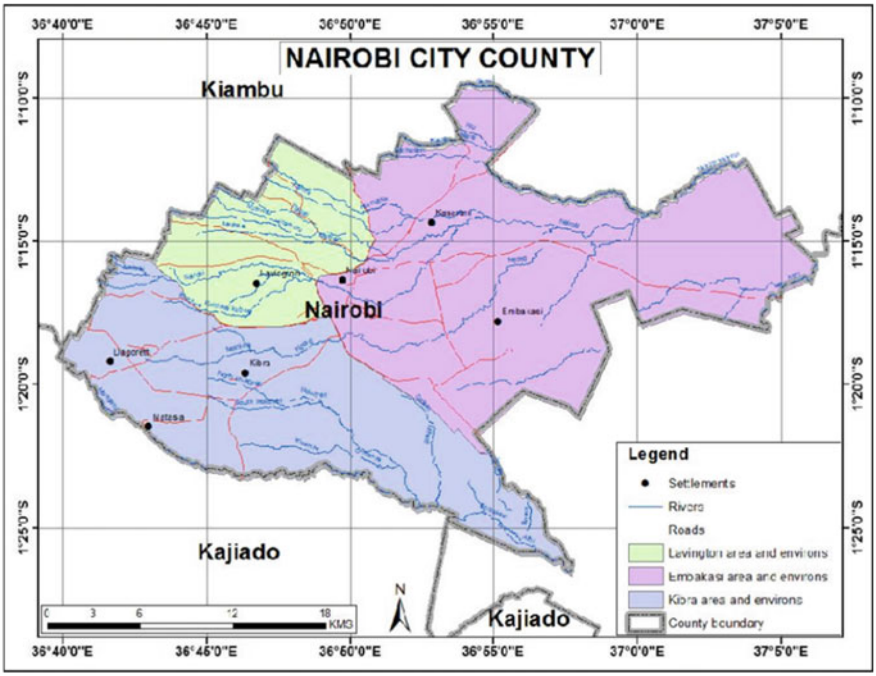


Fig. 27.1 Location of Nairobi City (Ogutu 2019)

and environment, national environmental management authority (NEMA), Nairobi County government, department of land and physical planning and the national environmental council, etc., but is overseen by the Nairobi County Council.

Although the above-mentioned are varied policies Nairobi City can exploit to manage its municipal waste, the implementation situation has worsened over time. Only about 50% of generated waste estimated at 3000 tonnes daily is collected even though generation patterns vary regionally within the city (City Council of Nairobi 2010, 2014). The city does not have a safe waste disposal facility or landfill and relies mainly on the Dandora dumpsite. The Dandora dumpsite is 26.2 ha but is set to expand as the generated waste quantities increase. Consequently, more than 75% of the waste-generated waste is not accounted for and statistic on waste produced is scanty and, in some cases, unavailable (Ogutu 2019). Additionally, more than 2000 city dwellers earn income from waste recovery and picking activities such as sorting and segregating for reuse and recycling and are exposed to hazardous and unsafe wastes directly (Halegu et al. 2017).

The growth in waste generation has not matched the management approaches in the city. Comparatively, in the 1990s, the city waste collection was rated at 90% (Gicheha 1990) but in the mid-1980s, only 20% of generated waste was collected (Esho 1997). In 2010, the collection services were rated at 33% with only 3.7% of the waste being channelled to recycling and recovery activities

Table 27.2 Sector-specific acts that regulate municipal waste management in Nairobi City (Halegu et al. 2017)

Policy/act	Function
Factories act of 1987	The act regulates the generation of waste in factories stipulating those factories and their vicinities should be kept clean and generated refuse and dirt should be removed daily
Radiation protection act of 1995	The act prohibits disposal, sale, possession and processing of radioactive material unless licenced and permitted to do so
Building code of 1995	The act prohibits the disposal of building and demolition wastes on streets
Birth and death registration act of 2012	In the act, the cremating, disposal and burying of cadavers without authorisation is prohibited
Occupational safety and health act of 2007	The act defines the operation of incinerators and plant machinery to prevent release of noxious chemicals to the environment
Physical planning act of 1996	The law makes provision, defines and designates areas that can be used for waste disposal
Food, drugs and chemical substance act of 1992	The law prohibits use and disposal of chemicals that can contaminate water and food in a manner posing danger and health hazards to humans

Table 27.3 Municipal waste management specific laws in Nairobi City (Halegu et al. 2017)

Legal notice	Function
Impact assessment and audit (2003)	The legal notice stipulates laws and procedures to licence, conduct and report environmental impact assessments
Waste management (2006)	Defines categories of wastes, procedures and rules for handling it
Water quality (2006)	The legal notice seeks to protect wastes from municipal and industrial pollution
Controlled substances (2007)	The law classifies controlled substances and defines provisions to handle them
Hazardous substances (2007)	The law prohibits disposal of hazardous substances unless licenced to do so
Air quality 2009	The legal notice seeks to prevent air pollution through activities such as municipal waste incineration and release of landfill gas

(Kasozi and Harro 2010). The trend is attributable to poor waste infrastructure to transport, sort and treat waste despite increased generation. In response to these challenges, the city and national government formulated the Kenyan solid waste management strategy in 2014 to manage waste management following complaints of poor waste services (World Bank 2018). The strategy and action plans have not borne

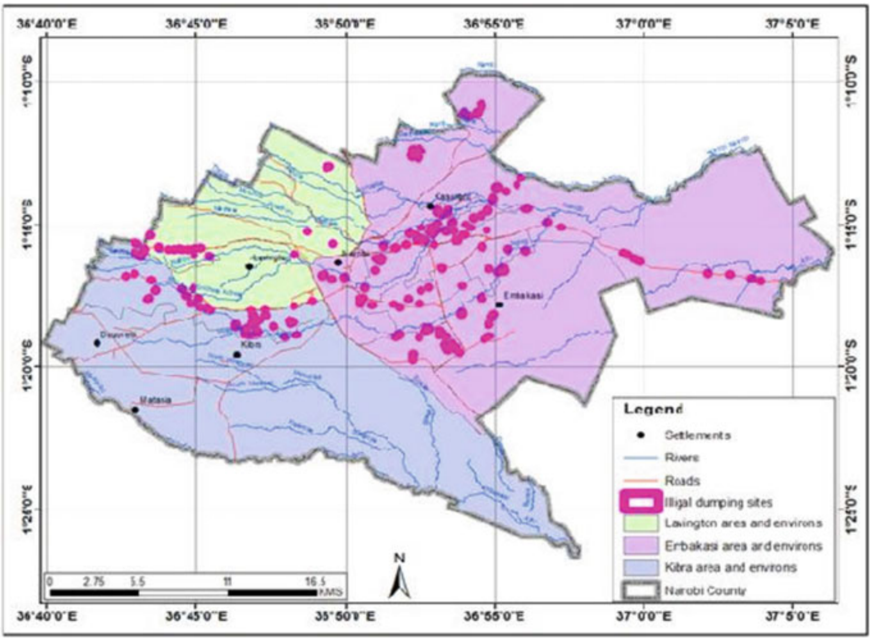


Fig. 27.2 Distribution of illegal dumping sites in Nairobi County as on 2017 (Ogutu 2019)

fruits. According to a recent study by Ogutu (2019), many illegal open dumping sites (Fig. 27.2) have emerged in the city over time showing that the waste predicaments are skewed to disposal rather than recovery.

A study by the Urban Africa Risk Knowledge, Urban-ARK (2016) in collaboration with the African population and health research centre showed that provision of waste services in Nairobi is low. Although many of the residents (76.2%) receive some form of collection services, they do not take any measures to reduce production and mix toxic and non-toxic wastes for collection, which complicates the management and treatment processes. Some of the reported statistics of the survey are summarised in Table 27.4.

The weak policy-action gap in reference to solid waste management in Nairobi City is affiliated with weak institutional management, which induces difficulty in coordinating public and private waste regulating agencies, encourages waste mixing complicating recycling and reuse undertakings, do not enforce new regulatory frameworks and have human and technological incapacities (Halegu et al. 2017; Ogutu et al. 2020). The challenges mostly affect informal settlement dwellers but are not limited to the entire city.

Table 27.4 Key indicators of solid waste management practices in Nairobi City (Urban-ARK 2016)

Municipal waste management indicator	Percentage
Receipt of some form of garbage collection services	76.2
Storage of waste in open containers	10.9
Use of informal waste disposal systems	12.0
No measures to reduce waste generation rates	56.8
Disposal of toxic wastes such as bulbs and batteries with other wastes	65.6
Burning of wastes	18.5
Perception of environment as dirty due to open dumping and waste mismanagement	44.9
Health risk from the waste, which can be rated as moderate-high	73.0
Health issues associated with municipal waste management in the last 12 months	28.2

State of Waste Management in Johannesburg City

The city of Johannesburg covers an area of 1646 km^2 (Fig. 27.3) and hosts more than 4.3 million people. It is the economic and commercial hub of South Africa and contributes 17 and 47% of the Gauteng Province and national economy, respectively (Dowling et al. 2012). It is a leading city in waste generation in South Africa (Kubanza and Simatele 2019). The city generates more than 1,500,000 tonnes of general waste yearly whose management is under Pikitup, which is an autonomous entity owned by the city of Johannesburg. In addition, about 230,000 tonnes are collected from illegal dumpsites and 88,869 tonnes from street littering (City of Johannesburg, COJ 2014). Just like other cities in developing countries, Johannesburg municipal waste is managed through landfilling, burning and dumping in open spaces (Dada and Mbohwa 2016). Involved practices include waste collection, reuse and recycling and landfill disposal (Mohee and Simelane 2015). The activities are foreseen by Pikitup in addition to collection of illegally dumped wastes and clearing street waste. The city has an integrated waste management plan that came in place in 2008 with the aim of overseeing waste services, instruments and management of funds (World Bank 2018). Collected waste is disposed in the Robinson Deep, Guodkoppies, Marie Louise and Ennerdale landfills whereby 93% of generated waste is landfilled (Chisadza 2015). Drivers such as rapid population growth and overwhelming demand for waste services to local and national government institutions have led to weaknesses and inadequacies in the city's waste management system (Nyika et al. 2019). Policies and practices towards municipal waste management in Johannesburg are detailed in the subsequent section.

Fig. 27.3 Map of Johannesburg city (Municipalities in South Africa 2022)

Municipal Waste Management Policies and Practices in the City of Johannesburg

South Africa generated 121 million tonnes of waste in 2017, which is an increase from 108 million tonnes in 2011 (Department of Environmental Affairs 2018). Most of the waste is general municipal waste consisting of 56.5% organic matter. Other portions of the composition include metals, glass, plastic and paper. Production of the waste is influenced by a number of factors. A survey by Kubanza and Simatele (2019) established that poor manage of waste, illegal dumping and littering are the main influencers of the city's waste management at 34, 35 and 21%, respectively. The city relies on various policies and legislations to regulate waste management as summarised in Table 27.5. The legislations, regulations and policies on waste management in the city is underpinned on the National Environmental Management Waste Act (NEMWA) provisions that have since been improved to the 2012 National

Table 27.5 Waste management legislations, policies and regulations of the city of Johannesburg (SAWIC 2015; Nyika et al. 2019)

Legislations	Policies	Regulations
1973 Environmental conservation act no. 73	2008 Integrate waste management policy	2003 Plastic bags and asbestos regulations
1977 Occupational health and safety act no. 85	2009 Thermal treatment of hazardous and general waste policy	2008 Waste tire regulation
1989 South African constitution act no. 108	2011 Policy on basic waste service provision to poor households	2009 National waste information regulations
1993 National water act no. 1998		2014 Regulation to phase out ozone-depleting substances
1996 National environmental management act no. 107		2015 Amended regulation on management of waste tire
1998 Municipal structures act no. 117		2016 Regulation on stockpiles and residue deposits
2000 Municipal systems act no. 32		2017 Regulation on waste imports and exports
2004 Air quality act no. 39		
2006 National Environmental Management Waste Act no. 59		
2006 National Environmental Management Waste Act no. 26		
2014 Amendments to the waste and NEMA act no. 25		

Waste Management Strategy (NWMS) (World Bank 2018). The aim of the strategy is to integrate waste management to efficient and effective use of resources at all levels of the country while at the same time, encouraging the valorisation of waste and its subsequent diversion from landfills.

Despite the many and diversified policies ensuring sound management of municipal waste, their stringent enforcement and adherence have not been realised throughout the city (Nyika et al. 2019). Consequently, impacts such as general environmental degradation, air pollution, water pollution and vegetation damage have occurred by 30, 20, 30 and 33%, respectively, as noted in a qualitative study (Kubanza and Simatele 2019). Additionally, poor municipal waste management in Johannesburg has been associated with diseases such as typhoid, tuberculosis, dysentery and diarrhoea. Wastes are dumped in open spaces where they are carried off by runoff to pollute water surfaces while those that are landfilled polluted natural resources due to the generation of leachate (Nyika et al. 2022). The city is also characterised by open dumpsites that are suitable breeding environs for disease-causing vectors. According to The Conversation (2021), more than 290,000 tonnes of waste was illegally dumped in Johannesburg between 2018 and 2019 and the situation is likely to worsen as four of the city's legal landfills will be full in the next five years. In addition to human health, the city's waste mismanagement results to harm in animals, pollutes freshwater and may injure to humans and animals if they step on hazardous wastes such as broken glasses that are dumped in public spaces (Godfrey et al. 2019).

The city of Johannesburg was one of the signatories to the Polokwane declaration whose goal was to reduce waste diversion to landfills by 50% in 2012 and realise zero waste by 2022 (Chisadza 2015). In this regard, the city was to extend the uptake of waste valorisation approaches including recycling and reuse after waste separation and sorting and conversion of waste-to-energy. Pikitup however has not realised the targets of the Polokwane declaration as landfilling is still a preferred method of waste disposal in the city and the uptake of waste valorisation is lax as noted by Nyika et al. (2019). Although coverage was rated at 98% the city was only able to divert 7% of the waste from landfills to recovery activities in addition to incurring more than R150 million to collect waste from street littering and illegal dumpsites (COJ 2014). In mid-2018, Pikitup began a pilot program to enhance waste diversion from landfill in collaboration with two private companies and set the target for collecting 50,000 tonnes of recyclables a year. However, according to The Conversation (2021), it managed to collect only 6500 tonnes of recyclables. The massive failure to collect enough recyclables is attributable to the use of private companies who deny reclaimers and waste pickers access to the recyclables during waste separation processes.

Recommendations Towards Sustainable Waste Management in African Cities

The results of the two case studies showed that municipal waste storage is rudimentary characterised by mixing of organic and inorganic wastes and with minimal attempts of waste separation. Waste collection and transportation to disposal areas using different systems are the most visible aspect of waste management with Nairobi City lacking an engineered landfill facility while the City of Johannesburg has four landfills. In both cases, waste management tendencies were found skewed to disposal rather than recovery. The local governments were active in the provision of waste services and in some cases, private organisations collaborated with them to enhance the municipal waste management system. Environmental and human health concerns due to the mismanagement of the waste amidst increased generation were pointed out in both case studies from the evaluated publications with waste pickers having direct exposure as they search for recyclables. There were attempts towards waste reduction through separation, reuse and recycling although at nascent and small-scale levels. Varied legislations, regulations and policies affiliated to waste management in both cities were described under the NEMA and NEMWA for Nairobi and Johannesburg, respectively, though a policy-action gap was evident due to non-cooperation of waste regulatory agencies and institutions and poor enforcement of laws hence their poor uptake and enforcement of the legislations.

To improve solid waste management towards environmental sustainability, this study recommends a viewpoint change for waste management and regulatory agencies with more emphasis on valorising waste. Such advances would enhance advances to waste reuse and recovery rather than disposal as is preferred in both cities. According to Kubanza and Simatele (2019), rethinking this viewpoint will encourage waste reuse and recycling considering that the preference has been on collection, transportation and disposal. Nyika and Dinka (2022) also suggested the uptake of valorisation approaches such as waste-to-energy since they have the potential to divert wastes from landfills. In another study of sustainable waste management in Indian cities, use of improved technology to separate recyclables, waste-to-energy prospects and waste segregation were suggested to prevent overreliance on landfill disposal as well as reduce the resultant waste (Kumar et al. 2017). It is also recommended that the functions of various waste stakeholders as defined in the policy frameworks of both cities be well-coordinated for effective operationalisation. Such measures ensure proper waste cycling, separation, collection and transportation treatment and scientific disposal, which has minimal impacts on the environment. To implement them could require a revision of the policy guidelines to incorporate these provisions by the enforcing authorities (Myers 2017). There is also need for public–private partnership in waste management that includes waste pickers to enhance waste sorting and subsequent diversion from landfills. This is because as indicated in the results, waste pickers play a crucial role in waste separation and soliciting for recyclables, which are diverted for recovery, reuse and recycling despite their minor recognition by relevant regulatory authorities. In the City of Lagos, Nigeria, the public–private partnership model was tested for municipal solid waste management. Overall, it had positive effects on aspects such as coverage and delivery of waste services, acquisition of vehicles to transport waste and their subsequent maintenance and enhanced human capacity of waste management personnel (Aliu et al. 2014). In both cities discussed herein, these aspects are lacking and such public–private partnerships would enhance their provision towards sustainable waste management in the regions.

Adoption of a circular economic model that encourages resource reuse, recycling, refurbishing and repairing is highly recommended. In such, a model municipal waste from the two cities will be cycled for valuable uses until its recyclable portion is exhausted. Such tendencies reduce the amount of waste diverted for disposal and also reduce the use of raw materials particularly those sourced from natural resources to manufacture final products. The circular economic model was tested in Marneuli City of Georgia and shown to be transformation if local participation is enhanced (Fehr et al. 2020). The cities of Nairobi and Johannesburg, therefore, must revamp their waste management planning systems to account for their social, economic and environmental aspects. In such a scenario, human health, efficient use of resources and environmental protection will all be prioritised. Such advances are possible by investing in new infrastructure to meet targets such as those aimed at diverting wastes from landfills and through enhanced public awareness, research and education on the diversion of waste at household levels. These solutions were found to be viable in improving municipal waste management in Zagreb City of Croatia and therefore can be replicated elsewhere (Ribic et al. 2017). A similar recommendation to enhance awareness on waste management and valorisation as well as incorporate joint action of local population, public and private sectors was made in a study to enhance sustainable waste management in fifteen towns of Recife Metropolitan Region of Brazil (Juca et al. 2020).

Conclusion

The Cities of Nairobi and Johannesburg have had progressive development of solid waste management regulations, laws and policies over time. However, this study found the progress towards better waste management to be slow due to poor policy enforcement, lax of the regulatory institutions in the cities amidst pressures from industrialisation, urbanisation and population rise resulting to more waste generation tendencies. While the outlook of the policies was towards bettered delivery of waste services, more ecological, economic and social outlooks need to be inculcated to ensure environmental protection is realised, economic proceeds are gained and aesthetic value of the environment is enhanced during municipal waste management undertakings. The advances can be realised by adopting circular models that encourage waste valorisation and recovery rather than promote waste disposal unlike the current situation observed in the two cities. As such, the need to involve all stakeholders in policy formulation and implementation and enforce existent policies is priority. This study emphasised the need to involve waste pickers who play a major role in waste separation and soliciting for recyclables. Participation of all stakeholders will balance the sustainable development aspects of waste management and make it an all-involving affair. Waste services also need to be extended to uncovered areas in both cities, which demands an overhaul in the municipal waste management implementation oversight and structure. Therefore, institutions and regulatory institutions involved must rise to the occasion in their assigned responsibilities in waste cycling while actively involving the waste generators for cooperative management. Despite the progressive evolution of policies in waste management in the cities, a policy-action gap was evident based on the evaluated publications and reports in this study. To close the gap, the focus must shift from disposal to valorisation and recovery of waste through strengthened implementation, modification and enforcement of policies towards sustainable waste management in the cities. Additionally, all stakeholders must be involved for cooperative management of the waste cycle.

References

Abdel-Shafy H, Mansour M (2018) Solid waste issue: sources, composition, disposal, recycling and valorization. Egypt J Pet 27(4):1275–1290. https://doi.org/10.1016/j.ejpe.2018.07.003

Aliu I, Adeyemi O, Adebayo A (2014) Municipal household solid waste collection strategies in an African megacity: analysis of public private partnership performance in Lagos. Waste Manage Res 31(9):67–78. https://doi.org/10.1177/0734242X14544354

Aryampa S, Maheshwari B, Sabiiti E, Bateganya N, Bukenya B (2019) Status of waste management in the East African cities: understanding the drivers of waste generation, collection and disposal and their impacts on Kampala city's sustainability. Sustainability 11:5523. https://doi.org/10.3390/su11195523

Bello I, Ismail M, Kabbashi N (2016) Solid waste management in Africa: a review. Int J Waste Resour 6(2):1000216. https://doi.org/10.4172/2252-5211.1000216

Chen J, Zhu L, Fan P, Tian L, Lafortezza R (2016) Do green spaces affect the spatiotemporal changes in P.M2.5 in Nanjing? Ecol Process 5(7):1–5. https://doi.org/10.1186/s13717-016-0052-6

Chisadza C (2015) Solid waste management (SWM) in Johannesburg: alternative futures. MSc. thesis, Stellenbosch University, South Africa

City of Johannesburg (COJ) (2014) Integrated annual report 2012/2013 (abridged version). Available online from https://www.joburg.org.za/Campaigns/Documents/2014%20Documents/annexure%20a.pdf

City Council of Nairobi (2010) Integrated solid waste management plan for the city of Nairobi, Kenya: 2010–2020, Nairobi

City Council of Nairobi (2014) Nairobi city county solid waste management bill, Nairobi.

Dada OR, Mbohwa C (2016) Municipal solid waste from landfills: a solution to the energy crisis in South Africa. University of Johannesburg, Johannesburg

Department of Environmental Affairs, (DEA) (2018) South Africa state of waste. A report on the state of the environment. First draft report. RSA, Pretoria

Debrah J, Vidal D, Dinnis M (2021) Raising awareness on solid waste management through formal education for sustainability: a developing countries evidence review. Recycling 6(1):6. https://doi.org/10.3390/recycling6010006

Dowling M, Kibaara S, Chowdhury S, Chowdhury S (2012) Economic feasibility analysis of electricity generation from landfill gas in South Africa. In: Paper presented at the IEEE international conference on power system technology (POWERCON), Auckland, New Zealand, October 30–November 2. https://doi.org/10.1109/PowerCon.2012.6401430

Esho L (1997) An assessment of the role of the private sector in urban infrastructure service provision: a case of solid waste management in the city of Nairobi. Msc. thesis, University of Nairobi

Fan P, Ouyang Z, Nguyen D, Park H, Chen J (2019) Urbanization, economic development, environmental and social changes in transitional economies: Vietnam after Doimoi. Landsc Urban Plan 187:145–155. https://doi.org/10.1016/j.landurbplan.2018.10.014

Fehr A, Urushadze T, Zoller N, Knerr B, Ploeger A, Vogtmann H (2020) Establishing a sustainable waste management system in a transitional economic context: analysis of the socio-economic dynamics. Sustainability 12(9):3887. https://doi.org/10.3390/su12093887

Gicheha M (1990) Solid waste management in Nairobi metropolis, University of Nairobi. Msc. thesis, University of Nairobi

Godfrey L, Ahmed M, Gebremedhin K, Katima J, Oelofse S, Osibanjo O, Richter U, Yonli A (2019) Solid waste management in Africa: governance failure or development opportunity? https://doi.org/10.5772/intechopen.86974

Guneralp B, Lwasa S, Masundire H, Parnell S, Seto K (2017) Urbanization in Africa: challenges and opportunities for conservation. Environ Res Lett 13:015002. https://doi.org/10.1088/1748-9326/aa94fe

Gutberlet J (2017) Waste in the city: challenges and opportunities for urban agglomerations. In: Ergen M (ed) Urban agglomeration. IntechOpen Publishers, London. https://doi.org/10.5772/intechopen.72047

Haas T, Troglio E (2013) Sustainable urban cells and the energy transect modeling: reconciling the green and the urban. In: Proceedings of 53rd ERSA congress regional integration: Europe, the Mediterranean and the world economy. Palermo, Italy, paper 377

Halegu T, Ziraba A, Aboderin I, Amugsi D, Muindi K, Mberu B (2017) An assessment of the evolution of Kenya's solid waste management policies and their implementation in Nairobi and Mombasa: analysis of policies and practices. Environ Urban 29(2):515–532. https://doi.org/10.1177/0956247817700294

Jansson A (2013) Reaching for a sustainable, resilient urban future using the lens of ecosystem services. Ecol Econ 86:285–291. https://doi.org/10.1016/j.ecolecon.2012.06.013

Juca J, Barbosa K, Sobral M (2020) Sustainability indicators for municipal solid waste management: a case study of the Recife Metropolitan Region, Brazil. Waste Manage Res 1–5. https://doi.org/10.1177/0734242X20941088

Kasozi A, Harro B (2010) Solid waste management in Nairobi: a situation analysis. City Council of Nairobi/United Nations Environment Program

Kubanza N, Simatele M (2019) Sustainable solid waste management in developing countries: a study of institutional strengthening for solid waste management in Johannesburg, South Africa. J Environ Plann Manage. https://doi.org/10.1080/09640568.2019.1576510

Kumar S, Smith S, Fowler G, Velis C, Kumar S, Arya S, Kumar R, Cheeseman C (2017) Challenges and opportunities associated with waste management in India. Royal Soc Open Sci 4:160764. https://doi.org/10.1098/rsos.160764

Liu J, Li Q, Gu W, Wang C (2019) The impact of consumption patterns on the generation of municipal solid waste in China: evidences from provincial data. Int J Environ Res Public Health 16:1717. https://doi.org/10.3390/ijerph16101717

Mesjasz-Lech A (2014) Municipal waste management in context of sustainable urban development. Procedia Soc Behav Sci 151:244–256. https://doi.org/10.1016/j.sbspro.2014.10.023

Mingaleva Z, Vukovic N, Volkova I, Salimova T (2020) Waste management in green and smart cities: a case study of Russia. Sustainability 12(1):94. https://doi.org/10.3390/su12010094

Miyata Y, Shibusawa H, Hossain N (2013) An economic analysis of municipal solid waste management of Toyohashi city, Japan. Evidences from environmental Kuznets curve. In: Proceedings of 53rd ERSA congress regional integration: Europe, the Mediterranean and the world economy. Palermo, Italy

Mohee R, Simelane T (2015) Future directions of municipal solid waste management in Africa. Africa Institute of South Africa, Pretoria

Municipalities in South Africa (2022) City of Johannesburg metropolitan municipality. Available online from https://municipalities.co.za/map/2/city-of-johannesburg-metropolitan-municipality

Musyoka M (2019) Assessment of community perception, policies and land use factors in relation to climate change processes in Nairobi city. PhD thesis, JKUAT

Myers G (2017) Disposable cities: garbage, governance and sustainable development in urban Africa. Taylor and Francis, USA

Nyika J, Onyari E, Mishra S, Dinka M (2019) Waste management in South Africa. In: Pariatamby A, Hamid F, Bhatti M (eds) Sustainable waste management challenges in developing countries. IGI Global, USA

Nyika J, Onyari E (2021) A review on solid waste management using the DPSIR framework in a Southern Africa case study. In: Rathoure A (ed) Handbook of research on waste diversion and minimization technologies for the industrial sector. IGI Global, USA

Nyika, J, Dinka M (2022) Converting solid waste materials to energy: a review. Mater Today Proc. https://doi.org/10.1016/j.matpr.2022.03.240

Nyika J, Dinka M, Onyari E (2022) Effects of landfill leachate on groundwater and its suitability for use. Mater Today Proc. https://doi.org/10.1016/j.matpr.2022.03.239

Ogutu F (2019) Assessment of the effectiveness of the policy framework on solid waste management in Nairobi, Kenya. PhD thesis, University of Nairobi

Ogutu F, Kimata D, Kweyu R (2020) A critique on sustainable cities waste management predicaments; case of Nairobi city, Kenya. J Appl Sci Environ Manage 24(10):1801–1810. https://doi.org/10.4314/jasem.v24i10.14

Oteng-Ababio M, Arguello J, Gabbay O (2013) Solid waste management in African cities: sorting the facts from the fads in Accra, Ghana. Habitat Int 39:96–104. https://doi.org/10.1016/j.habitatint.2012.10.010

Park H, Fan P, John R, Chen J (2017) Urbanization on the Mongolian Plateau after economic reform: changes and causes. Appl Geogr 86:118–127. https://doi.org/10.1016/j.apgeog.2017.06.026

Parker J, Zingoni M (2019) Green infrastructure in the urban environment: a systematic quantitative review. Sustainability 11:3182. https://doi.org/10.3390/su11113182

Ribic B, Voca N, Ilakovac B (2017) Concept of sustainable waste management in the city of Zagreb: towards the implementation of circular economy approach. J Air Waste Manag Assoc 67(2):241–259

Shaalan I (2013) Sustainable urban transformation in small cities in Egypt: a UN-habitat perspective. J Clean Prod 50:200–204. https://doi.org/10.1016/j.jclepro.2012.11.022

Shen L, Peng Y, Zhang X, Wu Y (2012) An alternative model for evaluating sustainable urbanization. Cities 29:32–39. https://doi.org/10.1016/j.cities.2011.06.008

South African Waste Information Centre (SAWIC) (2015) Waste classification and management regulations, norms and standards. Available online from http://sawic.environment.gov.za/documents/2177.pdf

Tausova M, Mihalikova E, Culkova K, Stehlikova B, Taus P, Kudelas D, Strba L, Domaracka L (2020) Analysis of municipal waste development and management in self-governing regions off Slovakia. Sustainability 12:5818. https://doi.org/10.3390/su12145818

The Conversation (2021) Johannesburg is threatening to sideline informal waste pickers. Why it's a bad idea. Available online from https://theconversation.com/johannesburg-is-threatening-to-sideline-informal-waste-pickers-why-its-a-bad-idea-159969

Trindade E, Hinnig F, Costa E, Marques J, Bastos R, Yigitcanlar T (2017) Sustainable development of smart cities—a systematic review of the literature. J Open Innov Mark Complex 3(11):1–14. https://doi.org/10.1186/s40852-017-0063-2

UN-Habitat (2020) World cities report 2020: the value of sustainable urbanization. UN-Habitat, Nairobi, Kenya

United Nations Environmental Program (UNEP) (2016) Frontiers 2016: emerging issues of environmental concern. Available online from https://www.unep.org/resources/frontiers-2016-emerging-issues-environmental-concern

Urban Africa Risk Knowledge (2016) Solid waste management and risks to heath in urban Africa: a study of Nairobi and Mombasa cities in Kenya. Nairobi, Kenya

Vojnovic I, Darden JT (2013) Class/racial conflict, intolerance, and distortions in urban form: lessons for sustainability from the Detroit region. Ecol Econ 96:88–98. https://doi.org/10.1016/j.ecolecon.2013.10.007

Wang M, Liu J (2016) Theoretical analysis of the concept of a sustainable city. Chin J Urban Environ Stud 4(4):1650029. https://doi.org/10.1142/S2345748116500299

World Bank (2021) Battling Kenya's plastic waste: young Kenyan woman is transforming waste into sustainable and affordable building materials. World Bank Group

World Bank (2018) What a waste 2.0. A global snapshot of solid waste management to 2050. The World Bank, Washington DC, USA

Wowrzeczka B (2021) City of waste-importance of scale. Sustainability 13:3909. https://doi.org/10.3390/su13073909

Ying J, Zhang X, Zhang Y, Bilan S (2021) Green infrastructure: a systematic literature review. Econ Res. https://doi.org/10.1080/1331677X.2021.1893202

Zaman AU, Lehmann S (2013) The zero-waste index: a performance measurement tool for waste management systems in a 'zero waste city.' J Clean Prod 50:123–132. https://doi.org/10.1016/j.jclepro.2012.11.041

Zhang Y, Huang G, He L (2014) A multi-echelon supply chain model for municipal solid waste management system. Waste Manage 34:553–561. https://doi.org/10.1016/j.wasman.2013.10.002

Zhang X (2016) The trends, promises and challenges of urbanization in the world. Habitat Int 54(3):241–252. https://doi.org/10.1016/j.habitatint.2015.11.018

Chapter 28
The City Green Landscapes: Environmental Benefits and Typologies of Green Landscapes in Delhi

Meenakshi Pawar and Meenakshi Dhote

Abstract Green landscapes help and provide many environmental benefits that will improve the air quality, water quality, biodiversity and habitat protection. The negative impact and pressure of an increase in population affect the environment locally, regionally and globally. Major environmental challenges which the cities are facing nowadays are the episodes of urban floods, urban heat, pollution, earthquakes, pandemics, etc. It is agreed through different literature that green landscapes are essential for the wellbeing of the people. Environmental strategies for an urban area need to be supported by several factors that are biotic and abiotic. The ecosystem services in the cities and the chain of the ecosystem's sustainability help to overcome the issues of environmental stresses in urban areas. Vegetation is considered one of the important biotic factors that immensely protects the environment and its surroundings in several ways. The density and spatial configuration of urban green landscapes like the canopy covers, buffers along the roads and patches of greens in between the built-up areas affect immediate environments and help in regulating the land surface temperatures and improve both local and city-wide urban air quality. This chapter will focus on the different typologies and environmental services of urban green landscapes in Delhi. The green landscapes in Delhi are maintained by various organisations and that is mainstream at the levels of spatial plans. The Planning Norms have tried to mainstream green landscapes but still, the green landscapes are in process of incorporating the different current environmental challenges like Climate Change, Urban Heat Islands effects and Air Pollution Management. Well-planned and designed green landscapes along different land uses have positive impacts on the environment.

Keywords Urban green landscapes · Environmental benefits · Typologies urban green landscapes

---

M. Pawar (✉) · M. Dhote
Department of Environmental Planning, School of Planning and Architecture, New Delhi, India
e-mail: meenakshiphd210ep18@spa.ac.in

M. Dhote
e-mail: m.dhote@spa.ac.in

U. Chatterjee et al. (eds.), *Urban Commons, Future Smart Cities and Sustainability*, Springer Geography, https://doi.org/10.1007/978-3-031-24767-5_28

Introduction

Urbanisation also refers to the expansion of the urban population scale and the corresponding series of economic and social changes (Wang et al. 2015). Urbanisation features are one of the important events in the development history that also produces environmental challenges, but development also creates opportunities for the cities to grow that can contribute to border visions of improving the quality of life of the people and its surroundings. Activities in urban areas have negative and positive impacts at different scales of spatial development and on green spaces.

India has the tenth-largest forest area in the world. In 2020, India ranked third globally in increasing its forest area from 2010 to 2020. The forests covered 24% of India's total geographical area, accounting for two percent of the world's total forest area in 2020.

Green landscapes in urban areas are manicured, cleaned and designed and have not much native vegetation. Landscapes depend on the different spatial scales in the city elucidated to many typologies: parks, gardens, cemeteries, tot lots, green buffers, etc. (Doherty 2017). Green infrastructure is the term coined that has soft as well as hard landscapes in their nature of designing. Green landscapes categorically viewed by the human eye are the different shades of greens, different patterns, shapes and sizes.

Urban green spaces provide various ecological, social and cultural services such as air and water purification, groundwater recharge, noise reduction, recreational purposes, social gatherings and many cultural activities. Increasing the green spaces in urban areas has a significant reduction in air temperatures and air quality purification (Ashraf et al. 2015).

Developmental plans are more focused on the economic development of the city and do give strict compliances or guidelines on how to integrate or protect green spaces in urban planning. The Government prioritised large-scale infrastructure projects to increase the local GDP and propel a world-class urban city. The integration of green infrastructure with the development plans interchangeably gives a way towards sustainable development spatially.

In the Indian context, there is a need to work on multiple spatial scales to adapt to changing precipitation dynamics focusing both on the installation of local solutions and developing zoning regulations for the integration of green landscapes for multi-functional urban systems. A strong interrelation between population growth, urbanisation and decreasing urban greens has been established by various literature; consequently, urban dwellers suffer from various kinds of pollutants-induced diseases. As the urban population has grown at a rapid pace during the past few years, the landman ratio in the cities is also shrinking which is impacting the urban green spaces (Ashraf et al. 2015).

Environmental Benefits of Urban Green Landscapes

Ecological Benefits

(a) Biodiversity and Nature Conservation: Urban landscapes host large amounts of biodiversity. 13 biodiversity indicators for both habitat and species diversity are taken into account for the monitoring study of urban parks in Flanders, North Belgium, the study concluded that Urban and suburban parks may be considered important 'hotspots' of biodiversity in cities (Cornelis and Hermy 2004). Green landscapes surrounding the urban build forms have less biodiversity as compared to the natural habitats or nondisturbed landscapes. Urban green spaces often contain simplified habitats with midstory vegetation with native grounds (Hatcher and Yu 2018) that prevent damage to the natural landscape, biodiversity and natural habitat. Such green spaces improve the quality of air, and canopy covers reduce the noise levels.

(b) Climate Improvement: Climate change will have far-reaching consequences for urban areas. Green landscapes affect weather and climate, and they influence both the albedo of the area and the amount of water vapor and carbon dioxide in the air.

(c) Temperature Reduction: Due to anthropogenic activities, the urban heat island (UHI) effect is primarily increased in the surroundings of densely built environments. But green landscapes surrounding the built forms help to regulate the local climate and heat sources in the area (Jin et al. 2018). Urban temperatures can be strategically handled through a network of planned urban green spaces. Urban landscapes have a cooling effect of between 2° and 8° due to increases in evapotranspiration (Fam et al. 2008).

(d) Water Efficiency: Green landscapes recharge the groundwater and improve the quality of surface water. Urban-built forms can be designed with green roofs and rain gardens, and bioswales that improve groundwater recharge reduce local flooding and improve the quality of water. These remedies are small-scale interventions that have little impact on the large-scale environmental disasters that pose the greatest danger to urban infrastructure and communities (Davis and Naumann 2017). Urban green landscapes have a positive impact on the hydrological characteristics of the highly modified urban catchments. Ground covers help in water recharge and infiltrations with effective removal of significant amounts of pollutants such as phosphorus, lead and nitrogen and fine sediments (Fam et al. 2008).

Pollution Abatement

(a) Air Pollution: Trees, Plants and the groundcovers have a variable capacity to capture or filter the air pollutants and absorb the gasses, which improves the air circulation and decreases the ambient temperatures (Impact of green space on Heat and Air pollution in urban communities: A meta-narrative Systematic Review, 2015). Air pollution has a severe impact on roadside trees, but many trees have a high air pollution tolerance index (APTI), trees such as people, neem and Sheesham are found to be the highest APTI along the roads (Erum and Satish 2020).
(b) Noise Pollution: Thick buffers of vegetation can reduce the noise limits, and it is expected to design large green landscapes from the beginning of the planning of the area (Gonzalez-oreja et al. 2010). In the urban residential environment to strive for lower sound levels and to ensure 'noise-free' places, it is mandated to protect, preserve and even increase the supply of urban green landscapes (Gidlof-Gunnarsson and Ohrstrom 2007). To design the cities and green areas like green belts/buffers/shelter belts/avenues to be created as noise barriers, it is essential to consider the bed of native species with high canopy volume and considerable foliage (Maleki et al. 2011).

Psychological Benefits:

(a) Recreational: Different typologies of green landscapes have different varieties of recreational facilities, for example, Tot lots, Neighbourhood parks are simply close to residential areas people and children can easily access everyday recreational activity. Recreational activities will include playing, walking, meditation, yoga, exercise, etc.
(b) Mental Health: People can attain physical, mental and spiritual healing by simply spending time out of doors in the parks, forest areas, near the mountains, or in, isolated spaces, where they can spend time with nature (Gesler 2003).

Economic Benefits

Mostly, the urban green landscapes are under local urban bodies that facilitate commercial, income income-generating from the fest, fairs and sports events. Economic efficiency results in net social welfare, typically in the form of reduced costs to society, such as reduced healthcare costs. Vegetations are the free source that improves the air, water and land pollution and provides oxygen to the people. Private property value on natural open space is higher as compared to the without an open space amenity. Implementation of green roofs and other urban green infrastructures has the potential cost-saving in building energy consumption.

Energy–Saving Benefits

(a) Efficient transport management: Green landscapes along the roads increase the opportunities for non-motorised movement, bicycling and pedestrian-friendly networks.
(b) Energy efficiency: Vegetation on the roofs or Roof gardens. Vertical gardens are the potential to reduce the load on-grid power supply. Many studies conducted show that healthy urban green spaces, in the conditions of drought shown to be a positive potential for energy consumption and cost-saving (Cornelis and Hermy 2004).

Typologies of Urban Green Landscapes in the Hierarchy of Spatial Plans in Urban Areas

Urban green landscapes are an important contributor and significant part of sustainable development. Developments of green spaces need to consider interdisciplinary and integrative approaches such as economic, political, social, cultural, management and planning aspects to improve existing landscapes and optimise landscapes' policies (Hartswick 2013).

Green spaces in urban landscapes are one of the important land uses that provide several ecological services. As the availability of green spaces is scarce in cities, this planner are usually faced with conflicting challenges. Green city modules such as street orientation concerning sun direction, prevailing wind direction, and albedo effects help in reducing the negative impacts of the built spaces.

Existing Hierarchy of Spatial Plans in Delhi NCR

The size and hierarchy of the maps used to depend on the size of the planning area and the coverage of the information to be shown. The spatial scales and typology of urban green landscapes are shown in the Table 28.1. The hierarchy of urban green landscape in Delhi NCR is related to different scales of spatial planning through different guidelines, master plans and zonal plans.

The existing status of the organised green landscapes by different urban local bodies in the cities makes a sincere effort to analyse the proportion of an area under the categorisation of parks.

As per the guidelines of Urban and Regional Development Plans Formulation and Implementation (URDPFI), the open spaces/green spaces are categorised into recreational spaces, organised green and other common open spaces (such as vacant lands/open spaces including floodplains and forest cover). Considering open spaces/green spaces including the above-mentioned categories, provision of

Table 28.1 Spatial scales and typology of urban landscapes

S. No	Spatial scales	Urban green landscapes
1.	Regional scale 1:250,000–1:100,000 (for larger regions) 1:100,000–1:50,000 (for smaller regions)	1. Forest • Dense green • Open scrub • Non-agricultural plantation 2. Wasteland • Gullied land • Waterlogged area • Barren land • River sand 3. Agriculture • Cultivated land • Open scrub • Non-agricultural
2.	City 1:50,000–1:25,000 (District development plan) 1:25,000–1:10,000 (Metropolitan region plan)	1. Regional park/biodiversity parks 2. City park 3. City multi-purpose grounds 4. Heritage areas 5. Greens along MRTS, highways, expressways 6. Airports 7. Flood plains 8. Forests 9. Buffers along railway lines 10. Institutional greens 11. Green belt
3.	Zonal 1:10,000–1:8000 (as per state provision)	1. District park 2. Community park 3. District multi-purpose ground 4. Greens along arterial and subarterial roads 5. Graveyards/cemeteries and burning Ghats 6. Sports facilities 7. Horticulture areas/nurseries 8. Vegetable farms/orchards
4.	Local 1:5000–1:1000 (as per the requirement of the project)	1. Neighbourhood park 2. Housing area park 3. Community multi-purpose ground 4. Tot lot at housing cluster level 5. Local road side plantation 6. Traffic islands

Source Urban and Regional Development Plans Formulation and Implementation (URDPFI) Guidelines, 2015, Master Plan of Delhi, 2021

10–12 m^2 per person is desirable. The number of organised green spaces is depend on the planning units. Different scales of planning units have different typologies of organised greens, for example botanical greens, zoological parks, local parks, playgrounds, sports complex etc. shown in Table 28.2.

As per the guidelines mentioned in National Building Code (NBC), 2005.

1. Open spaces/maidans should be spatially distributed and multiple functions in time to be promoted.
2. In any layout or subdivision of land measuring 0.3 ha or more in residential and commercial zones, the community open space shall be reserved for recreational purposes which shall as far as possible be provided in one place.
   (a) The minimum recreational space provided shall be 450 m^2.
   (b) The minimum average dimension of the recreational space shall not be less than 7.5 m, and the length shall not exceed 2.5 times the average width.
3. Each recreational area and the structure on it shall have an independent means of access.
4. Any building line is to be at least 3 m away from the boundary of recreational open space.
5. Zoological garden is to be as per central zoo authority provisions.

As per the Master Plan Delhi (MPD), 2021.

The green spaces/open spaces are categorised under the green belt along the border of NCT Delhi (Table 28.3).

Table 28.2 Hierarchy of organised green

S. No	Planning unit	Number of organised green spaces
1.	Housing cluster	3–4 local parks and playgrounds
2.	Neighbourhood	3–4 local parks and playgrounds
3.	Community	2–3 local parks and playgrounds
4.	District/zone	1 district-level park and sports centre, maidan
5.	Subcity centre	1 city-level park, sports complex, botanical/zoological garden, maidan

Source Urban and Regional Development Plans Formulation and Implementation (URDPFI) Guidelines, 2015, Ministry of Housing and urban affairs

Table 28.3 Hierarchy of urban landscape

S. No	Use zone	Activities permitted
1.	Green belt	Forest, agriculture use, vegetation belt, wildlife sanctuary, bird sanctuary, biodiversity park, plant nursery, orchard, floriculture, open playground, agroforestry
2.	Regional park	Biodiversity parks, ridge (Aravalli forest), shooting range, botanical garden, zoological garden
3.	City park	Aqua park, arboretum, open playground, botanical garden
4.	District park	The theme park, children's park, orchard, specialised park, children's traffic park, area for water harvesting, archaeological park, national memorial

Source Master Plan Delhi, 2021

Mainstreaming the Urban Green Landscapes in Urban Areas

Environmental planning is the planning of the natural resources, planning initiated through the base plan for better living environments and improvement of natural resources. Climate change and other environmental concerns cannot be mitigated only by providing green landscapes. This will have to be coupled with sustainable land management strategies. Planning the urban areas with the integration of green landscapes is a comprehensive task. All the different spatial plans at different levels from perspective plans to master plans, zonal plans and district plans are developed based on the size and character of the city.

Green spaces are rigorously decreased in many cities of India and are further decreasing with growing urbanisation and population increase. With the rising urban population, the per capita availability in many urban areas has reduced drastically and can be expected to decrease further (Govindarajulu 2014).

Mainstreaming of green spaces with urban areas and with spatial plans is studied by several countries that are having a positive impact on the environment but there are many hurdles to incorporating the techniques on the ground. In addition, in some countries there is a need for collaborative action on many fronts—social, economic, political and regulatory (Campbell et al. 2016). Integration of green spaces/green landscapes in the developmental plans is the need of the hour; in a few countries, it is adapted but still integration concerning climate change is pending. However, park size, shape, or location in the urban area have generally been determined by forces of urban planning and design; because of this, the capacity of urban parks and open green spaces improves the local environment (Gonzalez-oreja et al. 2010).

To moderate and eventually curb the environmental impacts of urbanisation, sustainable ways of planning are required planning and design of landscape around the urban built forms with high APTI trees support in reducing the environmental stress levels. In 2014, after severe flooding events affected 137 cities in China, the Chinese government decided to invest heavily into green infrastructure and create ‘sponge cities’ through a pilot construction program (Jin et al. 2018).

International and National Initiatives for Creating Blue-Green Infrastructures

Through different literature studies, the initiative is taken by different government departments to boost the green–blue infrastructure (Table 28.4).

Table 28.4 Initiative at international and national levels

S. No	Scale	Location	Initiative
At international level			
1.	City	Wuhan, China	Sponge city program
2.	City	Vancouver, Canada	Rain city
3.	City	Singapore	Active beautiful, clean (ABC) water program
4.	Regional	Hoeksche, Netherlands	Agro-land improvement through blue-green networking
5.	Regional	30 locations, Netherlands	Room for the river
6.	City	Portland, US	Gray to green
At national level			
7.	City	Delhi	Blue green policy, master plan 2041
8.	City	Bhopal	Blue green master plan, 2025
9.	City	Hubbali-Dharwad	Green mobility corridor
10.	City	Surat	Creating "wild valley bio-diversity park" as city lungs by rejuvenation of existing wasteland along the creek
11.	City	Bhubaneswar	B-active—parks, open spaces and public spaces up-gradation leads to creating gender-neutral open spaces

Source Observer Research Foundation, Occasional paper, 2021

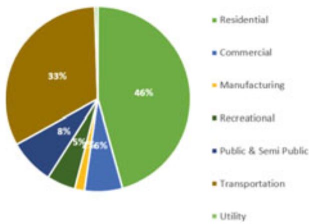
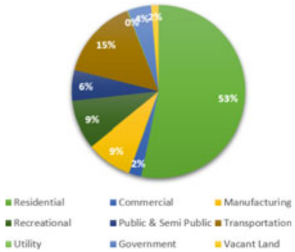
Urban Green Landscapes of Delhi

Delhi has a much larger green cover as compared to other metropolitan cities in the country and is called a green city. The percentage of green areas in Delhi as per the Master Plan Delhi 2021 constitutes 8722 ha, which is around 19% of the total urban land area of 44,777 ha. This includes the greens under the forest area (Delhi ridge), and the balance area under green land use is about 7145 ha, in the form of district parks, city parks, community parks, etc., comprising around 15% of the total urban land area. In addition to this, other green land uses include neighbourhood parks, tot lots in the residential areas, institutional areas like Jawaharlal Nehru University (JNU), Indian Institute of Technology (IIT), Delhi Technical University (DTU) and Delhi University, and plantation along drains and roadside plantations. In the urban extension of Delhi, the green cover is to be provided at the rate of 15% of the total land.

The distribution of green spaces given in the different zonal plans of Delhi indicates different green land uses in Delhi (Table 28.5).

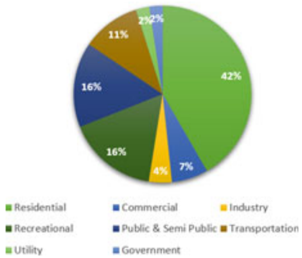
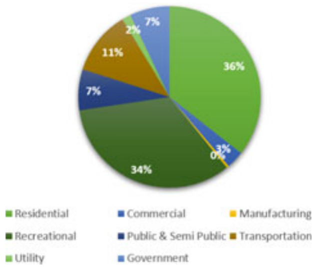
The different zonal plans of Delhi show the percentages of the green spaces and the typologies of urban green land uses (Fig. 28.1), and these green spaces are spatially shown in Fig. 28.2. The green land uses categories as mentioned in

Table 28.5 Distribution of green spaces in green land uses in different zones of Delhi

Zones/zonal plan		Land uses	Green land uses
Zone-A			Parks and open spaces • Netaji Subhash Park • Gandhi Ground, open area around Red Fort • Sports complex, Railways station stadium • Neighbourhood parks and play areas
Zone-B			Neighbourhood parks and playgrounds

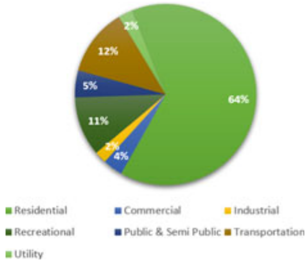
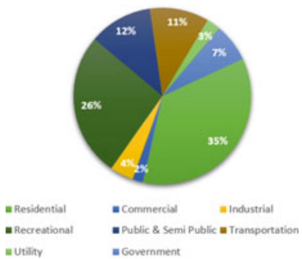
(continued)

Table 28.5 (continued)

Zones/zonal plan		Land uses	Green land uses
Zone-C			• Northern ridge • Greens surrounding historical monuments • District parks • Bungalow areas with large backyards • Sports complexes
Zone-D			• Greens in government offices • Central vista • Central ridge • Bungalow zone

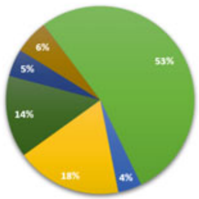
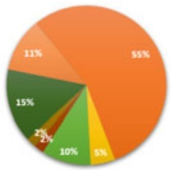
(continued)

Table 28.5 (continued)

<table>
<tr><th>Zones/zonal plan</th><th></th><th>Land uses</th><th>Green land uses</th></tr>
<tr><td>Zone-E</td><td>
</td><td>
</td><td>• Greens in Yamuna Sports Complex
• Green along Sanjay Lake
• Greens along the water bodies
• Greens along historical monuments</td></tr>
<tr><td>Zone-F</td><td></td><td>
</td><td>• Southern ridge
• Biodiversity parks
• City forests
• Greens along historical monuments
• Institutional greens
• Neighbourhood greens</td></tr>
</table>

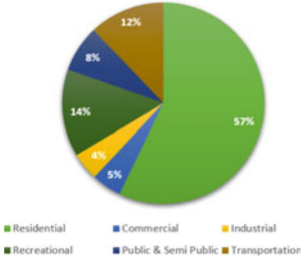
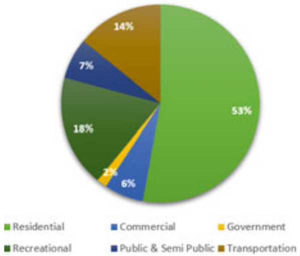
(continued)

Table 28.5 (continued)

Zones/zonal plan		Land uses	Green land uses
Zone-H			• Protected forest • Orchards • District park • Playground • Neighbourhood park
Zone-J			• Regional park • Green belt • Asola Bird Sanctuary

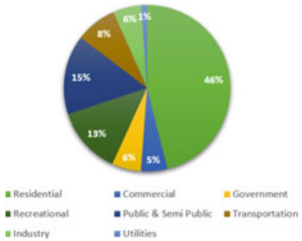
(continued)

Table 28.5 (continued)

Zones/zonal plan		Land uses	Green land uses
Zone-K-I			• City park • District park • Community park • Theme parks • Multi-purpose grounds • Facility corridors for greenways
Zone-K-II			• District park

(continued)

Table 28.5 (continued)

Zones/zonal plan		Land uses	Green land uses
Zone-L			• City park • Community park • District park • Neighbourhood park • Multi-purpose ground • Theme park

Source Zonal Plans Delhi, 2021
Source Master Plan Delhi 2021, Zonal Plans Delhi

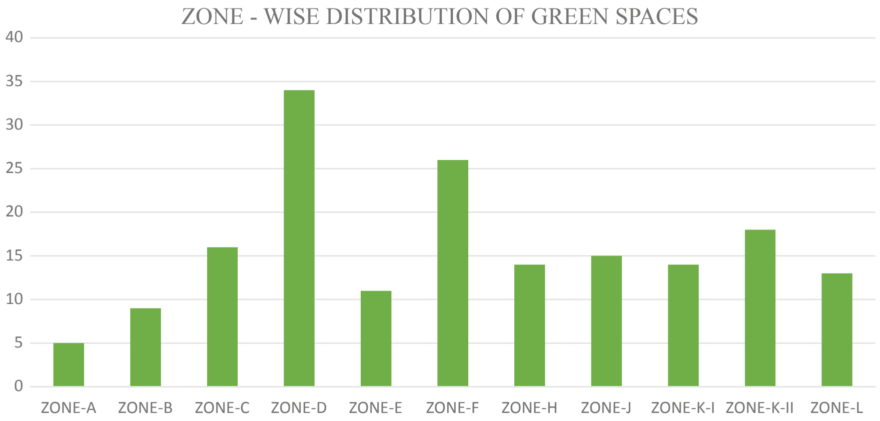


Fig. 28.1 Percentages of green spaces in each zone in Delhi. *Source* Master Plan Delhi 2021, Zonal plans Delhi

Master Plan Delhi 2021 include parks, playgrounds, city parks, district parks, neighbourhood parks, multi-purpose grounds with open spaces, forest areas, theme parks, biodiversity parks, etc.

The percentages in each zone vary as the sizes of the zones vary according to the Master Plan Delhi, 2021. The highest percentage of green spaces exists in Zone-D, which is approx. 34% but the variations of green land uses are less as compared to Zone-F. In Zone-F, the percentage of green spaces is approx. 26% and having variations in green land use. The green land uses here indicate the different typologies and variety of green spaces that exist in this zone which includes the southcentral ridge, biodiversity parks, city forests, greens around historical monuments, neighbourhood greens and institutional greens.

In Fig. 28.2, Zone-N, Zone-P–I and Zone-P–II are underdeveloped areas of Delhi and their green spaces are not considered for this chapter.

Delhi's every zone has not well-distributed green spaces as per the need to capture the air pollutants that result in the generation of dust from passing vehicular traffic and other polluting sources. Most of the built forms are devoid of the green spaces that are required to preserve the natural environments of the surrounding areas. The urban built forms should have integration with the 'Model Building Byelaws', and the associated green spaces along them, which strongly recommends purification, and enhancement of the surrounding areas and ultimately help in increasing rainwater harvesting, ameliorating air pollution, etc.

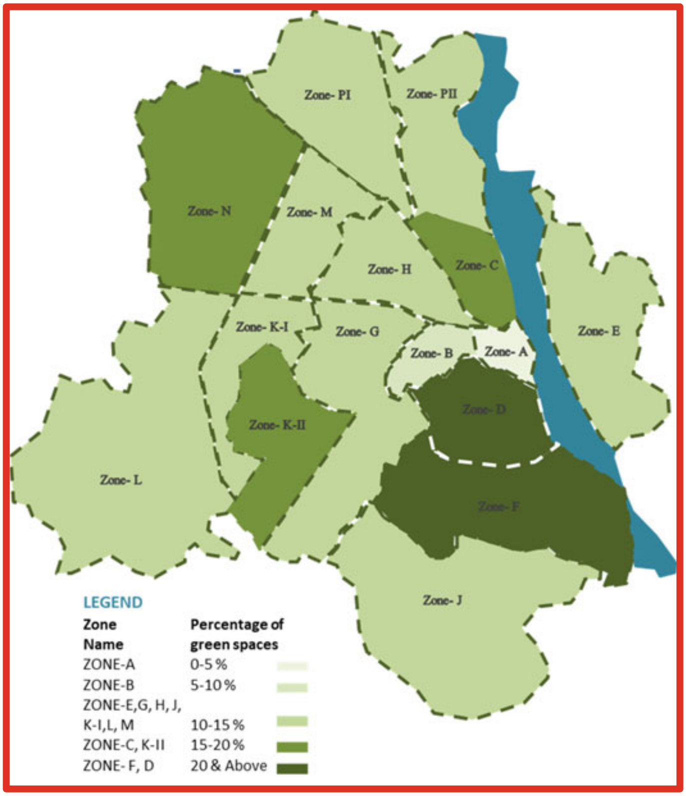


Fig. 28.2 Spatial distribution of green spaces in each zone in Delhi. *Source* Master Plan Delhi 2021, Zonal plans Delhi

Conclusion

The integration of green landscapes with spatial plans is not a new concept and many global cities have already integrated within their spatial plans and transition, driven by exacerbating climate impacts and events. It is crucial to consider urban green landscapes alongside the ecological while planning for adaptation and resilience.

In Delhi, there is a need to work on typologies of vegetation that has to be integrated with the different built forms and areas, for example near the industrial land uses need to plant the vegetation species that have the highest air pollution tolerance index, along the water bodies and River Yamuna, vegetation that helps in purification of polluted water.

This chapter revealed that green landscapes have many environmental potentials that cater to environmental issues and need to encompass spatial plans that acknowledge green landscapes with the development plans of the city. The integration of environmental planners in plan making process and implementation of the different development plans on the grounds is the need of the hour, and green resources will need to be planned mindfully for a sustainable future. According to the World Health Organization (WHO), the per capita green space should be 9.5 m^2. However, the percentages of greens in Delhi as compared to the other cities are higher but lower or negligible in zones A, B, E and H of Delhi whereas in zones M, G and N green spaces are available but partially accessible or not accessible by the people. It required the integration of green–blue infrastructure, as possible areas are along the different water bodies, along the River Yamuna, areas under depressions and green parks as the project examples of Neela Hauz and Tughlakabad biodiversity reveal that polluted water bodies can be rejuvenated and converted into blue-green infrastructure within the city.

Spatial planning and mapping of its natural resources are important steps towards providing precise locations of urban green and blue landscapes in Delhi. The proposed green land uses and activities are required to be adopted on spatial maps and their implementation on the grounds, such as urban farming, Biodiversity Parks, Nature conservation Zones, Forest areas, green buffers, shelterbelts and green mobility corridors. The planning techniques of mapping help to sustain green land uses and do their preservation and conservation by providing equal and associated green land uses along different built forms.

References

Ashraf M, Sarkar GD, Greens U, Area U (2015) An assessment of declining urban greens under Patna municipal corporation based on normalized difference vegetation index. Universal J Environ Res Technol 5(5):220–232

Campbell LK, Svendsen ES, Roman LA (2016) Knowledge co-production at the research-practice interface: embedded case studies from urban forestry. Environ Manage 57(6):1262–1280

Cornelis J, Hermy M (2004) Biodiversity relationships in urban and suburban parks in Flanders, October. https://doi.org/10.1016/j.landurbplan.2003.10.038

Davis M, Naumann S (2017) Making the case for sustainable urban drainage systems as a nature-based solution to urban flooding. https://doi.org/10.1007/978-3-319-56091-5_8

Doherty G (2017) Paradoxes of green: landscapes of a city-state. Univ of California Press

Dunnett N, Swanwick C, Woolley H (2002) Improving urban parks, play areas, and green spaces. Department for Transport, Local Government, and The Regions London

Fam D, Mosley E, Lopes A, Mathieson L, Morison J, Connellan G (2008) Irrigation of urban green spaces: a review of the environmental, social and economic benefits. 04

Gesler WM (2003) Healing places. Rowman & Littlefield

Gidlöf-Gunnarsson A, Öhrström E (2007) Noise and well-being in urban residential environments: the potential role of perceived availability to nearby green areas. Landsc Urban Plan 83(2–3):115–126

González-oreja JA, Bonache-regidor C, De La Fuente-díaz-ordaz AA (2010) Far from the noisy world ? Modeling the relationships between park size, tree cover, and noise levels in urban green spaces of the City of Puebla, Mexico

Govindarajulu D (2014) Urban green space planning for climate adaptation in Indian cities. Urban Clim 10:35–41

Hartswick KJ (2013) Part-1 topography and history. In: The gardens of Sallust: a changing landscape. University of Texas Press, pp 1–5

Hatcher WG, Yu W (2018) A survey of deep learning: platforms, applications, and emerging research trends. IEEE Access 6:24411–24432

Jin H, Cui P, Wong NH, Ignatius M (2018) Assessing the effects of urban morphology parameters on microclimate in Singapore to control the urban heat island effect. https://doi.org/10.3390/su10010206

Kazi EFH, Kulkarni S (2020) APTI (Air pollution tolerance index) of trees in Lohagaon area in Pune city in different seasons. EPRA Int J Econ Bus Rev. Peer-reviewed J 8(12)

Maleki K, Hosseini SM (2011) Investigation of the effects of leaves, branches, and canopies of trees on noise pollution reduction

Vaeztavakoli A, Lak A, Yigitcanlar T (2018) Blue and green spaces as therapeutic landscapes: health effects of urban water canal areas of Isfahan. Sustainability 10(11):4010

Wang XR, Hui ECM, Choguill C, Jia SH (2015) The new urbanization policy in China: which way forward? Habitat Int 47:279–284. https://doi.org/10.1016/j.habitatint.2015.02.001

Part IV
Smart Building, Ecosystem Services, Society and Future Smart Cities

Chapter 29
Growing Urban Tourism Activities While Increasing Vegetation Ecosystem Service Under Land Use Changes Pressure: A Case Study of Sanur, Bali, Indonesia

Abd. Rahman As-syakur, Martiwi Diah Setiawati, Laily Mukaromah, Takahiro Osawa, I. Wayan Sandi Adnyana, and I. Nyoman Sunarta

Abstract During pre-pandemic, tourist visits to the capital city of Bali grew by an annual average of 5%, and about 80% of them stayed in the Sanur. Increased tourism visits and activities and land use changes for build multi-functional buildings tend to reduce the quality of the environment and ecosystem services, including carbon sequestration. In this study, we utilised Gross Primary Productivity (GPP) as an indicator for measuring the urban green space ecosystem service of its ability to capture total carbon assimilation of terrestrial ecosystems via photosynthesis. High spatial resolution satellite remote sensing data for 2006 and 2015 were employed in this chapter. The result stated that despite much green space (e.g. agriculture and mixed forest) has been converted into a built-up area for tourism activity, the GPP was increased by 1067.47 tC/yr (i.e. 26%). Interestingly, the built-up area contributes

Abd. R. As-syakur (✉) · I. W. S. Adnyana
Centre for Environmental Research (PPLH), Udayana University, Denpasar-Bali, Indonesia
e-mail: ar.assyakur@pplh.unud.ac.id

I. W. S. Adnyana
e-mail: sandiadnyana@unud.ac.id

M. D. Setiawati
Research Center for Oceanography, National Research and Innovation Agency (BRIN), Jakarta, Indonesia
e-mail: mart009@brin.go.id

L. Mukaromah
National Research and Innovation Agency (BRIN), Purwodadi Botanic Garden, Pasuruan-East Java, Indonesia

T. Osawa
Center for Research and Application of Satellite Remote Sensing, Yamaguchi University, Ube-Yamaguchi, Japan
e-mail: osawaunud@yamaguchi-u.ac.jp

I. N. Sunarta
Tourism Faculty, Udayana University, Denpasar-Bali, Indonesia
e-mail: nyoman_sunarta@unud.ac.id

U. Chatterjee et al. (eds.), *Urban Commons, Future Smart Cities and Sustainability*, Springer Geography, https://doi.org/10.1007/978-3-031-24767-5_29

about 40% of the GPP increase in the study area. As shown by GPP, increasing vegetation ecosystem services was attributed mainly to the increased fraction of tree cover throughout the entire region, including the backyards and front yards maintained as multi-functional buildings for tourism activity between 2006 and 2015. This study also revealed that private sector involvement in urban greening significantly impacts the sustainable tourism industry. In addition, this information is helpful for carbon resource management, tourism, policy making and scholars concerned about carbon management in a tourism area.

Keywords GPP · Tourism · Land use changes · Remote sensing · Urban

Introduction

Tourism has been considered a crucial strategy to achieve many countries' Sustainable Development Goals (SDGs). Moreover, these hospitality-related sectors can be deemed vital in the movement towards a more sustainable future; yet, the top player's industries must overcome various obstacles to contribute to attaining the SDGs. For example, how the industries select and set the priorities among 17 SDGs with 169 related targets to meet the goals (Jones et al. 2017). Also, given native places hold deep cultural value and environmental sensitivity, sustainable tourist management must consider local perspectives to establish a partnership understanding and respect, tolerance, and viability that will win native social acceptance (Lai and Nepal 2006). However, there is a tendency to extend forest or agricultural areas to tourism development to achieve better economic valuation, like infrastructure development, cultural preservation, employment creation, environmental conservation and more investment options. Even though the tourism industry has a remarkable impact on economic growth, undesired consequences also are produced.

Urban tourism is a form of travelling in a metropolitan area for tourism activities. This type of tourism industry is indeed the fastest-growing among others. It differs from many other groups of tourists in that individuals visit sites with many people; they often stay there for less time than they would on leisure, and they accommodate many professionals and Meetings, Incentives, Conferencing and Exhibitions (MICE) travellers. Urban areas play a vital part in the tourism sector system, contributing to being essential places to visit. Also, the area serves as entry points for locals and foreigners and stopover locations for travellers travelling to numerous locations. Although urban areas are much more active and resilient than rural areas, the harmony between various stakeholders may be compromised due to increased tourism, thus lowering the quality of life in the area. It may be seen in some popular metropolitan tourist areas where over-tourism is a growing policy concern. These 'tourist difficulties' are connected to more significant societal problems, ecological pressure and municipal entities. In terms of ecological pressure, urban tourism has a substantial impact on land use and land cover changes (Li et al. 2015a, b) which is closely related to multi-functional buildings for tourism activities such as hotels, restaurants, commercial facilities and transport infrastructures (Shi et al. 2020). Therefore, the link between urban tourism development and land conversion associated with constructing multi-functional buildings for tourism activities is closely related.

During 2014–2019, Indonesia was recognised as a rapidly expanding popular destination in the world, whereas international visitors to this country have grown substantially by more than 10% (Rosselló et al. 2020), with even more than 16 million reported entries in 2019 (BPS 2020). Since this sector contributes about 6% of the Indonesian GDP (Susanto et al. 2020), the government set tourism as one of the priority sectors to boost its economy's growth. Indonesia is located in the Asia Pacific region with extensive archipelagos and high cultural diversity, creating more enormous tourism industry opportunities. Among Indonesia's archipelagos, Bali is the most popular tourist destination in the world because, since the Dutch colonial rule (1930), Bali has been promoted as a tourist destination. In 2019, the Indonesian Statistical agency revealed that almost 40% of foreign visitors to Indonesia visited Bali as the primary destination (BPS Bali 2021a), of which the number reached more than 6 million tourists. The number of foreign tourist visits to Bali has increased three times compared to 2008, which only reached about 2 million (BPS Bali 2021a). Therefore, the Bali economy heavily relies on the tourism industry, where more than half of Bali's population works in this sector, which accounts for 68% of the island's total economic output (Antara and Sumarsiasih 2017). This expanding tourism has driven significant land use changes and other related ecological pressure, particularly in the island's south.

Land use and land cover (LULC) is one of the critical elements in providing ecosystem services. The ability of ecosystems to supply ecosystem services is closely correlated with ecosystems (Kindu et al. 2016). Land use changes that have altered biophysical and biochemical processes have significantly impacted the supply of numerous ecosystem services globally (Polasky et al. 2011). For instance, various researches have revealed that changes in land use can reduce the provision of ecosystem services, such as lowering carbon storage and sequestration, deteriorating water availability and quality, diminishing biodiversity preservation and declining aesthetic and recreational values (Song and Deng 2017). Therefore, it is believed that LULC is a major factor of change in ecosystem services. However, land utilisation and its conversion are crucial to the tourist industry and are closely related to its growth. Also, it is important to note that the region impacted by tourist activity is more prominent and includes places like the seaside, conservation areas and natural parks. Although the utilisation and conversion of land are essential to the tourism industry, it is challenging to quantify the dynamic of LULC (Mao et al. 2014). It is due to the limitation of micro-level georeferenced datasets, the necessity of making many assumptions and the challenge of tracking tourism-related businesses that provide value to tourists and residents (Boavida-Portugal et al. 2016). The existence of new datasets, such as satellite remote sensing data and simulation techniques, may provide a foundation for expanding LUCC studies.

As explained above, LULC has the role of significant carbon storage and carbon sequestration at local, regional and global scales. The commodities and services provided by ecosystems are crucial to the living organism, particularly net ecosystem CO_2 exchange (NEE), which balances ecosystem respiration with gross primary production (GPP) (Lu et al. 2010). The GPP is an essential indicator of carbon mass flux in carbon cycle studies (Wang et al. 2012). Additionally, GPP can be utilised to calculate vegetation productivity and comprehend temporal productivity variability. Assessing land vegetation's carbon uptake and how it fluctuates due to LULC in urban areas is crucial since prospective future sequestration is affected by rising atmospheric CO_2 and changing climatic conditions (Nemani et al. 2003), particularly for tourist cities. Thus, estimating GPP in an urban region is crucial for calculating net land carbon and is particularly significant for studies on biogeochemical cycles. One of the fundamental steps in assessing the spatial distribution of carbon sequestration pathways in response to climate change is the remote sensing of vegetation GPP.

Previous studies on the impact of GPP on the land cover/land use change in urban areas using remote sensing data have been carried out in various cities in the world, such as studies conducted by Zhong et al. (2019) in Shanghai, China; Zhao et al. (2007, 2012) in Southeastern Michigan, USA; and Nuarsa et al. (2018) in Denpasar, Indonesia. However, generally, these studies use remote sensing data with moderate to medium spatial resolution. As a result of the use of remote sensing data that has a relatively poor spatial resolution, it causes the loss of object detail in heterogeneous urban landscapes, such as in the centre of tourism activity. However, MODIS data with a spatial resolution of 1 km is the most commonly used to study GPP because it has a good temporal resolution (e.g. Zhong et al. 2019). On the other hand, Landsat satellite data with 30 m spatial resolution is more widely utilised for estimating the GPP in major cities with diverse topographies (Gitelson et al. 2012), including the capital city of Bali Island, Denpasar (Nuarsa et al. 2018). However, in this chapter, we utilised a higher spatial resolution of satellite data, ALOS AVNIR-2 and Sentinel-2, with a spatial resolution of 10 m. We only targeted the prominent tourist spot within the capital city, Sanur. This study aimed to calculate the amount of vegetation carbon that urban tourist areas have absorbed/released within the ten years due to the changing land use through the remote sensing-based light-use efficiency (LUE) method of GPP. The results of this study are expected to provide more detailed spatial information regarding the impact of land use change due to the growth of tourism activities on ecosystem services, which is due to the use of satellite imagery with higher spatial resolution compared to previous studies.

Study Area

The study was done in Sanur, which is part of the administrative area of Sanur Village, Sanur Kaja Village and Sanur Kauh Village, hereafter just called the Sanur region (Fig. 29.1). Sanur is located in the south-eastern part of Denpasar City and is the centre of tourism activity in Denpasar City. Sanur is one of the oldest tourist areas in Bali, which has developed since the 1960s and began to develop rapidly after the first five-star hotel was built in Bali in 1966. Sanur is a tourist area located on the beach

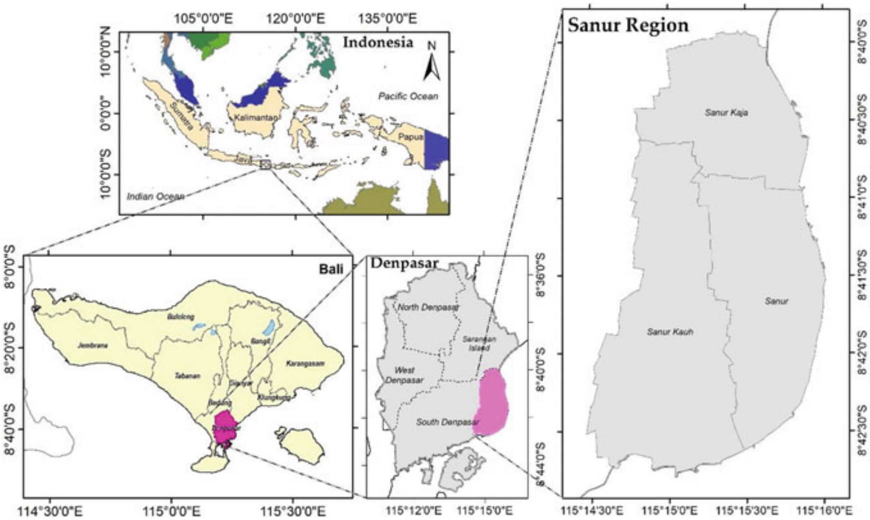


Fig. 29.1 Study area of Sanur, Denpasar City, Bali. Dark grey lines inside the grey area of Sanur are administration boundaries that divide the Sanur region into three villages administration

with attractiveness in the form of white sand, gentle waves and interesting culture, and it is close to the city centre of Bali Province. Generally, tourism-supporting facilities in the Sanur area are hotels, villas and restaurants.

Like other areas in Indonesia, Sanur has a tropical climate with an average rainfall of 2000 mm/yr, with peak rainfall generally occurring in January and valley rainfall in August (As-syakur et al. 2016). The air temperature is relatively the same throughout the year. Still, because it is influenced by the climate conditions of the Australian continent, warm temperatures occur in January and cold temperatures occur in August. In the Sanur area, there still is agricultural land and rice fields, and in the southwest, there is a wetland dominated by mangroves which is part of the Ngurah Rai Grand Forest Park, established through decision No. 544/Kpts-II/1993 in 1993.

Data and Methods

Data Uses

The main remote sensing data used in this study were Advanced Land Observation Satellite (ALOS) Advanced Visible and Near Infrared Radiometer type 2 (Avnir-2) and Sentinel-2A data acquired on 28 November 2006 and 21 October 2015, respectively, to calculate GPP on 10 m spatial resolution in surface radiance form. ALOS Avnir-2 was launched on 24 January 2006 by the Japan Aerospace Exploration

Agency (JAXA). The ALOS Avnir-2 sensor has four wavelengths that produce blue: 0.42–0.50 μm, green: 0.52–0.60 μm, red: 0.61–0.69 μm and NIR: 0.76–0.89 μm. We used ALOS Avnir-2 data and the processing level was 1B2 with radiometric correction and geometric correction were performed by JAXA. Level 1B2 provides data in the form of a digital number (8-bit) and was converted to physical measurements of sensor radiance (Lsat) using an equation that was presented by As-syakur et al. (2010). The Lsat values of all ALOS Avnir-2 bands were converted to the top-of-atmosphere (TOA) reflectance using an equation that was shown by Sambah and Miura (2016) to make it similar to the physical values of Sentinel-2 level 1C. All information needed to convert DN values to TOA reflectance can be found in the header file of ALOS Avnir-2.

The second satellite data used in the current study is Sentinel-2A Multispectral Instrument (MSI) TOA Level-1C (L1C) orthoimage products with spatial resolutions of 10, 20 and 60 m. In this study, we just use bands that have 10 m spatial resolution. Sentinel-2, including Sentinel-2A and Sentinel-2B, is a wide-swath, high-resolution, multi-spectral imaging mission supporting European Copernicus Land Monitoring studies. Several studies have used Sentinel-2 imagery for GPP analysis (e.g. Lange et al. 2017; Wolanin et al. 2019; Pabon-Moreno et al. 2022).

Land use maps of the Sanur area in 2006 and 2015 from QuickBird and WorldView-2, respectively, are used to analyse ten years of changes. Land use types for 2006 with a scale of 1:5000 are used in this study, which is interpreted by the Regional Planning and Development Board (Bappeda) of Denpasar city based on the QuickBird image acquired on May 16, 2006. The government of Denpasar City uses the spatial distribution of land use data as a base map to create a regional spatial plan map of the city. Moreover, the land use maps for 2015 were interpreted using manual digitising by revising the 2006 land use map, based on WorldView-2 imagery that was acquired on 20 May 2015. To address the complexity of high-resolution land use types, it was clustered into eight types, i.e. settlement, agriculture, mixed forest, wetland, shrubland, grassland, bare land and water.

GPP Calculation

The calculation of GPP in this study uses the light-use efficiency (LUE) model, introduced by Monteith (1972). In this work, the GPP of each land cover type for each 10 m was estimated using the following equation:

$$\mathrm{GPP} = \varepsilon \times \mathrm{fAPAR} \times \mathrm{PAR} = \varepsilon \times \mathrm{APAR}$$

where ε is light-use efficiency (gC/MJ; Table 29.1); fAPAR is the fraction of absorbed photosynthetically active radiation; and PAR is the photosynthetically active radiation (MJ/m^2/yr) calculated as $0.45 \times$ R (R, incoming global solar radiation). The R was calculated using the modified Sayigh universal formula for the Indonesian region (Halawa and Sugiyatno 2001). Moreover, the daily PAR was calculated using daily

Table 29.1 Land use/land cover types and corresponding to LUE max parameters

Land use/land cover	LUE max (ε; gC/MJ)	Source
Settlement	0.51	Zhao et al. (2012)
Agriculture	1.47	Yang et al. (2007)
Mixed forest	1.31	Yang et al. (2007)
Wetland	1.11	Zhao et al. (2012)
Shrubland	0.79	Yang et al. (2007)
Grassland	0.86	Yang et al. (2007)
Bareland	0.00	Yang et al. (2007)
Water	0.00	Yang et al. (2007)

average data of bright sunshine hours received during the day, maximum air temperature and relative humidity obtained from the Indonesian Meteorology, Climatology and Geophysics Agency (BMKG). The daily PAR is multiplied by the number of days a month to get the monthly PAR and is summed in a year to obtain an annual PAR value.

fAPAR is the fraction of PAR absorbed by leaves in the 0.4–0.7 μm spectrum for photosynthesis (Kamenova and Dimitrov 2021), which in this study is calculated in each land use type. The fAPAR is driven by vegetation cover, closely related to the biophysical parameters derived from remote sensing vegetation indices such as the normalised difference vegetation index (NDVI). Therefore, NDVI can be used as an index of plant photosynthetic activity (Zhao et al. 2007). In Southeast Asian countries, fAPAR was calculated from the NDVI following Ochi and Shibasaki (1999) as

$$\mathrm{fAPAR} = 1.075 \times \mathrm{NDVI} - 0.08$$

where NDVI is computed from remote sensing data, which is defined as follows:

$$\mathrm{NDVI} = \frac{\mathrm{NIR} - \mathrm{Red}}{\mathrm{NIR} + \mathrm{Red}}$$

where NIR and Red are the ALOS/Avnir-2 and Sentinel-2A surface radiance for the near-infrared and red bands, respectively.

To understand the impact of land use changes on GPP estimation in the Sanur region, GPP values are extracted during the study year and performing a comparative analysis of annual GPP. Land use data was used to capture the characteristics of the light-use efficiency (LUE) parameter (ε) on different ecological systems. The LUE values for each land use type were adopted from previously published studies (e.g. Yang et al. 2007; Zhao et al. 2012), which are presented in Table 29.1.

Results

Land Use Changes

Figure 29.2 shows the study area's LULC status between 2006 and 2015. We classified eight classes of the LULC based on remotely sensed data over the study period. Among eight categories, in 2006, the settlement area remained a major land use type (54.10%), followed by agriculture land (20.13%), mixed forest (15.56%), wetland (1.78%), shrubland (0.81%), grassland (4.91%), bareland (2.28%) and water (0.52%). Also, the settlement area expansion in the city centre was evident in 2015. Figure 29.3 shows the LULC changes in pilot sites during the study period. The result revealed that all the vegetation type of LULC (i.e. agriculture, mixed forest, shrub land and grassland) was transformed into settlement type. At the same time, there was no change indication from settlement to another type of LULC. Among the four types of transition, the greatest LULC change was from agricultural land to settlement area, which covered about 69.08 ha (Table 29.2). This transition change mainly occurred in the city centre, which indicated the red colour. Moreover, the second dominant transition was from mixed forest to settlement, indicated by the green colour, followed by the transition from shrubland to settlement. Overall the transition change occurred in the city centre to the south.

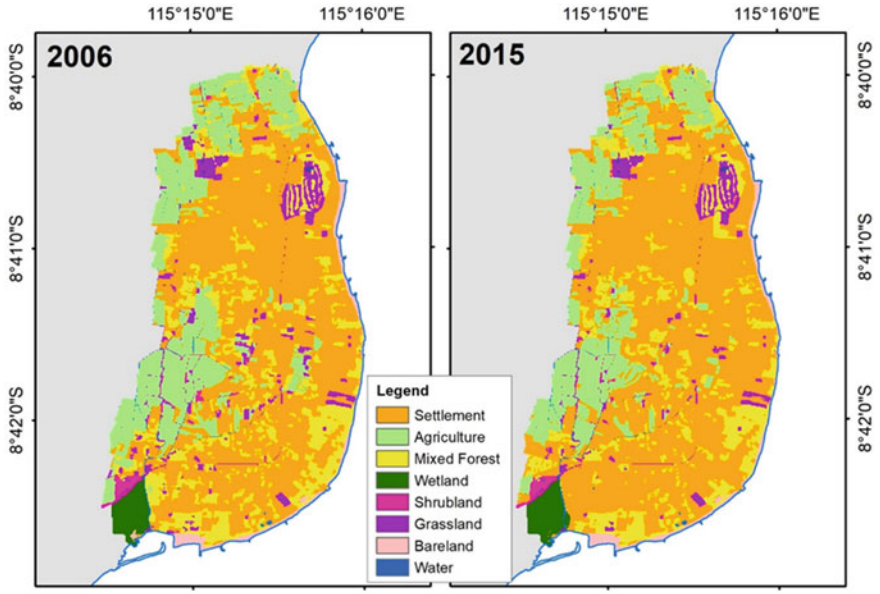


Fig. 29.2 Land use and land cover status in 2006 and 2015 in Sanur, Bali

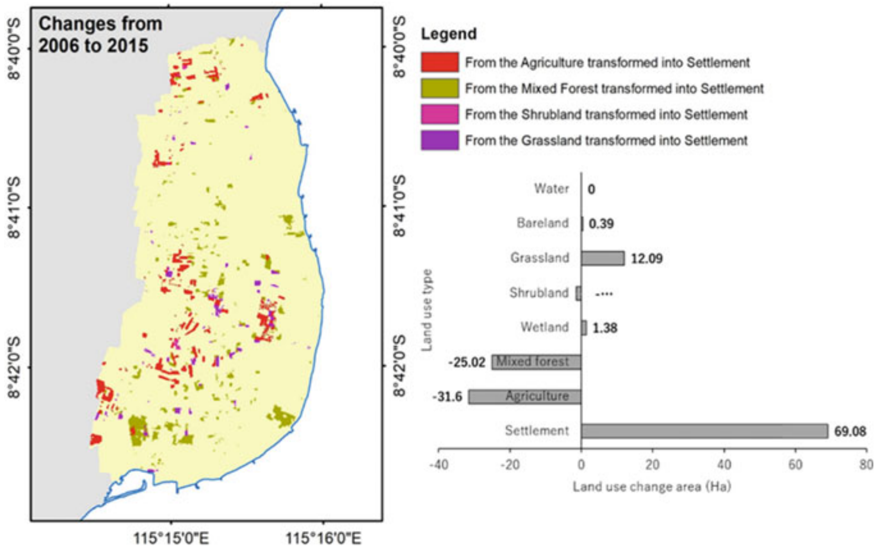


Fig. 29.3 Land use and land cover change between 2006 and 2015 in Sanur Bali

Table 29.2 Changes in land use types in Sanur region from 2006 to 2015 in hectarage and percent

Land use	2006		2015		Changes (ha)
	Area (ha)	%	Area (ha)	%	
Settlement	553.61	54.10	622.69	60.85	69.08
Agriculture	204.97	20.03	173.37	16.94	−31.60
Mixed forest	159.26	15.56	134.24	13.12	−25.02
Wetland	18.17	1.78	19.55	1.91	1.38
Shrubland	8.27	0.81	6.91	0.68	−1.36
Grassland	50.26	4.91	38.17	3.73	−12.09
Bareland	23.33	2.28	22.94	2.24	−0.39
Water	5.37	0.52	5.37	0.52	0.00
Total	1023.24		1023.24		

GPP Changes

Figure 29.4 shows the annual status of GPP in Sanur over the study period. The green colour indicates the lowest GPP, while the red colour presents the highest concentration of GPP. In 2006, the total GPP for the entire region was estimated to be 4080.29 tC yr^{-1} with an average of 398.76 gC m^{-2} yr^{-1}; meanwhile, in 2015, the total annual GPP increased to 5147.76 tC yr^{-1} with an average of 503.08 gC m^{-2} yr^{-1}. The lowest value of GPP generally was located around the settlement area, while the highest GPP was in the mixed forest area. According to the figure,

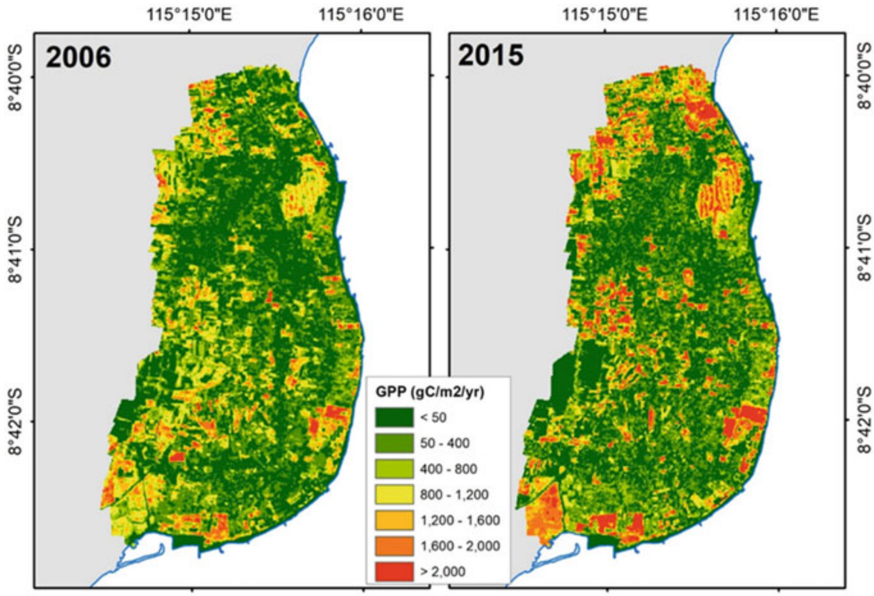


Fig. 29.4 GPP status in the tourism area of Sanur

there was a tendency to increase GPP in 2015 in most places, particularly in the northern part of Sanur.

Figure 29.5 depicts the GPP changes to LULC in the study area. The white colour indicates no difference; the black colour indicates decreasing trend while the red colour indicates an increasing trend of GPP. According to the figure, the highest increase of GPP was located in the settlement area, which reached 427 gC m^{-2} yr^{-1} (66%), followed by Agriculture (231 gC m^{-2} yr^{-1}; 17.6%), mixed forest (181.61 gC m^{-2} yr^{-1}; 10.8%), wetland (167.6 gC m^{-2} yr^{-1}; 112%) and grassland (75.63 gC m^{-2} yr^{-1}; 33%). However, the decreasing trend is also shown in the shrubland areas (−14.87 gC m^{-2} yr^{-1}; −25.3%). The significant increase in GPP mainly occurred in the northern part of the study area, while the significant decrease occurred in the western part.

Land Use and GPP Changes in the Centre of Tourism Area in Sanur

Here, we also try to calculate the changes in GPP values in the centre of tourism activities over the Sanur region, which is based on the division of zones carried out by the Denpasar City Government as stated in the regulation Number 12/2014 (Inside blue line in Fig. 29.5). Land use has changed in the centre of the tourism area of

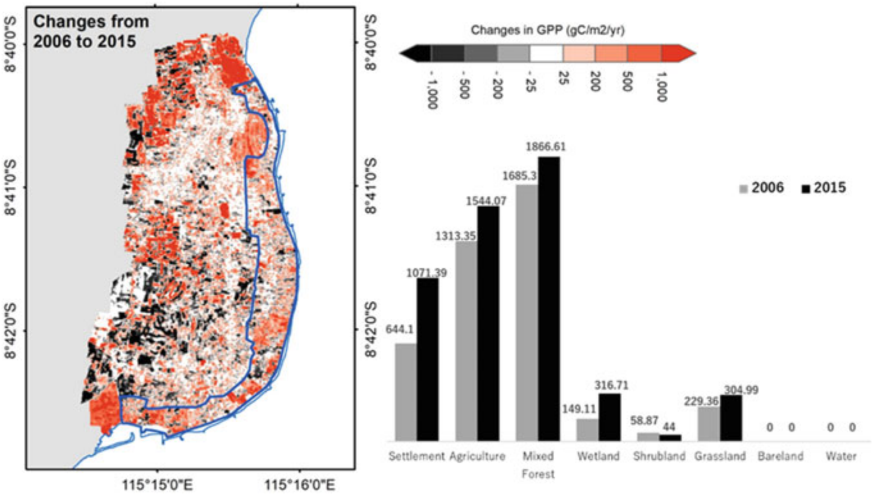


Fig. 29.5 Spatial distribution of GPP and their values changes in each land use type in the Sanur area from 2006 to 2015. The values dimension in the graph is gC m^{-2} yr^{-1}

Sanur from 2006 to 2015. Based on the area in 2006, the settlement that included general tourism services, including hotel and villa accommodation, shopping centre, restaurants and entertainment, increased by approximately 7.37 ha in 2015, and the mixed forest and agriculture land cover types decreased to 5.94 and 1.51 ha in 2015, respectively (Fig. 29.6). Although the settlement land use type has increased and mixed forest decreased, surprisingly, along the main centre of tourism activities, the GPP remained increased, especially in mixed forest land use type (Fig. 29.7). The annual GPP estimation for the centre of tourism increased during the ten years from 1187.36 to 1581.61 tonnes yr^{-1}, with an average increase of 39.42 tonnes per year. Much of this increase was contributed by the increased ability of mixed forests to fixation the carbon from the air through photosynthesis.

This increasing trend was mainly due to the environmentally friendly settlement landscape. The settlement area, including multi-functional buildings that provide general tourism services, was not crowded with enough open green space. The open green space does not only consist of grass but also high vegetation types such as annual plant trees. As shown in Fig. 29.8, the mean GPP estimation for settlements, mixed forest and grassland has increased, with dramatically increased in the mixed forest compared to that for the other two types of land use from 2006 to 2015 (1215.15–1635.96 gC m^{-2} yr^{-1}), which indicates good management of the garden, backyards and front yards of multi-functional buildings for tourism services such as hotels, villas and restaurants. These plants are one of the attractions sold to attract tourists to stay and have activities in Sanur; therefore, they are well-maintained by hotels, villas and restaurants, as well as Sanur tourism actors.

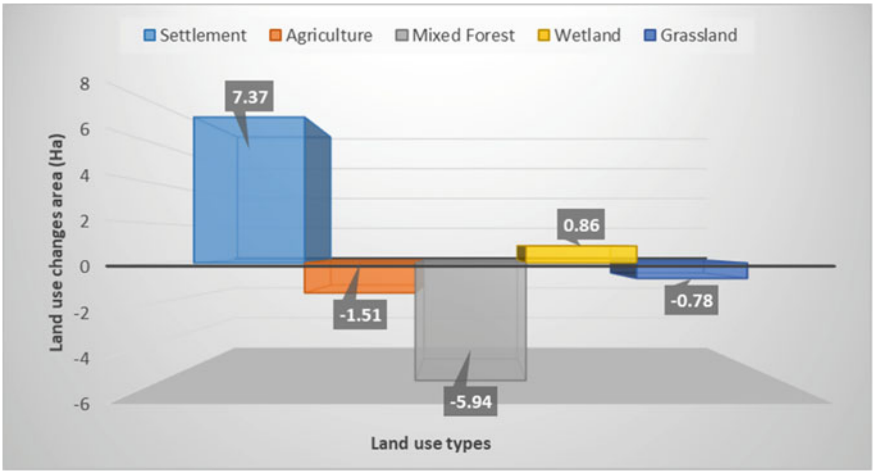


Fig. 29.6 Changes in land use type inside the centre of tourism areas of Sanur

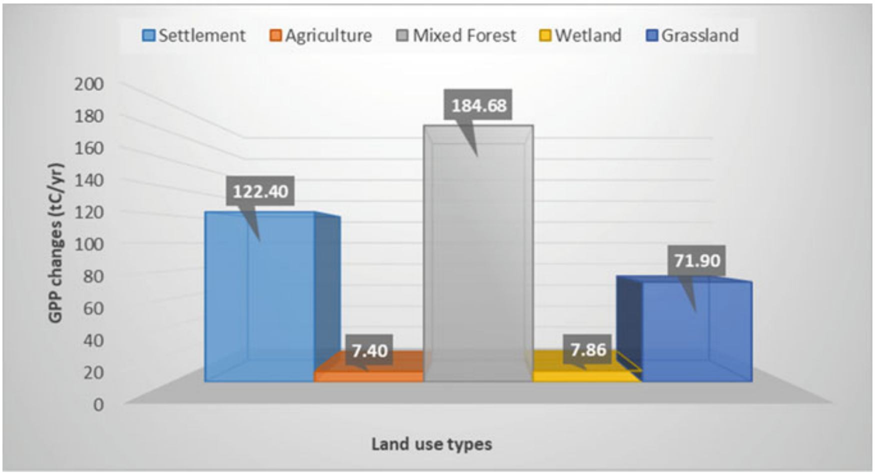


Fig. 29.7 Changes in annual GPP values of each land use type from 2016 and 2015 inside the centre of tourism areas of Sanur as illustrated by the blue line in Fig. 29.5

Discussions

Land Use Changes

Land use has shifted in the tourism area of the Sanur area from 2006 to 2015. The change in land use reveals a significant expansion in settlement areas (Fig. 29.2),

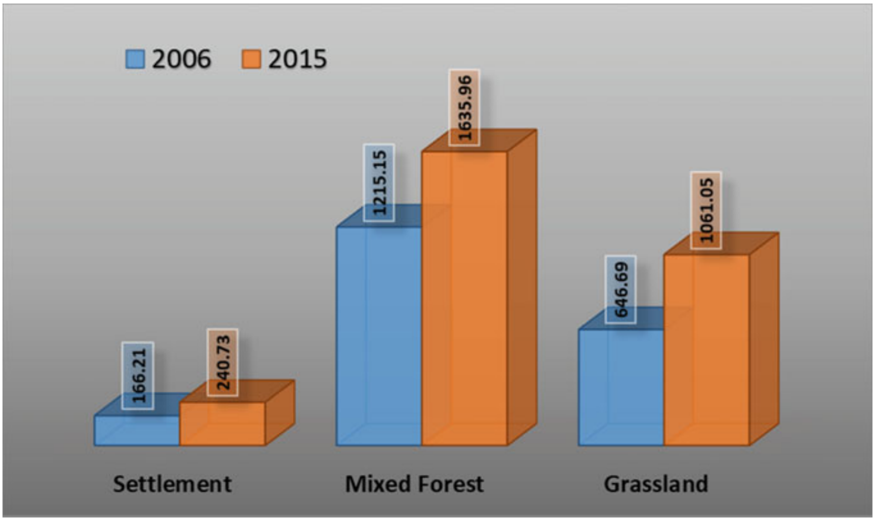


Fig. 29.8 Mean of annual GPP (gC m^{-2} yr^{-1}) in the centre of tourism region of Sanur of each dominant land use type (area > 1 ha)

where the major transition was from agricultural land and mixed forests into settlement areas (Fig. 29.3). The settlement area includes residential buildings and multipurpose structures that offer services for the tourism industry, such as lodging, dining, shopping and entertainment. Moreover, the analyses by Lee et al. (2019), Nuarsa et al. (2018), Mao et al. (2014) and Xi et al. (2014) are consistent with the apparent land use shift in this tourist city. However, Sanur's rate of greenspace conversion to settlement areas (0.17 ha/day) practically has a massive decline from that of Jakarta, Indonesia's largest metropolis and other urban city tourism area. For instance, between 1970 and 2008, the settlement area in Jakarta, the capital of Indonesia, increased by about 0.02 ha per day (Kunu and Leloteri 2010). Meanwhile, in the urban land teleconnection to Taipei City, the build-up area increased by 0.09 ha per day from 2006 to 2016 (Lee et al. 2019).

Sanur, together with Kuta and Nusa Dua, is one of Bali's three tourist hotspots that receive priority consideration for development under the National Tourism Strategic Area. Also, this study area is one of Bali's fastest-growing tourism industries. Therefore, these condition has led to a significant impact on land use change. Figure 29.3 presents most agricultural land in the central sites, and mixed forest in the southern area has changed into settlements. Another study by Nuarsa et al. (2018) also revealed that from 1992 to 2003, Sanur experienced a massive land use change from a mixed forest into a settlement area for tourism activities. Furthermore, Sanur was a pioneer area for Bali's tourism industry, where the first five-star hotel accommodation (i.e. the Inna Grand Bali Beach Hotel) was built in the region in 1966. Bali Statistical Agency reported that more than eleven thousand foreign visitors visited Bali in 1969, and by 2019 (before the pandemic), the number of foreign tourists was over six million (BPS

Bali 2021b). The highest growth rate of foreign visitors was 115% in 1970, with the annual average growth rate from 1969 to 2019 being 15%, respectively (BPS Bali 2021a). Also, the number of domestic visitors to Bali showed a significant amount where about two million people visited this island in 2004, and by 2019 the number of domestic visitors was over ten million (BPS Bali 2021b). This rapid growth of tourist visitors may have led to significant pressure on land use change to accommodate the demand, including accommodation, shopping centres, restaurants, cafés and others. This land use change drivers come from tourist visitors and locals who move to the southern part of Bali to work as an employee or open a new business.

Sanur is located within the capital city of Bali, which means this region has easy access to the provincial government, main core business, education services and digital business access. Thus, this area is preferable for tourist destinations and to live both for locals and foreign visitors. Sanur is located in the south Denpasar subdistrict, where the population density in 2010 was 25 people/ha, while in 2020, the population density was 62 people/ha (BPS Kota Denpasar 2022). Therefore, this condition also triggers the increasing need for residential buildings in this study area. Bali has experienced fast economic growth, which was more than 5% annually from 2011 to 2018, and among 34 provinces in Indonesia, Bali recorded top-five economic growth during those times (BPS 2022). This rapid economic growth mainly comes from the tourism industry, which directly contributes about 23.3% (i.e. food and accommodation). It indirectly contributes approximately 29.45% (i.e. manufacturing industry, information and communication, construction and transportation for tourism industry support) (BPS Bali 2022). Another study also revealed that more than half of Balinese income comes from tourist spending or tourism-related investment (Pitana 2010).

The hospitality sector has provided 30% of Bali Province's gross domestic product (GDP) over the past two decades, with southern regions, including Sanur, significantly influencing economic expansion (As-syakur 2011). Increases in population, quality of life and prosperity typically lead to urban land use alterations (Lambin et al. 2001; Parker et al. 2003). For instance, the increasing population and regional GDP in China's Yangtze River Basin posed a significant land use change (Wu et al. 2008). Xi et al. (2014), Allen et al. (1999) also reported that the growth in tourists could also affect the amount of land needed for their activities or hobbies.

Furthermore, governmental regulation with prospective measures affects tourism development, where it can control the commercialisation of tourism (Caffyn and Jobbins 2003), including in the study area. Governmental regulations are influential through establishing institutions that affect the land allocation, agriculture development, household registration, homestead management, town planning and census migration. With such a height of ten stories, the Inna Grand Bali Beach Hotel is the tallest structure in Bali right now. Under the Decree of the Governor of Bali Province No. 13/Perbang.1614/II/a/1971, the maximum permissible height in Bali is fixed at 15 m, or often just four stories. This legislation results from local Hindu and Balinese cultural knowledge regarding the procedures involved in the process of cities and tourism development strategies. This law prevents the development of skyward-expanding structures, including homes, companies, state buildings and designs with multiple uses for tourists. Therefore, horizontal development is a sensible option for getting massive buildings with maximum capacities, but it costs both direct and indirect green areas for populated/business-oriented areas. However, according to the Midterm Development Planning of Bali Province 2018–2023, the Bali Provincial Government has pledged to give an extra 5% of the urban area to natural green areas (Setiawati et al. 2021).

Changes in Annual GPP

Despite a massive land use change in settlement areas, the present study revealed that the total amount of GPP in Sanur increased by 1067.5 tC/yr (26%) from 2006 to 2015 (Fig. 29.4). Among the eight types of land use, the mixed forest has the highest amount of GPP, followed by agriculture, settlement, wetland, grassland and shrubland (Fig. 29.5). Even though the agricultural land and mixed forest area decreased by 31 ha and 25 ha, respectively (Fig. 29.3), the GPP amount increased by 17.6 and 10.7% (Fig. 29.5). Moreover, the settlement area experienced a significant increase in GPP amount by 66%, as shown in Fig. 29.5. Decreasing agricultural land and mixed forest with increasing GPP value is an exciting finding. It might be due to the higher density of these vegetation types in the study area. Meanwhile, a progressive increase in GPP in the settlement area occurred due to high vegetation proportions and expansion of tree cover (e.g. front yard and back yard) accompanied by good management of tourism activity. In addition, Sanur was known as a tourist destination that targeted middle to upper-class tourists where accommodation with ample green space is preferable. Moreover, although the wetland area did not increase significantly, there was a significant enough increase in the GPP value. Wetland cover in the study area is dominated by mangrove plants, part of the protected area established by the Indonesian government. This increase was due to the good management of wetland areas by maintaining and restoring mangrove forests in the protected area. Reforestation activities cause an increase in mangrove areas by replanting mangroves on bare land. However, protecting the wetland area from disturbance by making it a protected area is the main factor in increasing the value of the GPP (Romadhoni et al. 2022).

According to Denpasar Statistical Agency data from 2006 to 2015 and land use change in Fig. 29.3, the study area was characterised by increasing urbanisation, with the annual average population growth was 2.38% (BPS Kota Denpasar 2022) and the increasing trend of settlement land by 7.6 ha/yr (Fig. 29.3). Given this trend for growing settlement patterns, our research showed that the annual regional GPP rose rather than fell (Figs. 29.3 and 29.4). This finding has a contrast result by Zhang et al. (2021), Nuarsa et al. (2018), Zhao et al. (2012) which revealed that urban expansion has a solid and stable negative effect on GPP. However, our research finding is similar to the study conducted by Zhao et al. (2007), which found an increasing trend of GPP despite a growing trend for settlement areas in Southern Michigan. Then, what led to the higher GPP in these fast-growing urban surroundings? Thus, we investigated the daily average of precipitation and minimum temperature in 2006 and 2015, and the result stated that there was no significantly different climate trend between those years. Thus, we proposed that the changes in GPP may be due to the variation of solar radiation and land use type ratio. Previous researchers reported that increasing solar radiation would increase the GPP amount of a particular region (Wu et al. 2015; Li et al. 2015a, b), where the sunshine duration plays a vital role in estimating solar radiation (Li et al. 2015a, b). Our research revealed that sun intensity in the study area in 2015 was higher than in 2006 (i.e. the sun intensity in 2006 was 6.3%, while in 2015, it was 8.3%). Therefore, the increasing trend of GPP in 2015 might have occurred, as illustrated in Fig. 29.4. Moreover, as shown in Fig. 29.5, the higher density of vegetation cover in the settlement area might also influence the change of GPP in the study area.

Denpasar, particularly Sanur, is noteworthy because it has predominantly Hindu inhabitants with a lack of high-rise buildings and no skyscrapers. Therefore the settlement expansion in the horizontal direction is unavoidable. However, As-syakur et al. (2010) stated that Denpasar's settlement sites are not all occupied by buildings; some have different constructed land use patterns, including the front or back yards and vegetated and non-vegetated regions. Interestingly, every property in this city is a 'holy place' for Hindu religious practices, which is distinguished by the existence of greenery with diverse scales of canopy and height. Therefore, increasing settlement areas coupled with excellent management of 'holy spaces' (backyards and front yards) should have been helpful to raise the capabilities of settlements to absorb the carbon in the atmosphere through the greenery. They are considering that the growth of settlement areas of town is more challenging to control due to the high demand for tourism activities. Moreover, this is a unique case of local wisdom applied to governor regulation in this city, where this case was not found anywhere else among cities in Southeast Asia.

GPP is a critical process that controls how ecosystems are built and their function as well as the cornerstone of the entire carbon cycle. Moreover, a study on GPP plays a critical role in urban ecology. Therefore, GPP alteration would majorly impact the global carbon cycle (Wang et al. 2021), including urban areas and their ecosystems (Cui et al. 2017). A recent study by Holmberg et al. (2019) reported that the advantages of GPP increase are promoting carbon sequestration, forest regeneration and better stock of harvested plant timber. Moreover, climate parameters such as temperature, precipitation, solar radiation and relative humidity play an essential role in the GPP amount. Wang et al. (2021), Holmberg et al. (2019) revealed that warmer temperature negatively correlates with GPP, while higher precipitation positively correlates with GPP. This warmer temperature, in some instances, increases the amount of CO_2 that plants emit into the atmosphere (Holmberg et al. 2019). In our study, there was a tendency for warming temperature at night and cooler temperature during the day, which was indicated by the positive and negative local temperature anomaly from 1980 to 2015. Warming in the night-time (1992–2015) demonstrates that urban heat islands occurred in the study area. Meanwhile, cooler during the daytime (1999–2015) may indicate a tendency for GPP increase in this study area, which means this condition benefits carbon uptakes. This local climate trend also answers why the GPP of mixed forest and agricultural land increased in 2015 despite declining area. However, the precipitation anomaly in the study area remains fluctuated (As-syakur et al. 2013).

According to various studies, the degradation of agricultural and natural areas to create a way for the new cities led to declines in the gross and net primary production of plant and soil carbon (Zhang et al. 2021; Nuarsa et al. 2018; Zhao et al. 2012). However, some studies, including this study, show the opposite (Zhao et al. 2007; Cui et al. 2017). It may be due to the restoration of trees, shrubs and lawns and rigorous management (irrigation, fertilising, etc.) of vegetation which can enhance vegetation cover, yearly GPP, biomass production and soil carbon in city environments. Moreover, Golubiewskto (2006) revealed that urbanisation had boosted the grassland carbon pools. Another study also showed that urbanisation increased vegetation green space in several urban areas in China (Zhao et al. 2016). Those research proposed that temperature, sunlight and water might extend the growing conditions of plants, hence raising yearly photosynthesis and plant carbon uptake in cities (Zhang et al. 2004; Golubiewskto 2006). Moreover, urban areas in the terminal stage of urbanisation, such as New York, Osaka and Tokyo, experienced a major increment in yearly GPP from 2000 to 2014 (Cui et al. 2017). Still, cities in developing countries such as Mumbai, Shanghai and Cairo experienced a significant decrease in annual GPP. Those cities which experience GPP decline have rapid urban expansion (Cui et al. 2017).

The increase in the rate of land conversion in the Sanur area indicates the role of the tourism industry, both directly and indirectly, as stated by Nuarsa et al. (2018). If this continues to happen and is not controlled by strict rules, there is a possibility that the current increase in the value of GPP could turn into a decrease in value of GPP in the future.

The Use of High Spatial Resolution Satellite Imagery to Estimate the GPP

Satellite remote sensing provides multidimensional continuous datasets for measuring and tracking the primary productivity worldwide, including the GPP. With remote sensing variables as the main source dataset, three techniques for estimating the GPP were generally used: empirical models, LUE and enzyme Kinetic ecosystem process models. In this study, we utilised the LUE for estimating the GPP in the Sanur area since this model is a globally acknowledged concept for estimating the GPP (Gonsanmo and Chen 2018). There is some assumption utilised for the LUE method, such as LUE is the quantity of CO_2 fixed per unit of APAR and is mainly associated with APAR; environmental stresses such as temperature may cause the underestimation potential value of LUE (Gonsanmo and Chen 2018) and there is a linear relationship between NDVI and fPAR across various biomes (Ruimy et al. 1994; Yuan et al. 2007). Among many LUE methods, we utilised the fundamental equation of the LUE method conducted by Yuan et al. (2007). However, in this study, we did not use the eddy covariance flux due to the unavailability of eddy flux tower sites inside the cities. Therefore, understanding how to evaluate the GPP of urban regions is an issue for all satellite and processed-based models in developing nations. This challenge was also faced by Cui et al. (2017).

A previous study conducted by Nuarsa et al. (2018), also measured the GPP in the same city. However, they utilised more coarse spatial resolution (i.e. 30 m Landsat data) with the whole capital city areas and used the vegetation photosynthesis model (VPM) approach (i.e. fPAR is a function of Enhanced Vegetation Index). Meanwhile, this study utilised ALOS AVNIR data (i.e. spatial resolution 10 m) and used the fundamental LUE method. As-syakur et al. (2010) revealed that various spatial resolutions in the satellite data utilised for GPP analysis in cities would result in different averages for settlement areas. More precisely, the detailed horizontal extension will produce greater average values. Moreover, the visual quality is lost when pixel sizes increase (or spatial resolution decreases) (Rocchini 2007). Also, satellite-derived data from high-resolution satellites could solve the problems of lower-resolution satellite data (Cui et al. 2017). However, the total yearly GPP calculated using the VPM was not significantly different from the annual total GPP predicted using the other LUE models (As-syakur et al. 2010). Therefore, this study can measure the GPP in more detail or the specific region interest, such as the centre of tourism activities, instead of the whole capital city. Nevertheless, the current study is still uncertain because it has not been validated with field data. The validation of the GPP estimation results which are analysed using the LUE model and utilising high-resolution satellites of ALOS/Avnir-2 and Sentinel-2 with eddy flux towers, still needs to be done to improve a better understanding of the ability of high-resolution imagery to estimate GPP values, especially in heterogeneous areas such as urban areas. Although Sentinel-2 validation in estimating GPP values based on eddy flux tower data has been carried out across Europe and the USA by Pabon-Moreno et al. (2022) with good results, nothing was done for urban areas. However, the results of our study can indicate that there is indeed an increase in the value of GPP in the span of a decade, which is indicated by the increase in the value of the NDVI, which is the basis for calculating the GPP of the LUE model that used in this study. NDVI has a close relationship with ecological variables such as vegetation leaf area index and primary productivity (Myneni and Williams 1994) and has also been used to figure out the development of the ecological function of gardens in urban areas (Parece and Campbell 2017).

Conclusions

This study measured the GPP-based LUE Method in the Sanur area between 2006 and 2015. The result revealed that, despite a significant increase in settlement area and decreased vegetation area, the GPP trend in Sanur tends to increase. Interestingly, a substantial GPP concentration rose in the settlement area during the study period.

This increasing trend may be due to a significant sun intensity difference between those years and vegetation intensification efforts by corporate or local tourism actors. Vegetation maintenance is one of the attractions to increase tourist visits to this area, where the management of the gardens, backyards and front yards of multi-functional buildings for tourism, by maintaining, caring for, and not converting them into a building, is expected to be utilised optimally in the services of tourists who come to hotels, villas and restaurants.

References

Allen J, Lu KS, Potts TD (1999) A GIS-based analysis and prediction of land-use change in a coastal tourism destination area. In: Proceedings of the 1999 international symposium on coastal and marine tourism: balancing tourism and conservation, Vancouver, BC, Canada, 26–29 April 1999, pp 287–297

Antara M, Sumarniasih MS (2017) Role of tourism in economy of Bali and Indonesia. J Tourism Hospitality Manage 5(2):34–44

As-syakur AR, Osawa T, Adnyana IWS (2010) Medium spatial resolution satellite imagery to estimate gross primary production in an urban area. Rem Sens 2(6):1496–1507

As-syakur AR (2011) Perubahan penggunaan lahan di Provinsi Bali. Ecotrophic J Environ Sci 6(1):1–7

As-syakur AR, Tanaka T, Osawa T, Mahendra MS (2013) Indonesian rainfall variability observation using TRMM multi-satellite data. Int J Rem Sens 34(21):7723–7738

As-syakur AR, Osawa T, Miura F, Nuarsa IW, Ekayanti NW, Dharma IGBS, Adnyana IWS, Arthana IW, Tanaka T (2016) Maritime Continent rainfall variability during the TRMM era: the role of monsoon, topography and El Niño Modoki. Dyn Atmos Oceans 75:58–77

Boavida-Portugal I, Rocha J, Ferreira CC (2016) Exploring the impacts of future tourism development on land use/cover changes. Appl Geogr 77:82–91

BPS (2020) Jumlah kunjungan wisman ke Indonesia Desember 2019 mencapai 1,38 juta kunjungan. https://www.bps.go.id/pressrelease/2020/02/03/1711/jumlah-kunjungan-wisman-ke-indonesia-desember-2019-mencapai-1-38-juta-kunjungan-.html

BPS Bali (2021a) Jumlah Wisatawan Asing ke Bali 1969–2021a. Access date: 27 June 2022. https://bali.bps.go.id/statictable/2018/02/09/28/jumlah-wisatawan-asing-ke-bali-dan-indonesia-1969-2019.html

BPS Bali (2021b) Jumlah Wisatawan Domestik ke Bali 2004–2021b. Access date: 27 June 2022. https://bali.bps.go.id/statictable/2018/02/09/29/kunjungan-wisatawan-domestik-ke-bali-per-bulan-2004-2018.html

BPS Kota Denpasar (2022) Proyeksi Penduduk Kota Denpasar. https://denpasarkota.bps.go.id/indicator/12/49/1/proyeksi-penduduk-kota-denpasar.html

BPS (2022a) Laju Pertumbuhan Produk Domestik Regional Bruto Per Kapita Atas Dasar Harga Konstan Provinsi Bali. https://www.bps.go.id/linkTableDinamis/view/id/964

BPS (2022b) PDRB Provinsi Bali atas dasar harag berlaku tahun 2019. https://bali.bps.go.id/indicator/52/140/4/pdrb-triwulanan-provinsi-bali-atas-dasar-harga-berlaku-menurut-lapangan-usaha.html

Caffyn A, Jobbins G (2003) Governance capacity and stakeholder interactions in the development and management of coastal tourism: examples from Morocco and Tunisia. J Sustain Tour 11:224–245. https://doi.org/10.1080/09669580308667204

Cui Y, Xiao X, Zhang Y, Dong J, Qin Y, Doughty RB, Zhang G, Wang J, Wu X, Qin Y, Zhou S, Joiner J, Moore B (2017) Temporal consistency between gross primary production and solar-induced chlorophyll fluorescence in the ten most populous megacity areas over years. Sci Rep 7:14963

Gitelson AA, Peng Y, Masek JG, Rundquist D, Verma SB, Suyker AE, Baker JM, Hatfield JL, Meyers TP (2012) Remote estimation of crop gross primary production with Landsat data. Remote Sens Environ 121:404–414. https://doi.org/10.1016/j.rse.2012.02.017

Halawa EEH, Sugiyatno, (2001) Estimation of global solar radiation in the Indonesian climatic region. Renew Energ 24(2):197–206

Holmberg M, Aalto T, Akujärvi A, Arslan AN, Bergström I, Böttcher K, Lahtinen I, Mäkelä A, Markkanen T, Minunno F, Peltoniemi M, Rankinen K, Vihervaara P, Forsius M (2019) Ecosystem services related to carbon cycling—modeling present and future impacts in boreal forests. Front Plant Sci 10:343

Golubiewski NE (2006) Urbanization increases grassland carbon pools: effects of landscaping in Colorado's front range. Ecol Appl 16(2):555–571

Gonsamo A, Chen JM (2018) Vegetation primary productivity. In: Comprehensive remote sensing, pp 163–189. https://doi.org/10.1016/b978-0-12-409548-9.10535-4

Jones P, Hillier D, Comfort D (2017) The sustainable development goals and the tourism and hospitality industry. Athens J Tourism 4(1):7–18

Kamenova I, Dimitrov P (2021) Evaluation of Sentinel-2 vegetation indices for prediction of LAI, fAPAR and fCover of winter wheat in Bulgaria. Eur J Rem Sens 54(sup1):89–108

Kindu M, Schneider T, Teketay D, Knoke T (2016) Changes of ecosystem service values in response to land use/land cover dynamics in Munessa-Shashemene landscape of the Ethiopian highlands. Sci Total Environ 547:137–147

Kunu PJ, Lelolterry H (2010) Penggunaan Lahan dan Evolusi Penggunaan Lahan di Provinsi DKI Jakarta. Jurnal Agroforestri 5(3):203–207

Lai PH, Nepal SK (2006) Local perspectives of ecotourism development in Tawushan Nature Reserve, Taiwan. Tourism Manage 27(6):1117–1129

Lambin EF, Turner BL, Geist HJ, Agbola SB, Angelsen A, Bruce JW et al (2001) The causes of land-use and land-cover change: moving beyond the myths. Glob Environ Change 11(4):261–269

Lange M, Dechant B, Rebmann C, Vohland M, Cuntz M, Doktor D (2017) Validating MODIS and sentinel-2 NDVI products at a temperate deciduous forest site using two independent ground-based sensors. Sensors 17(8):1855

Lee Y, Huang S, Liao P (2019) Land teleconnections of urban tourism: a case study of Taipei's agricultural souvenir products. Landsc Urban Plan 191:103616

Li D, Ju W, Lu D, Zhou Y, Wang H (2015a) Impact of estimated solar radiation on gross primary productivity simulation in subtropical plantation in southeast China. Sol Energ 120:175–186

Li M, Fang L, Huang X, Goh C (2015b) A spatial–temporal analysis of hotels in urban tourism destination. Int J Hosp Manag 45:34–43

Lu D, Xu X, Tian H, Moran E, Zhao M, Running S (2010) The effects of urbanization on net primary productivity in southeastern China. Environ Manage 46(3):404–410

Mao X, Meng J, Wang Q (2014) Modeling the effects of tourism and land regulation on land-use change in tourist regions: a case study of the Lijiang River Basin in Guilin, China. Land Use Policy 41:368–377

Monteith JL (1972) Solar radiation and productivity in tropical ecosystems. J Appl Ecol 9(3):747–766

Myneni RB, Williams DL (1994) On the relationship between FAPAR and NDVI. Rem Sens Environ 49(3):200–211

Nemani RR, Keeling CD, Hashimoto H, Jolly WM, Piper SC, Tucker CJ et al (2003) Climate-driven increases in global terrestrial net primary production from 1982 to 1999. Science 300(5625):1560–1563

Nuarsa IW, As-syakur AR, Gunadi IGA, Sukewijaya IM (2018) Changes in Gross Primary Production (GPP) over the past two decades due to land use conversion in a tourism city. ISPRS Int J Geo Inf 7(2):57

Ochi S, Shibasaki R (1999) Estimation of NPP based agricultural production for Asian countries using remote sensing data and GIS. Institute of Industrial Science. University of Tokyo. Japan

Pabon-Moreno DE, Migliavacca M, Reichstein M, Mahecha MD (2022) On the potential of Sentinel-2 for estimating Gross Primary Production. IEEE Trans Geosci Rem Sens 60:1–12
Parece TE, Campbell JB (2017) Assessing urban community gardens' impact on net primary production using NDVI. Urban Agric Reg Food Syst 2(1):1–17
Parker DC, Manson SM, Janssen MA, Hoffmann MJ, Deadman P (2003) Multi-agent systems for the simulation of land-use and land-cover change: a review. Ann Assoc Am Geogr 93(2):314–337
Pitana IG (2010) Tri Hita Karana–the local wisdom of the Balinese in managing development. In: Conrady R, Buck M (eds) Trends and issues in global tourism 2010. Springer, Berlin/Heidelberg, Germany, pp 139–150, ISBN 978-3-642-10829-7
Polasky S, Nelson E, Pennington D, Johnson KA (2011) The impact of land-use change on ecosystem services, biodiversity and returns to landowners: a case study in the state of Minnesota. Environ Resour Econ 48(2):219–242
Rocchini D (2007) Effects of spatial and spectral resolution in estimating ecosystem α-diversity by satellite imagery. Rem Sens Environ 111(4):423–434
Romadhoni LSR, As-syakur AR, Hidayah Z, Wiyanto DB, Safitri R, Utama RYS, Wijana IMS, Anugrah AP, Antara IMOG (2022) Annual characteristics of gross primary productivity (GPP) in mangrove forest during 2016–2020 as revealed by Sentinel-2 remote sensing imagery. IOP Conf Ser Earth Environ Sci 1016(1):012051
Rosselló J, Becken S, Santana-Gallego M (2020) The effects of natural disasters on international tourism: a global analysis. Tour Manage 79:104080
Ruimy A, Saugier B, Dedieu G (1994) Methodology for the estimation of terrestrial net primary production from remotely sensed data. J Geophys Res Atmos 99(D3):5263–5283
Sambah AB, Miura F (2016) Spatial data analysis and remote sensing for observing tsunami-inundated areas. Int J Remote Sens 37(9):2047–2065. https://doi.org/10.1080/01431161.2015.1136450
Setiawati MD, Jarzebski MP, Gomez-Garcia M, Fukushi K (2021) Accelerating urban heating under land-cover and climate change scenarios in Indonesia: application of the universal thermal climate index. Frontiers Built Environ 7:622382
Shi H, Li X, Yang Z, Li T, Ren Y, Liu T et al (2020) Tourism land use simulation for regional tourism planning using POIs and cellular automata. Trans GIS 24(4):1119–1138
Song W, Deng X (2017) Land-use/land-cover change and ecosystem service provision in China. Sci Total Environ 576:705–719
Susanto J, Zheng X, Liu Y, Wang C (2020) The impacts of climate variables and climate-related extreme events on island country's tourism: evidence from Indonesia. J Clean Prod 276:124204
Wang M, Wang S, Zhao J, Ju W, Hao Z (2021) Global positive gross primary productivity extremes and climate contributions during 1982–2016. Sci Total Environ 774:145703
Wang X, Ma M, Huang G, Veroustraete F, Zhang Z, Song Y, Tan J (2012) Vegetation primary production estimation at maize and alpine meadow over the Heihe River Basin, China. Int J Appl Earth Obs Geoinf 17:94–101
Wolanin A, Camps-Valls G, Gómez-Chova L, Mateo-García G, van der Tol C, Zhang Y, Guanter L (2019) Estimating crop primary productivity with Sentinel-2 and Landsat 8 using machine learning methods trained with radiative transfer simulations. Rem Sens Environ 225:441–457
Wu X, Shen Z, Liu R, Ding X (2008) Land use/cover dynamics in response to changes in environmental and socio-political forces in the upper reaches of the Yangtze River, China. Sensors 8(12):8104–8122
Wu X, Ju W, Liu Y, Zhou Y, Li D et al (2015) Impacts of changes in solar radiation on terrestrial gross primary productivity of China. In: AGU fall meeting abstracts, vol 2015, pp B21E-0521
Xi J, Zhao M, Ge Q, Kong Q (2014) Changes in land use of a village driven by over 25 years of tourism: the case of Gougezhuang village, China. Land Use Policy 40:119–130
Yang F, Ichii K, White MA, Hashimoto H, Michaelis AR, Votava P, Zhu AX, Huete AR, Running SW, Nemani RR (2007) Developing a continental-scale measure of gross primary production by combining MODIS and AmeriFlux data through Support Vector Machine approach. Rem Sens Environ 110(1):109–122

Yuan W, Liu S, Zhou G, Zhou G, Tieszen LL, Baldocchi D et al (2007) Deriving a light use efficiency model from eddy covariance flux data for predicting daily gross primary production across biomes. Agric Forest Meteorol 143(3–4):189–207

Zhang X, Friedl MA, Schaaf CB, Strahler AH, Schneider A (2004) The footprint of urban climates on vegetation phenology. Geophys Res Lett 31(12):L12209

Zhang Y, Song C, Hwang T, Novick K, Coulston JW, Vose J et al (2021). Land cover change-induced decline in terrestrial gross primary production over the conterminous United States from 2001 to 2016. Agric Forest Meteorol 308:108609

Zhao S, Liu S, Zhou D (2016) Prevalent vegetation growth enhancement in urban environment. Proc Natl Acad Sci 113(22):6313–6318

Zhao T, Brown DG, Bergen KM (2007) Increasing gross primary production (GPP) in the urbanizing landscapes of southeastern Michigan. Photogramm Eng Rem Sens 73(10):1159–1167

Zhao T, Brown DG, Fang H, Theobald DM, Liu T, Zhang T (2012) Vegetation productivity consequences of human settlement growth in the eastern United States. Landscape Ecol 27(8):1149–1165

Zhong Q, Ma J, Zhao B, Wang X, Zong J, Xiao X (2019) Assessing spatial-temporal dynamics of urban expansion, vegetation greenness and photosynthesis in megacity Shanghai, China during 2000–2016. Rem Sens Environ 233:111374

Chapter 30
Price Tagging on Urban Farming Benefit in the Context of Ecosystem Services

Tri Atmaja, Kiyo Kurisu, and Kensuke Fukushi

Abstract Rapid urbanisation, along with urban poverty, leads to social and environmental challenges that require cities to improve their resilience. Urban farming is promoted as an essential strategy for improving cities' resilience by providing ecosystem services, namely strengthening the community, improving the urban environment and saving energy. The research aimed to estimate urban farming benefits in the context of ecosystem services in the monetary unit. It took place in Malang City, East Java–Indonesia, as a case study. The study utilised the Total Economic Value framework in conjunction with the Economics of Ecosystems and Biodiversity concept to develop and estimate indicators of urban farming benefit into valuation through the direct market and stated preferences approaches. The study employed field surveys, in-depth interviews and remote sensing analysis. Here we show for the first time that the Total Economic Value of urban farming benefits reached up to US$ 13.11 in a square metre annually if all urban farming forms occupy a square metre each. However, this value had a gap with the benchmark of US$ 15.89/m^2 annually. The gap value could be a policy recommendation to incentivise citizens to participate in emerging urban farming initiatives actively. This benefit value indicates that urban farming is feasible and valuable for further development.

Keywords Urban farming · Ecosystem services · Benefit · Valuation · Incentive · Policy

---

T. Atmaja (✉) · K. Kurisu
Department of Urban Engineering, Graduate School of Engineering, The University of Tokyo, Tokyo, Japan
e-mail: atmaja@env.t.u-tokyo.ac.jp

K. Kurisu
e-mail: kiyo@env.t.u-tokyo.ac.jp

K. Fukushi
Institute for Future Initiative (IFI), The University of Tokyo, Tokyo, Japan
e-mail: fukushi@ifi.u-tokyo.ac.jp

U. Chatterjee et al. (eds.), *Urban Commons, Future Smart Cities and Sustainability*, Springer Geography, https://doi.org/10.1007/978-3-031-24767-5_30

Introduction

Over the years, rapid urbanisation and urban poverty have exposed cities' vulnerabilities. Urban settings could lead to significant inequalities and health problems, particularly a major negative impact on the nutritional health of poor populations (Kuddus et al. 2020). The share of urban poor in total poor in Indonesia cases, already substantial, will almost certainly rise with the higher levels of urbanisation in years to come (Burger et al. 2012; UN 2018). Furthermore, urbanisation coupled with climate change will lead to heat stress with a range of 0.5–2.0 °C (Oleson et al. 2013; Argüeso et al. 2015). Urban activities and urbanisation have become key contributors to more than 70% of global GHG emissions for energy needs (UN-Habitat 2016). It includes 26% of food emissions, where 6% comes from transportation (Poore and Nemecek 2018). The nexus of increasing economic growth and accelerating urbanisation has increased energy needs and, thus, leading to pollution and environmental degradation (Wang and Dong 2019; Parveen et al. 2020). Cities have been stressed by providing services to urban demand (Kremer et al. 2016). These phenomena were experienced in many cities in Indonesia (Bappenas 2018; UN 2018; Subadyo et al. 2019). Cities must improve their resilience to respond to and cope with challenges by maintaining essential services (Elmqvist et al. 2019; Lehmann 2019).

Presently, urban farming is promoted as one of the systemic solutions to evolving multidimensional benefits for society, nature and the economy to achieve resilience (Eigenbrod and Gruda 2015; Mumenthaler 2015; Knapp et al. 2016; Fernández Andrés 2017). Urban farming (hereinafter UF) is the practice of growing, cultivating producing, and distributing food and other products by utilising yards, vacant lots, or designated areas in and around cities that provide many benefits. These benefits were well-acknowledged as ecosystem services (ES) which have been extensively documented in past decades (Artmann and Sartison 2018; Wilhelm and Smith 2018). For instance, UF provided benefits such as food provision and revitalisation of the local economy, as assessed by Jonck et al. (2018), Pulighe and Lupia (2019). UF also increases wellbeing and social benefit (Wang and Pryor 2019) and improves water and waste management, and reduces energy use (Lee et al. 2015). Policy study on UF indicated that it could be acknowledged as an urban green space (Contesse et al. 2018) and Hybrid Strategy or Nature-based Solution (Depietri and McPhearson 2017; Artmann and Sartison 2018; Skar et al. 2019). It was hypothesised that UF holds promise to expand the portfolio of ES available in in-built environments and thus improve urban resilience.

Research on UF services valuation in the context of ES has been documented (Clinton et al. 2018; Wilhelm and Smith 2018; Wang and Pryor 2019). However, only a few studies consider Urban-Peri Urban Agriculture (UPA), which UF included in, discussed in the context of ES. A review paper by Wilhelm and Smith (2018) found that only a few studies (15 out of 320 papers) place UPA in the context of ES. A recent study on UPA found that when measured at a global scale using limited indicators, it could provide over $160 billion annually (Clinton et al. 2018). While the specific study on the estimation of the social value of urban rooftop farming through the state preference approach found that the average willingness to pay for this benefit was HK$ 440 (~US$ 56.20) per month per person for a square metre, a bit higher compared with the charge for renting (Wang and Pryor 2019). Most studies are still scattered indicators used in the valuation. Researchers used food production as the main indicator to measure UF's role in alleviating food insecurity through the economic return method (Saha 2016; Parece et al. 2017; Pulighe and Lupia 2019). Moreover, it has not yet established a consistent quantitative framework, especially in monetising the UF benefit by integrative indicators.

Rational of the Study

Given the limited quantitative measurement of UF benefits utilising compact indicators, this chapter was a research paper that directed to estimate actual and potential UF benefits in a monetary unit, so-called Total Economic Value (TEV), in the context of ecosystem services through integrative measurement indicators. The integrative indicators were defined as benefits of UF, which were final products of ES that were directly or indirectly perceived by people. Malang City, Indonesia, was selected as a case study which is still facing various environmental challenges (Suroso et al. 2012; Subadyo et al. 2019). In another hand, the city was awarded as the best city that implements UF initiative in 2019. Expanding research on UF valuation is expected to shed light on the contribution of this initiative to the city's resilience.

Material and Method

Identification Urban Farming Performance

UF takes multiple forms, and its categorisation sometimes becomes argued. This chapter adapted UF typology from previous work and adjusted it with the site study (Mumenthaler 2015; Skar et al. 2019; Atmaja et al. 2020). They are Nursery, Allotment, Residential, Institutional and Rooftop farming, as illustrated in Fig. 30.1.

Fig. 30.1 Urban farming typology

Table 30.1 Distribution of target respondent

Target respondent	Number	Involvement of respondents in each UF form				
		Nurseries	Allotment	Institutional	Residential	Rooftop
Urban farmers	60					
• Chairman	10	10	10	1	5	1
• Manager	12	12	12		11	2
• Member	36	30	30	11	28	
• Personal urban farmer	2				1	1
Non-urban farmers	34					

In total, there were 21 UF plots where 12 belong to community, four private plots and five unidentified. Each plot consisted of at least one of the UF forms. To obtain UF performance data (i.e., production, kind of vegetables cultivated, and so on) and perceive the value earned by the beneficiaries, a field visit observation, survey and in-depth interview were conducted to specific respondents across UF forms above. In the case of Malang City's UF, its community generally consists of 10–20 members in every plot. Thereby, the total population size was 210 urban farmers distributed in 21 plots for 10 members each. Through the random sampling technique of Slovin's formula, the minimum sample size with a 10% margin of error was 68 respondents. The survey selected 60 respondents, as urban farmers and 34, as non-urban farmers. Table 30.1 shows the distribution of respondents associated with the UF form.

Development of Integrative Indicator

The study developed integrative indicators through the 'cascade model' (Cordier et al. 2014; Potschin and Haines-Young 2016). The model described the pathway of causal interrelations between the ecosystem at one end and the human wellbeing at another. The indicators were acknowledged as *Benefits*, the final product of ES provided by UF, which directly or indirectly affects or is used by humans. The development of indicators also considered The Economic of Ecosystem and Biodiversity (TEEB) concept followed by the TEV framework (TEEB 2010) consisting of four ecosystem service types: Provisioning, Regulating, Supporting or Habitat, and Cultural Services. TEV framework consists of direct use value (consumptive or non-consumptive) and indirect use value which was derived from the regulation services provided by species and ecosystems. This study concept was also adopted from Common International Classification for Ecosystem Services (CICES 2017). Each selected indicator was aligned with an index indicating the resilience aspect, namely Economic (E), Social (S), Environmental (V) and Human (H) (Gonçalves 2013; Elmqvist et al. 2019). Finally, each indicator was assigned to certain UF forms. The cascade model is shown in Fig. 30.2.

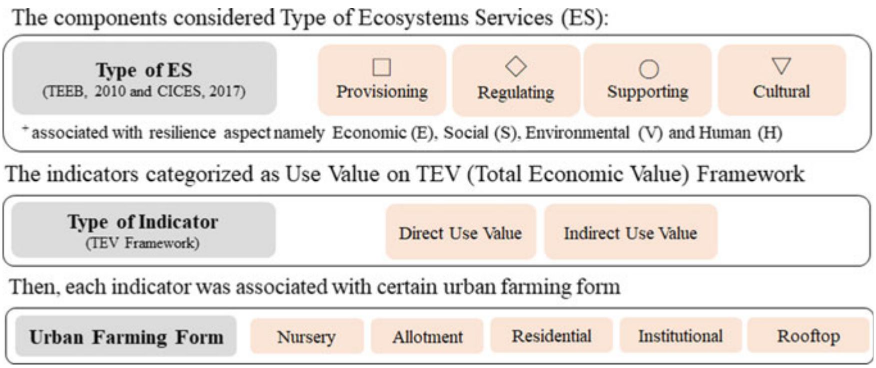


Fig. 30.2 Cascade model in the development of indicator of UF benefit

Metric and Monetary Valuation of the Integrative Indicators

The integrative indicator above was assessed under the Total Economic Value (TEV) approach. The idea of this assessment was to estimate indicators in the metric unit and then convert it into the monetary unit. Each indicator followed a specific method and conversion factor, as summarised in Table 30.2. An exception in the indicator of S1, S2 and H1, which followed the State Preference Approach through the Contingent Valuation Method, was directly assessed in monetary value. Detail description of each indicator was given in the following sections.

A. Provisioning food supply (E1)

The provisioning food supply was measured using annual vegetable yield, Y_i (kg/m^2/yr), as:

$$Y_i = \left[\frac{P_i}{A_i} . f_i \right] \tag{30.1}$$

where A indicated the total area of ith UF form in m^2, the symbol of P was the average production of ith UF form per harvest time in kg where f was harvesting frequency of ith UF form in a year.

To monetise this indicator, it was used different prices of inventoried vegetables between consumer price from the market (i) and producer price (ii), indicated as R as US$ 0.75/kg as shown in formula (30.2). The average consumer and producer price of inventoried vegetables were obtained from statistical data for US$ 1.66/kg and US$ 0.90/kg, respectively.

$$V_{\text{food}} = Y_i . R \tag{30.2}$$

Table 30.2 Valuation of indicators of UF benefit

Indicator of urban farming benefit	Data	Metric value estimation	Monetary value estimation
E1. Provisioning food supply	■	Annual vegetable yield	The economic return of vegetable production
E2. Local income generation	■	Added-value product created	The economic return of selling product
S1. Recreational and community-building S2. Education and learning H1. Urban comfort	▼	CVM is determined from willingness to pay (WTP): S1. Recreation ticket S2. Learning/visiting ticket H1. Monthly payment by household	
V1. Stormwater (runoff) management	●	Difference runoff between on impervious surface and community garden (ΔR) derived from design rainfall value (P) of the given return period (T, assumed ten years)	The replacement cost of stored water in the reservoir can be used to monetise the runoff (Zhang et al. 2012) Unit cost per volume of water stored in a reservoir is US$ 1.72/m^3 (adopted from (Prabowo 2015)
V2. Supporting urban biodiversity	◆	Using reference values from previous study through Benefit Transfer method which was used mean willingness-to-pay citizens for the preservation of biodiversity and habitat services provided by greenspace (Nijkamp et al. 2008)	
E2. Food mileage	●	Reducing carbon results from fuel (food mileage)	It used a median carbon price of US$ 0.060/kg CO_2 (World Bank Group 2018)
V3. Carbon storage and sequestration	◆	Using reference values of carbon storage for vegetable farms from previous study through Benefit Transfer method (Matsuura et al. 2018)	This chapter adopted a medium price of social cost provided by Hungate et al. (2017), US$ 0.0493/kg C, to monetise carbon storage value
V5. Energy-saving (cooling)	●	It was used energy saved per unit area in every reducing temperature, E_s (kWh/m^2/°C)	It used electricity price of total energy used (kWh) in the cooling room through air-conditioner, US$ 0.065/kWh

Data source ◆ (Literature); ● (Statistical analysis using secondary data); ■ (Field visit observation); ▲ (Questionnaire survey)

B. Local income generation (E2)

In addition to food provision, UF also performs as income generation. However, this indicator was only limited to perceived by the urban farmer community. This included selling seeds from the Nursery and the derivative product (added-value product) from the allotment. The economic return was used to estimate the value indicator by selling the urban farmer's total product (seeds and derivative products). It utilised the following formula (V_{income}, US$/m^2/yr),

$$V_{\text{income}} = \left(\frac{f_s.R_s}{A_n}\right) + \left(\left[\%\ \text{profit margin}\right].\frac{f_p.R_P}{A_l}\right) \quad (30.3)$$

where f was the frequency of selling in a year, A was the total area in m^2, and R was the selling price of seed (s) or products (p). The percentage profit margin used was 50%. The selling products are determined based on markup pricing and penetration pricing. The chapter only considered markup pricing, which the seller primarily determines. According to previous research, it was adjusted to 50% for selling farming products (Gullstrand et al. 2013; Santoso et al. 2018). It was assumed that created products were associated with area size.

C. Recreational, community-building (S1); Education and learning (S2); and Maintenance of urban comfort (H1)

These indicators were grouped as assessed using the Contingent Valuation Method (CVM) by directly asking urban and non-urban farmers about their willingness to pay (WTP) through a hypothetical market. CVM is one of the valuation techniques which come under stated preferences in measuring individuals' value for environmental goods through WTP form. This valuation revealed the monetary unit directly. WTP is the amount that must be taken away from the person's income while keeping his utility constant. Respondents were given several price offers through this hypothetical market and select base on their WTP preference. The range of price option was considered based on focus group discussion (FGD) with stakeholders responsible for the project and being adjusted from previous research related as well as adapted from previous studies. The range of options for the recreation indicator was used recreation ticket adapted from a study by Harahap (2015), who assessed WTP citizens who enter tourist lakes and heritage villages (ticket price) for recreation. While on indicator education, the price option range was adjusted with a case study on ticket prices entering the tourism village in Malang City (based on a field visit). For maintenance of urban comfort, the option was based on research by Brenner (2007), who assessed the value of urban comfort derived from green open space, and research by Widiastuti et al. (2016), who evaluated WTP respondents to preserve mangrove site.

A questionnaire was utilised to collect WTP of selected respondents. Since the payment question was open-ended, the WTP can simply be averaged to produce an estimate of mean WTP (MWTP) as follows (TEEB 2010; Widiastuti et al. 2016; Wang and Pryor 2019).

$$\text{MWTP} = \frac{1}{n}\sum_{i=1}^{n} y_i \quad (30.4)$$

where n was the sample size, and y_i is a reported WTP amount.

D. Stormwater (runoff) management (V1)

Since UF is able to act as reservoir or stormwater runoff management, therefore, this benefit was calculated using the difference runoff between impervious surface and community garden (Δ ***R***) derived from the design rainfall value (***P***) of the given return period (***T***, assumed ten years).

$$\Delta R = R_{\text{impervious surface}} - R_{\text{community garden}} \tag{30.5}$$

Runoff (***R***, m^3) was calculated using Natural Resource Conservation Service (NRCS) method for urban hydrology (USDA 1986). This methodology was also adopted to calculate change runoff in the urban community garden (Gittleman et al. 2017) and urban agriculture (Clinton et al. 2018).

$$R = Q.(0.0254).A \tag{30.6}$$

$$Q = \frac{(P - 0.2S)^2}{(P + 0.8S)} \tag{30.7}$$

$$S = \frac{1000}{\text{CN}} - 10 \tag{30.8}$$

where Q is the runoff rate in inches for a given P-inch, A is the area in a m^2, and S indicates the maximum potential runoff after runoff begins (determined by Curve Number, CN). Mass rainfall value (***P***) was converted to mass runoff using a runoff curve number (CN). CN was based on the Hydrologic Soil Group (HSG), i.e. on soils, plant cover, impervious areas, interception, and surface storage. To identify specific CN in Malang City following HSG, this study utilised and downscaled CN-Based Runoff Modelling provided by the previous study (Ross et al. 2018). To obtain proper CN values for community gardens, it utilised values used for parks in the Centre for Neighbourhood Technology (CNT) Green Values Stormwater Calculator, which was also adopted in a previous study (Gittleman et al. 2017).

According to CN-Based Runoff Modelling, Malang City is mainly categorised into C and D types of Hydrologic Soil Group. It was assumed that HSG Type C for institutional farms indicated moderately high runoff potential (< 50% sand and 20–40% clay) while HSG Type D for allotment farms showed high runoff potential (< 50% sand and > 40% clay).

Design rainfall value (***P***) was calculated using the Gumbel frequency analysis method (formula 30.9). The method was based on extreme value distribution (annual maximum daily rainfall, x) and uses frequency factors (K) developed for theoretical distribution with standard deviation, Sd. It used daily precipitation data for 1996–2016 ($n = 20$). The frequency factor (K) was 1.625, followed by the table of frequency factors for the Gumbel Method for T for ten years and n data for 20 years. According to this assumption, the rainfall design for analysis was found to be 111.4 mm.

$$\boldsymbol{P} = \overline{x} + K.\text{Sd} \tag{30.9}$$

The replacement cost method was considered the most appropriate valuation method to monetise the avoid runoff value or runoff management services in urban areas. It represents the indirect valuation approach, where the cost of a close substitute was used to measure the value of the replaced non-priced environmental good or service (Barbier and Hanley 2009). In addition, urban green space can perform as rainwater storage temporarily (White 2002). Here it was adopted and assumed that the service of rainwater storage by UF could be replaced with a reservoir which is calculated as follows (V_{roff}, US$/m^2/yr):

$$V_{\text{roff}} = \Delta R.(\text{Rr}) \tag{30.10}$$

The economic benefit of rainwater storage as the replacement cost of the reservoir was also applied in a study by Zhang et al. (2012). Its value can be calculated by the unit cost per volume of water stored in the reservoir (Rr). The unit cost can be estimated by dividing the construction cost for those reservoirs and the capacity to store water. Unit cost reservoirs based on average reservoir value in Indonesia (Rr) were obtained from the Ministry of Public Works Indonesia (2020) as **US$ 1.72/m^3** (Prabowo 2015). The conversion value was similar to research on potential avoiding runoff provided by Campus Forest, Tucson, Arizona, USA, for US$ 1.10/m^3. In other studies, Zhang et al. (2012) used US$ 1.25/m^3 to monetise this value, and Silvennoinen et al. (2017) used US$ 1.41/m^3 as the annual cost of controlling runoff by infrastructure in Finland.

E. Supporting urban biodiversity (V2)

Due to the study could not investigate and screen the richness species in full detail of all UF plots, it was adopted previous research valuation on biodiversity benefits using the Benefit Transfer method following Brink et al. (2000), Nijkamp et al. (2008). The general idea is to explore the use of previous and original valuation studies ('study site') and to transfer their estimates' values to the site where the new value estimate is needed ('policy site'). This Benefit Transfer method can be applied across different sites—spatial value transfer or, for specific site over time.

Brink et al. (2000), Nijkamp et al. (2008) assessed a comparative study of biodiversity valuation through the meta-analytical method. They estimated biodiversity valuation through mean WTP for biodiversity preservation of urban greenspace. The value was US$ 38.99/person/yr (US$ 2018), which was associated with demographic characteristics. To avoid the bias, the study adjusted the value with a ratio of GDP per capita in Indonesia and Europe.

$$V_{\text{bio}} = \frac{\text{GDP per capita Indonesia}}{\text{GDP per capita original case study}}.\text{US\$38.99/person/yr} \tag{30.11}$$

F. Food mileage (E3)

Production of UF ($\mathbf{Y_i}$) reduces food imported and transported from other areas, thus reducing food mileage (**D**). Food mileage was defined as the distance that food materials were transported from the supplier (producer) or a particular market point to the consumer. Lee et al. (2015) stated that the rise of UF initiatives is also associated with a desire to reduce food mileage. Reducing food mileage has two benefits such as (i) reducing carbon emitted resulting from fuel $VmilCO_2$ and (ii) cost-avoidance of fuel consumption (V_{mil} Cost). However, the study emphasised only the first point since the second point was associated with production, which was already accounted for previously. Meanwhile, the $VmilCO_2$ was also indirectly related to the production of vegetables provided by UF. Since only the nursery did not produce vegetables, it was excluded from estimation. Metric estimation of CO_2 reduction was calculated using the following formula:

$$CO_2 \text{ reduction} = Yi.D.\text{FC}_t \tag{30.12}$$

where

- **Y** is the yield of *i*th UF form [$kg/m^2/yr^1$] earned in Indicator E1.
- **D** is food mileage calculated based on the distance of vegetables primarily delivered from the Main market to Malang City ($D = 7.38\ km$) using trucks on the road (national public road).
  - The truck can transport at least a ton of vegetables.
  - The carbon emission coefficient for the truck (FC_t) is 0.2265 $\frac{\text{kg C}}{\text{t - km}}$; delivery vehicle i.e., truck type class I (0.2265 kg CO_2/1 t-km = 0.2265 kg CO_2/t-km) (UK Government GHG Conversion Factors).

To convert in a monetary unit of reduction of CO_2, it was used median carbon price (C_{price}) where a minimal price range needed by 2020 to be consistent with achieving the Paris Agreement temperature target. It was US\$ 60/t CO_2 or **US\$ 0.060/kg CO_2 emitted**. The minimal carbon price range was US\$ 0.040–0.080/kg C emitted (World Bank Group 2018). As a comparison, to capture the highest value of carbon price, the most increased replacement cost of a carbon price of Swedish was used. It was US\$ 127/t C or **US\$ 0.127/kg C emitted** (World Bank Group 2019). This value was used to compare the median (as a minimum) and maximum C price (Ramstein et al. 2019). This overseas benchmark was used because similar regulations on taxing carbon emissions were unavailable in Indonesia and Sweden puts the highest price on carbon taxing comparing other countries. This approach was also used by Jim and Chen (2009) to acknowledge the ecosystem service of the urban forest in carbon storage. They put RMB 339.8/t (US\$150/t) of a carbon price in the monetary valuation. Monetary valuation of V_{mill} (US\$/m^2/yr) was calculated as follows:

$$V_{mill} = CO_2 \text{ reduction}. C_{price} \tag{30.13}$$

where

$$C_{price} = 0.060 \frac{\text{US\$}}{\text{kg } CO_2} \tag{30.14}$$

G. Carbon Storage (V3)

The study utilised the Global Soil Organic Carbon Map provided by FAO (2020) and World Soil Information (ISRIC) to estimate the matric value of stored carbon in UF in Malang City. It delivered the Soil grid 250 m, soil organic carbon stock in tones/ha for depth intervals of 0.00–0.05 m. The map was then resampled into a smaller grid size (30 m) for Malang City as a case study to capture more specific areas of different UF plots. The vegetables in UF plots were considered **Herbaceous vegetation** (no-woody plants) to reduce complexity and broadly account for heterogeneity in vegetation structure across plots (Mette et al. 2003).

The economic benefit of the carbon storage value of vegetables can be seen as the total damages avoided by removing greenhouse gases such as CO_2 from the atmosphere. Recently, an estimation valuation of carbon storage was done by Hungate et al. (2017), who used the social costs of carbon in US dollars per metric ton of carbon (\$ MT C^{-1}). The social cost of carbon is the damage done by emitting an additional unit of carbon dioxide (CO_2). The social costs of carbon used the value discounted over time as carbon accumulation occurred over the 50-yr simulation. The estimates of the social were derived from the recent synthesis conducted by a consortium of US federal agencies for regulatory impact analysis (Government 2015).

The social cost proposed by Hungate et al. (2017) contained three estimations. The low estimate was US\$ 0.0493/kg C, the medium assessment was US\$ 0.1614/kg C, and the high estimate was US\$ 0.4707/kg C. All social costs estimated were already converted into 2020 USD. Compared with the Carbon Price provided by the World Bank Group (2018), those social cost values have similarities. World Bank Group offered a medium carbon price of US\$ 0.0600/kg C as a minimal price range needed by 2020 to be consistent with achieving the Paris Agreement temperature target. The minimal carbon price range is US\$ 0.040–0.080/kg C emitted, while the highest carbon price is US\$ 0.127/kg C emitted (Ramstein et al. 2019).

This study adopted the medium price of social cost provided by Hungate et al. (2017), US\$ 0.0493/kg C, as a monetary valuation of carbon storage. To quantify the carbon storage in kg C/m^2/yr and carbon price in US\$/kg C, it was utilised the following equation (V_{car}, US\$/m^2/yr)

$$V_{\text{car}} = C_{\text{storage}}.C_{\text{price}} \tag{30.15}$$

It was assumed that all UF form has the same potential carbon storage value. However, as mentioned earlier, it was only concerned with allotment and institutional farms, which mostly contained mixed and diverse vegetables.

H. Energy Saving (H2)

UF could contribute to reduce energy consumption for cooling which can be monetise through energy consumption from using Air Conditioner (Wang et al. 2011). Less energy will be consumed when the temperature set point is higher. Therefore, the chapter examined the difference temperature on rooftop farming and compared to conventional rooftop (ΔT, °C). The temperature on the rooftop farm was read directly through field observation and utilised a digital instrument thermometer. Only four rooftop farms can be accessed. The other has limitations to be accessed of privacy issues. The average temperature on the green roof accessed was 27.88 °C. The conventional roof temperature used data of average temperature in the area neighbourhood of the rooftop farming. According to the estimation, the traditional temperature of the rooftop was 28.90 °C. Detail identification was shown in Table 30.3.

Since it was related to energy consumption for electricity, thereby monetising the energy used, the electricity base prices in Indonesia were utilised. The base electricity price, P_e in Indonesia (2019), was **US$ 0.065/kWh**. Then, the total economic of rooftop farming services in energy saving (V_{eng}, US$/m^2/yr) was calculated as follows:

$$V_{\text{eng}} = \Delta T.E_c.P_e.T_{\text{days}} \tag{30.16}$$

where ΔT was average difference temperature [°C]; while E_c was energy converter from degree to kWh/m^2 [kWh/m^2/°C], **0.1956 kWh/m²/°C** (Wang et al. 2011); P_e was electricity price [US$/kWh]; and T_{days} was total days in using the air conditioner in a year. It was assumed that the air conditioner was only used in the summer season and only used half day. Thereby, the total days was **90 days**. For energy consumption

Table 30.3 Green and conventional rooftop temperature

Location	Rooftop area (m^2)	Temperature on green roof (°C)	Temperature on conventional roof (°C)	ΔT (°C)	Note
Polehan	140	27.1	28.5	1.4	The area of rooftop farming was the biggest one
Sawojajar	20	24.9	25.3	0.4	Rooftop farming does not have any cover or building in the surrounding
Balearjosari	15	29.3	30	0.7	Big trees in the surrounding covered rooftop farming
Dinoyo	16	30.2	31.8	1.6	The location of the green roof has limited sunlight since covered by other building
Average				1.03	

needed to reduce a degree temperature in unit area, E_c, through air-conditioner was **0.1956 kWh/m²/°C**. The study adopted this value in order to convert each lowering temperature into reduction of energy consumption.

Total Economic Value (TEV) Actual and Potential

The Total Economic Value (TEV) of UF was then calculated by summing all indicators. TEV of *i*th indicator on *j*th UF form followed this formula:

$$\text{TEV of UF}_{ik} = \sum_{ik}^{n} V_{ik} \tag{30.17}$$

V was the kth indicator's value on ith UF form [US$/m^2/yr].

Since UF was mostly land-based except for rooftop farming, the total value obtained above was compared to the land value as a benchmark for the analysis. Based on the regulation of the Indonesian Bank (PBI) No.9/PBI/2007, the land can be used as a guarantee object for credit loans. The benchmark was calculated by multiplying between the Bank interest scheme (I_{Bank}) if a land was pawned for loans by land prices (P_L) and subtracted by the annual land tax (Tax). Land price is an average of the Selling Price of a Taxable Object (land) in a square metre provided by the Ministry of Agrarian Affairs and Spatial Planning Indonesia. The benchmark was given as follows

$$\text{Benchmark} = (I_{\text{Bank}} \times P_L) - \text{Tax} \tag{30.18}$$

Based on Bank Interest scheme, the benchmark was US$ 29.00/m^2 annually.

Result and Discussion

Integrative Indicator of Urban Farming Benefit

Based on cascade model following the TEEB concept of four ecosystem services, the study developed the integrative indicators and applied them to selected UF forms under three main components such as strengthening community, improving the urban environment, and resource or energy efficiency (Table 30.4). Strengthening the community is the role of UF as provisioning and diversifying urban food sources and income opportunities, particularly for the urban poor. In addition, it provides cultural value for human wellbeing. Therefore, this component was built by indicators such as provisioning food (E1), local income generation (E2), recreation-community-building (S1), and, education and learning (S2). These indicators fall under the category of ecosystem services as provisioning and cultural value, which can be used by people directly (Saha 2016; Wang and Pryor 2019). While 'Improving urban environment' indicated that by maintaining urban green space, the urban environment would be enhanced through urban comfort (H1), regulating the water runoff through acting as a natural reservoir (V1), or supporting diverse biodiversity (V2), in which these were indirectly perceived by people (VanWoert et al. 2005; Zhang et al. 2012; Clinton et al. 2018). Allocating resources and energy efficiency, which is acknowledged to help and maintain surrounding areas by reducing heat and energy, i.e., food transport/mileage (E3), carbon storage (V3) and energy saving by lowering temperature (H2) (Davies et al. 2009; Costanza et al. 2014; Elmqvist et al. 2015b; Lee et al. 2015; Vilem et al. 2017). Therefore, these indicators were indirectly perceived by the people surrounding them.

UF could provide vegetables that allow saving money from buying. The study by Saha (2016) estimated food yield as a measurement valuation in allotment and rooftop farming. While Pulighe and Lupia (2019) also considered this indicator to assess food self-sufficiency potential. The food provision indicator worked for all UF forms except for nurseries. It was due to the nursery being solely addressed for cultivating purposes. Therefore, it produced nothing except seeds. Local Income Generation (E2)

Table 30.4 Integrative indicators of UF benefit

Indicator	ES type	TEV type	UF form				
			1	2	3	4	5
I. Strengthening community							
E1. Provisioning food (V_{food})	□	■		✓	✓		✓
E2. Local income generation (V_{inc})	□	■	✓	✓			
S1. Recreational, community-building (V_{rec})	▽	■	✓	✓	✓		
S2. Education and learning (V_{edu})	▽	■	✓	✓	✓		
II. Improving the urban environment							
H1. Maintenance of urban comfort (V_{comf})	◇	●	✓	✓	✓		
V1. Stormwater (runoff) management (V_{roff})	◇	●		✓	✓		
V2. Supporting urban biodiversity (V_{bio})	○	●	✓	✓	✓	✓	✓
III. Allocating resources and energy efficiency							
E3. Food mileage (V_{mill})	◇	●		✓	✓	✓	✓
V3. Carbon storage and sequestration (V_{cst})	◇	●		✓	✓		
H2. Energy-saving (cooling) (V_{eng})	◇	●					✓

UF form: (1) Nursery; (2) Allotment; (3) Institutional yard; (4) Residential; (5) Rooftop
resilience aspect: economy (E); Social (S); Environment (V); Human (H)
E.S. type: □ (Provisioning); ◇ (Regulating); ○ (Supporting or Habitat); and ▽ (Cultural)
TEV type: ■ (direct use value) and ● (indirect use value)

was acknowledged as income earned from selling added-value products (derivative products). Since the products estimated here are only seeds and derivative products, this indicator works only on nursery and allotment forms because of their ability to sell the seeds and produce a derivative product not provided by other UF forms.

UF is also performed as social or cultural services, i.e. Recreational, community-building (S1); Education and learning (S2); and Maintenance of urban comfort (H1) (Wang and Pryor 2019). Since the UF level did not limit social value, these indicators work in all forms. These values were categorised as perceived cultural values and microclimate regulation of UF. The limitation was that the value obtained could not be aggregated to each form.

UF, as part of green space, performs in Avoiding Stormwater Runoff (V1) and acknowledged to act as reservoir (VanWoert et al. 2005; Zhang et al. 2012; Clinton et al. 2018). UF has also the potential to Support Biodiversity (V2) not only within UF sites but also nearby due to a landscape-mediated 'spill over' of energy, resources and organisms across habitats. Specifically, it is essential to provide habitats for diverse species and conservation benefits to cities (Davies et al. 2009; Costanza et al. 2014; Vilem et al. 2017). The study examines habitat provision as an UF service supporting biodiversity for all UF forms. Production of vegetables can reduce the food demand and purchase from the market, thus Reducing Food Mileage (E3). The indicator of Food Mileage was associated with Food Provision. Thereby, it worked for all UF forms except for the nursery. A study on UF services in reducing food mileage was documented by Lee et al. (2015). Other indicators used in valuation, i.e. Carbon storage and sequestration (V3), used literature review of previous studies related to carbon storage, especially on Herbaceous vegetation. UF mainly was cultivating vegetables which are considered Herbaceous vegetation. Since only land-based cultivation techniques provide this value, it worked for allotment and institution farms only. Besides, the benefit of UF in saving energy (cooling) (H2) was also estimated. It was proven by Elmqvist et al. (2015a, b), who reviewed literature and found that urban green space and its vegetation, including green roofs and green walls, reduce the urban heat island effect. Thereby, it worked for rooftop farming only.

Urban Farming Value

A. Provisioning Food Supply (E1)

Based on field visit observations, the allotment farm produced 1.32 kg m^{-2} annually, lower than the residential farm, which was 4.02 kg m^{-2} (Fig. 30.3). Urban farmers usually cultivate short-term vegetables within their residential or rooftop farming area and manage intense. However, community farms (Allotments) are mostly used for education or demo plots within survey areas.

According to the field visit, most allotment farms were used for demo plots, which resulted in low yield, although the area size was bigger. McDougall et al. (2019),

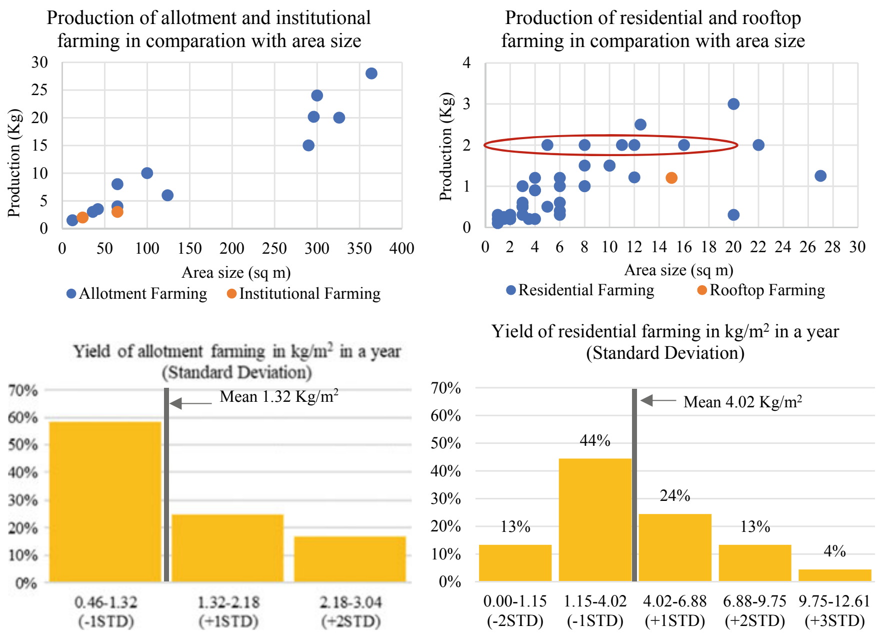


Fig. 30.3 Comparison of each UF form production

in their study, stated that most gardeners indicated that they were not highly motivated by the desire to produce large quantities of food on a community farm. In another hand, community farm has a high ranking in environmental, social, recreational and personal health-related motivation. The allotment and institution farm especially, only used soil-based cultivation, while residential and rooftop used polybags, containers or chambers to cultivate. A square metre area can be contained up to 25 medium sizes of polybags. According to McClintock et al. (2013), vegetables' yield will differ under different management practices. Under conventional management, vegetables could be harvested up to 2.47/m^2/yr; low-bio-intensive at 3.71 kg/m^2/yr; and medium-bio-intensive at 6.18 kg/m^2/yr. The operation in residential and rooftop farming in Malang City can be categorised as low-bio-intensive where gardeners were not professional but understood how to cultivate.

B. Local income generation (E2)

According to inventoried, Malang City only has 16 out of 21 plots of UF that were still cultivating. It was only 12 of 16 plots belonged to UF community. The community means that those plots have all UF forms except rooftop farms. This indicator specified these 12 plots as only the community that sold seeds and derivative products such as vegetable chips. The results indicated that only 9/12 plots are selling seeds as their products. The average income from selling seeds per unit area was US\$ 2.16/m^2/yr, as shown in Fig. 30.4 left-panel. One plot or community farmer supplies seed to the private company as a customer. This outlier was excluded from

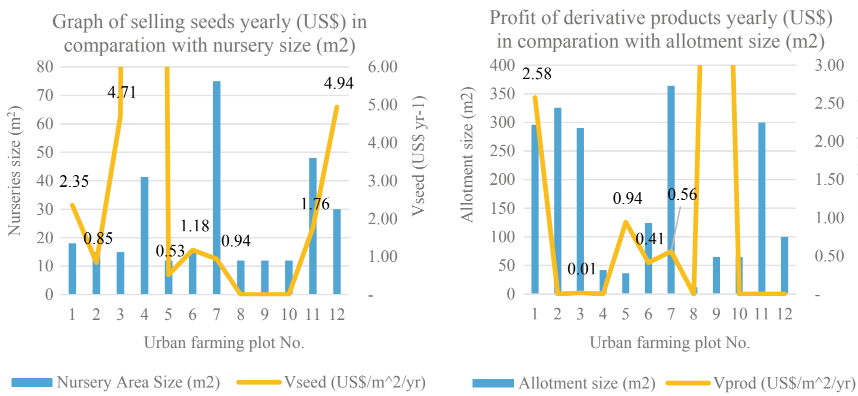


Fig. 30.4 Local income generation from selling seeds (left) and derivative products (right)

estimation. While only 7 out of 12 plots created derivative products, only six sold the products. The average income by selling this product were US$ 0.90/m^2/yr, as shown in Fig. 30.4 right-panel.

C. Recreational, Community-Building (S1); Education and Learning (S2); and Maintenance Urban Comfort (H1)

As documented by previous research, UF has potential values for human wellbeing (Calvet-Mir et al. 2012; Kabisch et al. 2016; Wang and Pryor 2019). These values can be assessed through WTP. According to the survey, WTP was associated significantly to the degree of understanding of UF. All urban farmers understood and perceived the social values provided by UF. Only 71% of non-urban farmers (citizens) understood and perceived the values. Thereby, it was essential to increase the perception of social values among citizens about UF's social/cultural benefits. Nevertheless, most non-urban farmers were willing to pay for this benefit. These worked among all indicators. According to Wang and Pryor (2019), asking questions about individual payment decisions encouraged respondents to consider the benefits and the maximisation of utility. WTP also was found to be associated with the level of education. Most of the respondents willing to pay were from higher levels of education (senior high school and university level). However, the WTP has a low association with income level. The respondents have not influenced by their income level for paying. This worked for both farmer and non-urban farmers. In conclusion, many respondents were willing to pay for the cultural value perceived in UF.

According to survey to urban farmer and non-urban farmer, the result showed that WTP on recreation did not follow the linear line. Most respondents were concentrated on the range US$ 0.18–0.35 for the non-urban farmer while more than US$ 0.71 for the urban farmer. This indicated that non-urban farmer has no intention or are undesired to enjoy UF for recreation. The result shows that urban farmers' WTP on recreation visiting tickets was, US$ 0.80 per person per visit, twice higher than non-urban farmer. While for education, the farmer will pay up to US$ 1.10 per person per visit, higher if compared with non-farmer who will only pay the amount of US$ 0.45 per person per visit. While opposite on the indicator of urban maintenance comfort, non-urban farmers' WTP was higher than WTP's urban farmer although the difference was only US$ 0.04. WTP for maintenance urban comfort was documented as only US$ 0.34 per household per month. This was because the citizens perceived that their areas, i.e., temperature and humidity, were properly maintained through the availability of UF. In addition, the farmer thought that they would prefer to use UF areas for recreational and educational purposes since the money will be used for them to operate urban farms directly, and they will be involved in the activity of educating and learning to the audience. While WTP of education and maintenance of urban comfort, were associated with an increasing range of options. In education, urban and non-urban farmers were concentrated for range of US$ 0.15–0.35, similar to Maintenance of urban comfort. To conclude, each WTP was averaged to get MWTP. They were US$ 0.58 per person per visit for recreational and community-building; US$ 0.77 per person per visit for education and learning; and US$ 0.37 per household per month for maintenance of urban comfort. Since this value was aggregated, it cannot be separated and divided by UF form.

D. Storm Water (Runoff) Management (V1)

The valuation shows that a square metre UF area can save money by US$ 0.12 and US$ 0.14 in the allotment and institutional farm, respectively (Table 30.5). Silvennoinen et al. (2017) mentioned that the green space has a value ranging from US$ 10.11–30.33/m^2 in avoiding a runoff depending on the degree of imperviousness. In addition, the result was still low compared with the study by Zhang et al. (2012), who concluded that urban green space in Beijing, China has a value of US$ 0.26/m^2 in avoiding a runoff. For a 10 cm thick substrate and a heavy rainfall event, defined as exceeding 6 mm rainfall per day, 54% of precipitation was retained by the growth medium (VanWoert et al. 2005).

Table 30.5 Metric and monetary unit of UF benefit for runoff management

	Q (inches)	R (m^3/m^2)	ΔR (m^3/m^2/yr)	% ΔR of total P (%)	V_{roff} (US$/m^2/yr)
Impervious surface (CN = 100)	4.3861	0.1114			
Allotment farming (CN = 70)	1.5936	0.0405	0.0709	63.67	0.12
Institutional farming (CN = 63)	1.1353	0.0288	0.0826	74.12	0.14

E. Supporting Urban Biodiversity (V2)

Biodiversity is variability among living organisms from all sources, including, among other things, terrestrial, marine, and different aquatic ecosystems, and the ecological complexes they are part of. This includes diversity within species, between species, and ecosystems (Convention on Biological Diversity). The urban garden provides biodiversity among farms plot and ecological function (Davies et al. 2009; Speak et al. 2015). The study concluded that UF benefit in supporting biodiversity can be acknowledged as diversity of vegetables and plant species within farm plot (species richness and distribution pattern). Biodiversity was provided by all UF plot and its combination as green space in urban areas. Instead of disaggregated the valuation of this indicator on each UF form, the study combined all UF as a unity.

Based on Benefit Transfer method, the result found that UF value on supporting urban biodiversity is US$ 2.22 per person annually. This value cannot be aggregated to certain UF form. Thereby, the value obtained was combination of all form. As comparison, other studies found that urban greenspace was also valuable for biodiversity as biocontrol for amount $ 41.20 (2018 US$/ha/yr) (Costanza et al. 2014) and $ 148.46 (2018 US$/ha/yr) as biodiversity protection (Chen et al. 2018). Another studies of urban biodiversity on providing nest or species habitat for bird in domestic garden was documented (Davies et al. 2009).

UF activities are diverse and can include the cultivation of vegetables, medicinal plants, spices, mushrooms, fruit trees, ornamental plants and other productive plants (Lovell 2010). UF also could provide diversity for plants, insect and vertebrate within the farming area and nearby neighbourhood. The different types of urban allow for a diverse set of vegetation structures to contribute to the edible landscape in a range of community types (McLain et al. 2012) and this wide range of products means that UF were highly heterogeneous in size, form and function.

F. Food Mileage (E3)

The result show that production of UF in a square area annually can reduce food mileage in monetary unit for number of US$ 0.00008–0.00040 if it is transported in a km distance using truck. Detail was shown in Table 30.6. If it was compared with the maximum value using maximum carbon price, the value of food mileage reached for range US$ 0.00016–0.00085. This value was categorised too small if compared with other indicators. However, still, production of vegetables locally might provide other cobenefits as well. Study by Lee et al. (2015) found that reducing CO_2 emission from transportation reached 11,668 t/yr Food may account for 40% of all road freight; fossil fuel used in food transport 'in most cases exceeds the energy consumed in (production)' (UK-Jones 2002). The production and supply of food currently accounts for 20–30% of greenhouse gas (GHG) emissions (Kulak et al. 2013).

G. Carbon Storage (V3)

UF has potential to store carbon in the vegetation and soil through carbon storage and sequestration (Zhao et al. 2016). Carbon sequestration refers to the removal of

Table 30.6 Monetary valuation of food mileage

UF form	Yield (Y) (kg/m^2/yr)	Food mileage (D) (km)	CO_2 reduction (kg CO_2/m^2/yr)	V_{mil} (US$/m^2/yr)	$V_{mil\ max}$ (US$/m^2/yr)
Nurseries					
Allotment	1.32	7.38	0.0022	0.00013	0.00028
Institutional	0.78	7.38	0.0013	0.00008	0.00016
Residential	4.02	7.38	0.0067	0.00040	0.00085
Rooftop	1.42	7.38	0.0024	0.00014	0.00030

carbon (in the form of carbon dioxide) from the atmosphere through the process of photosynthesis. While carbon storage refers to the amount of carbon bound up in woody material above and below ground. Carbon storage under soil was assumed in 0–30 cm soil depth. Therefore, this study considered stored carbon as carbon biomass above-ground within vegetation in UF. It was applied for allotment and institutional farm which mostly contained by mix and diverse vegetables.

Based on resampled map obtained from Global Soil Organic Carbon Map provided by FAO (2020) and World Soil Information (ISRIC), Malang City predominantly consisted of **0.08–0.15 kg C/m²** or less than 15 tonnes C/ha (Fig. 30.5). This range had similarity with study by Davies et al. (2011) who identified above-ground carbon biomass in the vegetation based on land cover and landownership. It was found that carbon storage per unit area in the 35 plots of domestic garden contained by *Herbaceous Vegetation* was **0.14 kg C/m²** in a growing session. Whereas carbon storage on Domestic Garden contained by mix vegetation reached **0.76 kg C/m²** (here it is assumed as year). Other studies also have been compiled. Zhao et al. (2016) documented carbon storage on street ornamental plant in Beijing, China. It was found that ornamental plant can store carbon for amount **0.13 kg C/m²/yr**. This value has similar with carbon storage in herbaceous plants in domestic garden and campus garden, **0.14 and 0.13 kg C/m²/yr** which documented by Audu et al. (2018), Davies et al. (2011). Interestingly, mix vegetation within domestic garden has big value of carbon storage for amount **0.76 kg C/m²/yr**. Matsuura et al. (2018) obtained difference value of carbon storage on vegetables within organic farming for amount **0.28 kg C/m²/yr**. Finally, by considering the map and previous studies, this chapter adopted that UF which contained by mix vegetables could store carbon for amount **0.15 kg C/m²**.

By using medium price of social cost, **US$ 0.0493/kg C**, for monetary valuation of carbon storage, the study found that estimated carbon storage value was **US$ 0.0074/m²/yr**. This value has limit and lower compared to other valuation. Zhao et al. (2016) estimated average C storage and sequestration of individual trees in Beijing City for amount of 130.62 kg and 5.85 kg/yr (Elmqvist et al. 2015b) also analysed empirically included estimating monetary benefits from urban ES of urban

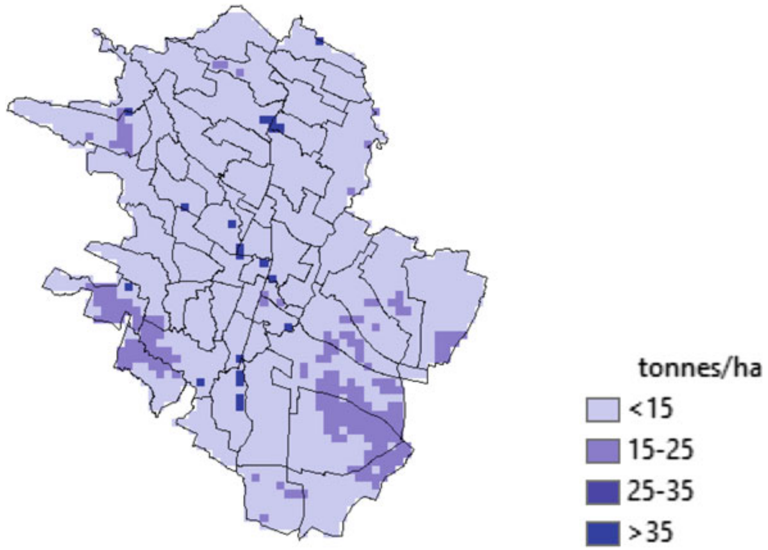


Fig. 30.5 Downscaled carbon storage in mix vegetation in Malang City

forest on data from 25 urban areas in the USA, Canada and China, found average price for carbon storage (stock value): US$ 3125/ha/yr or US$ 0.3125/m^2/yr.

H. Energy Saving (H2)

Rooftop farming as green roofs removes heat from the air through the process of evapotranspiration and acts as insulators for buildings, then reduces the energy needed to provide cooling or heating. Based on observation, there was a different temperature between rooftop farming and non-farming, about **1.03 °C**. This value had similar to previous studies by Santamouris (2014) mentioned that green roof temperatures can be 1.1–4.4 °C lower than those of conventional roofs and can reduce city-wide ambient temperatures by up to 5 °C. While (Souza et al. 2018), who examined using sensors which put in both rooftop conditions and estimated in 30 days, found that the difference was about **1.98 °C**. The result found that urban rooftop farming could reduce energy savings for amount of **US$ 1.17 m^2/yr**. This value was quite higher compared to a study by Sailor et al. (2012) found that green roofs reduce building energy use by 0.7% compared to conventional roofs, reduce peak electricity demand and lead to annual savings of **US$ 0.0213/m^2**.

Table 30.7 Total Economic Value (TEV) each indicator

UF Form	Nurseries	Allotment	Inst. yard	Resident.	Rooftop	Aggregate
I. Strengthening community						
E1. Provisioning food supply		1.00	0.59	3.03	1.07	5.68
E2. local income generation	2.16	0.90				3.06
S1. Recreational, community-building	✓	✓	✓			0.58
S2. Education and learning	✓	✓	✓			0.77
II. Improving the urban environment						
H1. Maintenance urban comfort	✓	✓	✓			0.37
V1. Stormwater (runoff) management		0.12	0.14			0.26
V2. Supporting urban biodiversity	✓	✓	✓	✓	✓	1.20
III. Allocating resources and energy efficiency						
E3. Food mileage *(city scale)*		0.00013	0.00008	0.0004	0.00014	0.0008
V3. Carbon storage and sequestration		0.0074	0.0074			0.0148
V5. Energy-saving (cooling)					1.17	1.17
Total Economic Value (TEV)	V_{nurs}	V_{allo}	V_{inst}	V_{resd}	V_{roof}	**13.11**
	5.08	**4.95**	**3.66**	**5.95**	**5.16**	

Total Economic Value (TEV) of Urban Farming

Total Economic Value (TEV) of UF for entire form and indicator was US$ 13.11/m annually. The value for each form and indicator was shown in Table 30.7. This benefit shows a promising result indicating that UF was valuable and could improve the city's resilience. The benchmark used in this analysis was US$ 29.00/m annually. When it was compared with the benchmark, this TEV had a gap of US$ 15.89/m annually. This gap amount was expected to be a policy recommendation for stakeholders to provide the incentive and engage citizens to participate in UF initiatives and development actively.

Conclusion and Recommendation

This chapter focused on assessing UF benefits in the context of ecosystem services revealed in the monetary unit. UF has valuable services in improving city resilience through strengthening community, urban environment and energy efficiency. These services can be acknowledged as ecosystem services (ES) provided by the urban farm. The benefit was measured using developed integrative indicators as final products provided by UF. The chapter estimated the total valuation, Total Economic Value (TEV) as the sum of all indicators. UF contributed up to US$ 13.11/m^2/yr. if implemented in all forms. This value had a gap with the benchmark for US$ 15.89/m^2/yr, which could be an incentive to engage citizens actively participating in the UF initiatives. The results proposed a policy recommendation that in emerging

UF, the Government should provide a stimulus for US$ 15.89/m^2/yr as a gap for each community. This mechanism may support and engage local citizens to actively participate in the UF initiative and maintain its continuity.

Acknowledgements This chapter was supported by the Asian Development Bank–Japan Scholarship Program, Dept. of Urban Engineering, The University of Tokyo, and JST SPRING, Grant Number JPMJSP2108.

References

Argüeso D, Evans JP, Pitman AJ, Di Luca A (2015) Effects of city expansion on heat stress under climate change conditions. PLoS ONE 10:e0117066

Artmann M, Sartison K (2018) The role of urban agriculture as a nature-based solution: a review for developing a systemic assessment framework. Sustainability 10:1937. https://doi.org/10.3390/su10061937

Atmaja T, Yanagihara M, Fukushi K (2020) Geospatial valuation of urban farming in improving cities resilience: a case of Malang city, Indonesia. In: ISPRS annals of photogrammetry, remote sensing and spatial information sciences. Copernicus GmbH, Gottingen, pp 107–113

Audu Y, Linatoc AC, Idris A (2018) Assessment and potential of carbon storage capacity of species of herbaceous plants in Universiti Tun Hussein Onn Malaysia, Main Campus, Batu Pahat, Johor Malaysia. Int J Eng Technol 7:109. https://doi.org/10.14419/ijet.v7i4.30.22063

Bappenas (2018) Roadmap of SDGs Indonesia: a highlight. Jakarta, Indonesia

Barbier E, Hanley N (2009) Pricing nature: cost-benefit analysis and environmental policy-making. Edward B Barbier

Brenner J (2007) Valuation of ecosystem services in the catalan coastal zone

Brink BJE, Van Strien A, Van Hinsberg A et al (2000) Natuurgraadmeters voor de behoudoptiek. Bilthoven, RIVM, 2000 RIVM Rapp 408657005, 109 blz

Burger N, Glick P, Perez-Arce F et al (2012) Indonesia urban poverty analysis and program: review. California

Calvet-Mir L, Gómez-Baggethun E, Reyes-García V (2012) Beyond food production: ecosystem services provided by home gardens. A case study in Vall Fosca, Catalan Pyrenees, Northeastern Spain. Ecol Econ 74:153–160. https://doi.org/10.1016/J.ECOLECON.2011.12.011

Chen S, Wang W, Xu W et al (2018) Plant diversity enhances productivity and soil carbon storage. Proc Natl Acad Sci 115:4027–4032. https://doi.org/10.1073/pnas.1700298114

CICES (2017) Towards a common classification of ecosystem services. European Environment Agency. https://cices.eu/. Accessed 3 July 2020

Clinton N, Stuhlmacher M, Miles A et al (2018) A global geospatial ecosystem services estimate of urban agriculture. Earth's Futur 6:40–60. https://doi.org/10.1002/2017EF000536

Contesse M, van Vliet BJM, Lenhart J (2018) Is urban agriculture urban green space? A comparison of policy arrangements for urban green space and urban agriculture in Santiago de Chile. Land Use Policy 71:566–577. https://doi.org/10.1016/J.LANDUSEPOL.2017.11.006

Cordier M, Pérez Agúndez JA, Hecq W, Hamaide B (2014) A guiding framework for ecosystem services monetization in ecological–economic modeling. Ecosyst Serv 8:86–96. https://doi.org/10.1016/J.ECOSER.2014.03.003

Costanza R, de Groot R, Sutton P et al (2014) Changes in the global value of ecosystem services. Glob Environ Chang 26:152–158. https://doi.org/10.1016/j.gloenvcha.2014.04.002

Davies ZG, Edmondson JL, Heinemeyer A et al (2011) Mapping an urban ecosystem service: quantifying above-ground carbon storage at a city-wide scale. J Appl Ecol 48:1125–1134. https://doi.org/10.1111/j.1365-2664.2011.02021.x

Davies ZG, Fuller RA, Loram A et al (2009) A national scale inventory of resource provision for biodiversity within domestic gardens. Biol Conserv 142:761–771. https://doi.org/10.1016/J.BIOCON.2008.12.016

Depietri Y, McPhearson T (2017) Integrating the grey, green, and blue in cities: nature-based solutions for climate change adaptation and risk reduction. In: Kabisch N, Korn H, Stadler J, Bonn A (eds) Nature-based solutions to climate change adaptation in urban areas: linkages between science, policy and practice. Springer International Publishing, Cham, pp 91–109

Eigenbrod C, Gruda N (2015) Urban vegetable for food security in cities. A Review. Agron Sustain Dev 35:483–498. https://doi.org/10.1007/s13593-014-0273-y

Elmqvist T, Andersson E, Frantzeskaki N et al (2019) Sustainability and resilience for transformation in the urban century. Nat Sustain 2:267–273. https://doi.org/10.1038/s41893-019-0250-1

Elmqvist T, Setälä H, Handel SN et al (2015a) Benefits of restoring ecosystem services in urban areas. Curr Opin Environ Sustain

Elmqvist T, Setälä H, Handel SN et al (2015b) Benefits of restoring ecosystem services in urban areas. Curr Opin Environ Sustain 14:101–108. https://doi.org/10.1016/j.cosust.2015b.05.001

Fernández Andrés J (2017) Can urban agriculture become a planning strategy to address social-ecological justice?

Gittleman M, Farmer CJQ, Kremer P, McPhearson T (2017) Estimating stormwater runoff for community gardens in New York City. Urban Ecosyst 20:129–139. https://doi.org/10.1007/s11252-016-0575-8

Gonçalves C (2013) Framework and indicators to measure urban resilience

Government US (2015) Technical update of the social cost of carbon for regulatory impact analysis. US

Gullstrand J, Olofsdotter K, Thede S (2013) Markups and export-pricing strategies. Rev World Econ 150:221–239. https://doi.org/10.1007/s10290-013-0178-x

Hungate BA, Barbier EB, Ando AW et al (2017) The economic value of grassland species for carbon storage. Sci Adv 3:e1601880. https://doi.org/10.1126/sciadv.1601880

Jonck AV, Ribeiro JMP, Berchin II et al (2018) Urban agriculture practices as initiatives for mitigation and adaptation to climate change: possibilities for urban farms in a South American City BT—theory and practice of climate adaptation. In: Alves F, Leal Filho W, Azeiteiro U (eds). Springer International Publishing, Cham, pp 493–506

Kabisch N, Frantzeskaki N, Pauleit S et al (2016) Nature-based solutions to climate change mitigation and adaptation in urban areas: perspectives on indicators, knowledge gaps, barriers, and opportunities for action. Ecol Soc 21:art39. https://doi.org/10.5751/ES-08373-210239

Knapp L, Veen E, Renting H et al (2016) Vulnerability analysis of urban agriculture projects: a case study of community and entrepreneurial gardens in the Netherlands and Switzerland. Urban Agric Reg Food Syst 1(urbanag2015):01. https://doi.org/10.2134/urbanag2015.01.1410

Kremer P, Hamstead ZA, McPhearson T (2016) The value of urban ecosystem services in New York City: a spatially explicit multicriteria analysis of landscape scale valuation scenarios. Environ Sci Policy 62:57–68. https://doi.org/10.1016/j.envsci.2016.04.012

Kuddus MA, Tynan E, McBryde E (2020) Urbanization: a problem for the rich and the poor? Public Health Rev 41:1. https://doi.org/10.1186/s40985-019-0116-0

Kulak M, Graves A, Chatterton J (2013) Reducing greenhouse gas emissions with urban agriculture: a life cycle assessment perspective. Landsc Urban Plan 111:68–78. https://doi.org/10.1016/J.LANDURBPLAN.2012.11.007

Lee G-G, Lee H-W, Lee J-H (2015) Greenhouse gas emission reduction effect in the transportation sector by urban agriculture in Seoul, Korea. Landsc Urban Plan 140:1–7. https://doi.org/10.1016/J.LANDURBPLAN.2015.03.012

Lehmann S (2019) Urban regeneration: a manifesto for transforming UK cities in the age of climate change

Lovell ST (2010) Multifunctional urban agriculture for sustainable land use planning in the United States. Sustainability 2

Matsuura E, Komatsuzaki M, Hashimi R (2018) Assessment of soil organic carbon storage in vegetable farms using different farming practices in the Kanto Region of Japan. Sustainability 10
McClintock N, Cooper J, Khandeshi S (2013) Assessing the potential contribution of vacant land to urban vegetable production and consumption in Oakland, California. Landsc Urban Plan 111:46–58. https://doi.org/10.1016/j.landurbplan.2012.12.009
McDougall R, Kristiansen P, Rader R (2019) Small-scale urban agriculture results in high yields but requires judicious management of inputs to achieve sustainability. Proc Natl Acad Sci 116:129 LP–134. https://doi.org/10.1073/pnas.1809707115
McLain R, Poe M, Hurley PT et al (2012) Producing edible landscapes in Seattle's urban forest. Urban For Urban Green 11:187–194. https://doi.org/10.1016/j.ufug.2011.12.002
Mette T, Hajnsek I, Papathanassiou K (2003) Height-biomass allometry in temperate forests performance accuracy of height-biomass allometry. In: IGARSS 2003. Proceedings of 2003 IEEE international geoscience and remote sensing symposium (IEEE Cat. No.03CH37477), pp 1942–1944
Mumenthaler C (2015) Developing a methodology to analyse and compare governance of urban agriculture. Switzerland
Nijkamp P, Vindigni G, Nunes P (2008) Economic valuation of biodiversity: a comparative study. Ecol Econ 67:217–231
Oleson K, Monaghan A, Wilhelmi O et al (2013) Interactions between urbanization, heat stress, and climate change. Clim Change 129.https://doi.org/10.1007/s10584-013-0936-8
Parece TE, Serrano EL, Campbell JB (2017) Strategically siting urban agriculture: a socioeconomic analysis of Roanoke, Virginia. Prof Geogr 69.https://doi.org/10.1080/00330124.2016.1157496
Parveen S, Khan AQ, Farooq S (2020) The causal nexus of urbanization, industrialization, economic growth and environmental degradation: evidence from Pakistan. Rev Econ Dev Stud 5. https://doi.org/10.26710/reads.v5i4.883
Poore J, Nemecek T (2018) Reducing food's environmental impacts through producers and consumers. Science (80-)360:987 LP-992. https://doi.org/10.1126/science.aaq0216
Potschin M, Haines-Young RH (2016) Defining and measuring ecosystem services. In: Potsch (ed) Routledge handbook of ecosystem services. Routledge, London and New York, pp 25–44
Prabowo RS (2015) Analisa Manfaat Biaya Pembangunan Proyek Waduk Konto Wiu Di Desa Wiyurejo Kecamatan Pujon Kabupaten Malang. Institute of Technology Sepuluh Nopember
Pulighe G, Lupia F (2019) Multitemporal geospatial evaluation of urban agriculture and (non)-sustainable food self-provisioning in Milan, Italy. Sustainability 11:1846. https://doi.org/10.3390/su11071846
Ramstein C, Dominioni G, Ettehad S (2019) State and trends of carbon pricing 2019. Washington DC
Ross CW, Prihodko L, Anchang J et al (2018) Global hydrologic soil groups (HYSOGs250m) for curve number-based runoff modeling. https://doi.org/10.3334/ORNLDAAC/1566
Saha M (2016) Geospatial modeling of urban buildings and land use for climate change impacts and resource productivity. Northeastern University
Sailor DJ, Elley TB, Gibson M (2012) Exploring the building energy impacts of green roof design decisions – a modeling study of buildings in four distinct climates. J Build Phys 35:372–391. https://doi.org/10.1177/1744259111420076
Santamouris M (2014) Cooling the cities—a review of reflective and green roof mitigation technologies to fight heat island and improve comfort in urban environments. Sol Energ 103:682–703
Santoso SI, Susanti S, Rizqiati H et al (2018) Potensi Usaha Mi Bayam sebagai Diversifikasi Produk Mi Sehat. J Apl Teknol Pangan 7:127–131. https://doi.org/10.17728/jatp.2690
Silvennoinen S, Taka M, Yli-Pelkonen V et al (2017) Monetary value of urban green space as an ecosystem service provider: a case study of urban runoff management in Finland. Ecosyst Serv 28:17–27. https://doi.org/10.1016/j.ecoser.2017.09.013

Skar SLG, Pineda-Martos R, Timpe A et al (2019) Urban agriculture as a keystone contribution towards securing sustainable and healthy development for cities in the future. Blue-Green Syst. https://doi.org/10.2166/bgs.2019.931

Souza C, Souza S, Secco D et al (2018) Green roofs and their contribution for the reduction of room temperature in buildings in Cascavel-State Paraná/green roofs and energy efficiency. Acta Sci Technol 40:35267. https://doi.org/10.4025/actascitechnol.v40i1.35267

Speak AF, Mizgajski A, Borysiak J (2015) Allotment gardens and parks: provision of ecosystem services with an emphasis on biodiversity. Urban Urban Green 14:772–781. https://doi.org/10.1016/j.ufug.2015.07.007

Subadyo AT, Tutuko P, Bimatyugra Jati RM (2019) Implementation analysis of green city concept in Malang–Indonesia. Int Rev Spat Plan Sustain Dev 7:36–52. https://doi.org/10.14246/irspsd.7.2_36

Suroso D, Fitriyanto M, Salim W et al (2012) Synthesis report: climate change risk and adaptation assessment greater Malang

TEEB (2010) The economics of ecosystems and biodiversity ecological and economic foundations. Earthscan, London and Washington

UN-Habitat (2016) Urbanization and development: emerging futures, in world cities report 2016. Norway

UN (2018) 2018 Revision of world urbanization prospects

USDA USD of A (1986) Urban hydrology for small watersheds TR-55. New York, USA

VanWoert ND, Rowe DB, Andresen JA et al (2005) Green roof stormwater retention. J Environ Qual 34:1036–1044. https://doi.org/10.2134/jeq2004.0364

Vilem P, Machar Ivo, Sterbova L et al (2017) Monetary valuation of natural forest habitats in protected areas. Forests 8(11). https://doi.org/10.3390/f8110427

Wang J, Dong K (2019) What drives environmental degradation? Evidence from 14 sub-Saharan African countries. Sci Total Environ 656:165–173. https://doi.org/10.1016/j.scitotenv.2018.11.354

Wang N, Zhang J, Xia X (2011) Energy consumption of air conditioners at different temperature set points

Wang T, Pryor M (2019) Social value of urban rooftop farming: a Hong Kong case study. In: Agricultural economics—current issues. IntechOpen

White R (2002) Building the ecological city. Woodhead Publication, Cambridge

Widiastuti MMD, Ruata NN, Arifin T (2016) Economic valuation of mangrove ecosystem in the coastal of Merauke district. Sosio Ekon Kelaut Perikan 11:147–159

Wilhelm JA, Smith RG (2018) Ecosystem services and land sparing potential of urban and peri-urban agriculture: a review. Renew Agric Food Syst 33:481–494. https://doi.org/10.1017/S1742170517000205

Zhang B, Xie G, Zhang C, Zhang J (2012) The economic benefits of rainwater-runoff reduction by urban green spaces: a case study in Beijing, China. J Environ Manage 100:65–71. https://doi.org/10.1016/j.jenvman.2012.01.015

Zhao S, Tang Y, Chen A (2016) Carbon storage and sequestration of urban street trees in Beijing, China. Front Ecol Evol 4.https://doi.org/10.3389/fevo.2016.00053

Chapter 31
Building Extraction of Kolkata Metropolitan Area Using Machine Learning and Earth Observation Datasets

Prosenjit Barman and Sk. Mustak

Abstract Rural-to-urban migration and increasing population has created urban agglomeration, particularly in metropolitan cities. This agglomeration creates pressure on cities which interrupts the city to become sustainable. Evaluation of the pattern of urban growth pattern is a crucial task for a city's long-term development. The building footprint is one of the most important features of a city form to support urban management and development. Previous studies show that high-resolution images are robust to extract building footprints using machine learning algorithms. The main objective of this study is to extract the building footprint from the satellite imagery using machine learning algorithms. In this study, Sentinel-2 multispectral satellite imagery and support vector machine (SVM) linear and radial basis function (RBF) have been used to extract the building footprints in Kolkata metropolitan area. In addition, both pixel-based and object-based image classification approaches have been applied and compared in this study. This result shows that in pixel-based image classification SVM linear gives a high accuracy than the SVM RBF. The accuracy level of SVM linear is 92.58% while Kappa is 0.89. On the other hand, object-based image analysis LULC classification has been done using the SVM ML algorithm. In this image classification, the SVM RBF kernel type gives high accuracy. The overall accuracy of this OBIA image classification is 91.58% and the Kappa is 0.87. For the building extraction in an urban area from the medium-resolution image Sentinel 2 using a machine learning algorithm with high accuracy gives a significant approach. Policymakers and planners can develop the city sustainably from this building footprint in an urban region and use sustainable urban planning to achieve the Sustainable Development Goal.

Keywords Building extraction · Machine learning · Earth observation dataset · Kolkata metropolitan area

P. Barman (✉) · Sk. Mustak
Department of Geography, Central University of Punjab, Bhatinda, Punjab, India
e-mail: prosenjitkm147@gmail.com

Sk. Mustak
e-mail: sk.mustak@cup.edu.in

U. Chatterjee et al. (eds.), *Urban Commons, Future Smart Cities and Sustainability*, Springer Geography, https://doi.org/10.1007/978-3-031-24767-5_31

Introduction

Currently, cities are home to 55% of the world's population, and if this trend continues, it is predicted that by 2050, that number would more than double to 7/10 of the world's population. Because of the speed and extent of urbanisation, it is difficult to find inexpensive housing, essential services, and employment, especially for those who live in urban informal settlements (Urban Development Overview: Development News, Research, Data|World Bank). Rapid population growth and rural-to-urban migration put enormous demand on the infrastructure of growing cities. To gain a strong alternative for resource use and further maximising sustainability through land use pattern analysis, the United Nations has concentrated on urbanisation challenges in 2015 to attain the SDG by 2030. Furthermore, Article 76 of the 2030 Agenda declares the use of geospatial data for tracking and monitoring the development of various projects covered by the SDGs. In this regard, it will be crucial to create massive data about cities, specifically the buildings that make up the majority of them (Chandrashekar et al. 2019). Not all cities have an equally dispersed distribution of the enormous population. Most people live in Indian census class I cities. Such massive population growth in cities with a million or more residents has spurred peripheral physical expansion through built-up development. Unfortunately, this rapid physical growth involves unplanned, low-density, fragmented and chaotic patchwork construction, or sprawl, which consumes agricultural land, forests, unoccupied land, villages and anything else in its path (Barnes et al. 2002; Kumar et al. 2007; Mithun et al. 2016). Urban built-up areas can be thought of as an urban expansion pattern, which is the spatial arrangement of a city's physical growth at a specific time period (Bhatta 2010). Researchers have developed a variety of indices and models that are combined with remote sensing and GIS to measure the pattern, process and growth of built-up areas (Bhatta 2010; Kumar et al. 2007; Mithun et al. 2016; Rahaman et al. 2018). Land use/cover classification was carried in several studies using traditional image classification approach which shows lower classification accuracy based on overall accuracy and quality of the map. Machine learning (e.g. SVM-linear, SVM-RBF, etc.) coupled with the object-based classification approach recently increasing using in several studies which shows robust classification outcomes (Anthony et al. n.d.). This is because of the several challenges in image classification such as dimensionality, feature selection, contextualisation, parameter optimisation, over- and undersegmentation and mixed pixel issues.

The proposed classification approach is robust and recently increasing using for the land use/cover classification of the cities of the global south (Gupta et al. 2021). The use of geospatial technologies for built-up area extraction has been the subject of numerous studies. The various modified Normalised Difference Vegetation Index (NDBI) to extract the built-up area have been explored in one study work. IBI, BUI, NDBI and IBUI have all been used in this work to retrieve the built-up data (Santra et al. 2021). To calibrate the spatiotemporal urban footprint of Kolkata city from the years 1990 to 2017, Chandan et al. attempted to demonstrate a fresh notion of merging PSO with the SELUTH model and compared this to the conventional approach BFM. To comprehend urban expansion, buildings were retrieved using the high-resolution data sigma nought value obtained from the HH and HV polarised data by Sinha et al. (2018). A sigma nought value was obtained from the HH and HV polarised data by Sinha et al. (2018). The normalised ratio and then equated HH and HV sigma nought pictures are used to create an index that has been validated over several regions using ground truth data. The map has been created using this index to identify the built-up and non-built-up areas. Mithun et al. (2016) used Shannon's entropy and other landscape indices linked with remote sensing and GIS to attempt to examine the built-up dynamics in the Kolkata metropolitan area at three zones: total KMA, KMA urban, and KMA panchayat level during the time period between 1980 and 2010. This study examines the performance of the five spectral indicators stated above using Resourcesat LISS III imageries over India's urban agglomeration of Kolkata and Howrah. The indices were compared, and it was discovered that the innovative IBUI gave the highest level of accuracy (94%) in identifying impervious built-up regions (Santra et al. 2021). For the example of object-based mapping of an agricultural area using Unnamed vehicle imagery (UAV) for object-based image analysis for agriculture pattern recognition. Ma et al. (2017) evaluated the effect of the advanced feature selection method of well-known supervised classifiers like SVM and RF. The high-accuracy robustness algorithm for classification is the classification of the SVM algorithm. Li et al. (2014) applied segmentation-based classification based on pixels to TM Landsat data. They have concluded that the SVM algorithm has successfully classified images in a limited training sample. Using geospatial data from Gaode and Baidu Maps, like point-of-interest (POI) data, building footprints, land use polygons, and highways, there has suggested a framework in this study to determine the building type. Using natural language processing (NLP)-based techniques, POI categories have been automatically reclassified into categories that can be used to infer building kinds. Second, using the type ratio and area ratio as markers of building types, we determined the link between building footprints and POIs (Chen et al. 2020). Norman et al. (2020) have explained that building footprint extraction using object-based image analysis requires segmentation due to a variety of factors, including the complexity of geo-objects and the spatial and spectral resolution of remote sensing images. From high-resolution Worldview 3 (WV3) satellite data, the Taguchi statistical approach and a spatial plateau objective function (POF) were created to extract the building footprint. Using the non-parametric supervised classification SVM technique, five classes were divided, and the accuracy of the classification was evaluated using the ROC curve. Hosseinpor et al. have used a fusion model to extract buildings from data derived from extremely high-resolution remote sensing photography. An end-to-end cross-modal gated fusion network (CMGFNet) has been introduced for obtaining building footprint. Sentinel-2B, a medium-resolution remote sensing image with a 10-m spatial resolution, was used by Norman et al. (2021) to classify the buildings in Selangor, Malaysia. Support vector machine (SVM) and decision tree (DT) classifiers from machine learning (ML) methods have been used to categorise five different classifications, including water, forest, green space, buildings, and roads. By applying ML methods to build extraction accuracy for medium-resolution images, the SVM classifier may create 20% greater accuracy than the DT classifier, improving OBIA's classification methodologies.

The majority of the previous study mentioned how to recognise the pattern of urban growth by measuring how densely built-up an urban region is. They have classified the built-up and non-built-up areas using a variety of landscape metrics. Studies have looked at building extraction from high-resolution satellite pictures. Very high resolution has been classified using various classical as well as machine learning techniques of pixel and object-based image analysis. The ML algorithm for developing detection performance analysis has not been compared by anyone previously. Here, urban footprint mapping also employs medium-resolution data for building detection. The main objective of this study is to perform an analysis of the SVM algorithm in pixel-based and object-based image analysis for urban footprint mapping.

Study Area

For the urban footprint mapping, Kolkata metropolitan area has been selected (Fig. 31.1). In this study, area mainly consists of 4 municipal corporations, 38 municipalities and many other villages. This is India's fourth-largest metropolitan area. The largest metropolitan area in north-eastern India is the Kolkata metropolitan area. This metropolitan area has primarily expanded on both sides of the Hooghly River. KMA includes six districts: Kolkata, Howrah, Hooghly, Nadia, North 24 Parganas and South 24 Parganas. These districts are located on each side of the Hooghly River (Kolkata Metropolitan Development Authority n.d.). The KMA, the largest urban agglomeration in West Bengal and the third largest in India, is regarded as the research area. The KMA currently extends over an area of 1886.67 km^2. The population growth of the KMA has also been very dynamic over time. The KMA had a population of 14.77 million in 2001, which was projected to be 17 million in 2011, and is expected to be 20 million in 2021 and 21.1 million in 2025 (Census of India 2011).

Materials and Methods

Materials

To measure the urban compactness in the Kolkata metropolitan area, there has been used many datasets which have mentioned and the entire methodology which has followed in this study has been presented (Fig. 31.2). The Kolkata metropolitan area's Sentinel 2B image was obtained from the cloud-based version of Google Earth Engine in the year 2021 (Table 31.1). There are ten bands in the Sentinel 2B satellite image

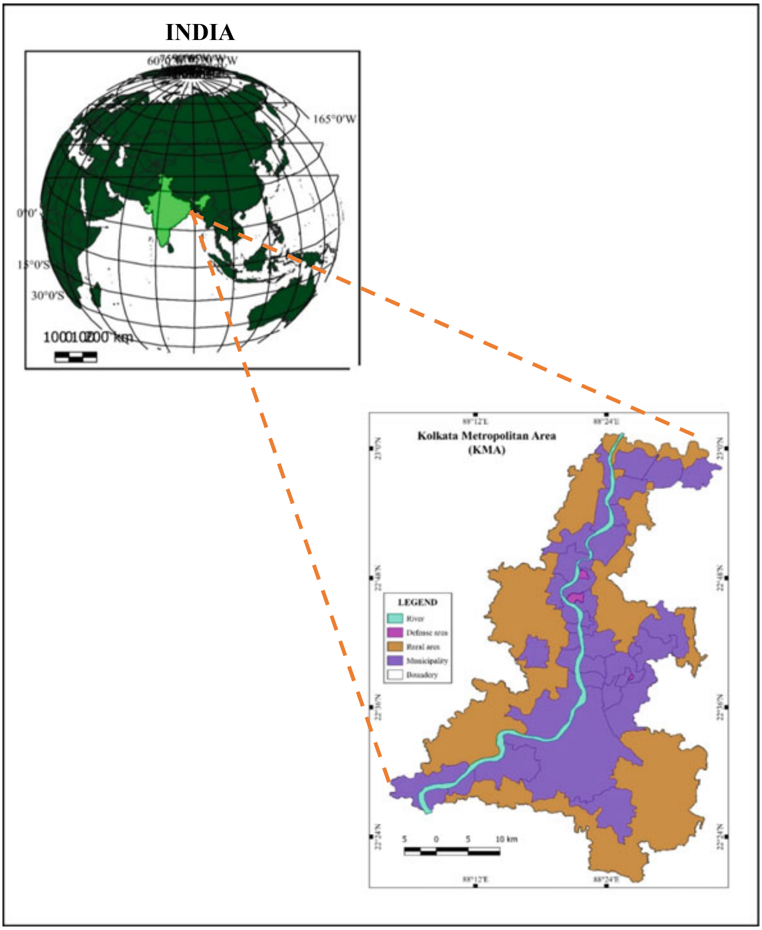


Fig. 31.1 Location of study area (KMA)

collection. The files essentially consist of bands with a 10- and 20-mm resolution (Table 31.1).

Methods

The methodology has been broken down into three sections: first, preprocessing the bands and normalising them; second, pixel-based image classification for the extraction of buildings; and third, object-based image classification for the extraction of urban buildings. In this study, land use/cover classification was done using SVM machine learning algorithm. For the LULC in Kolkata metropolitan area, five LULC

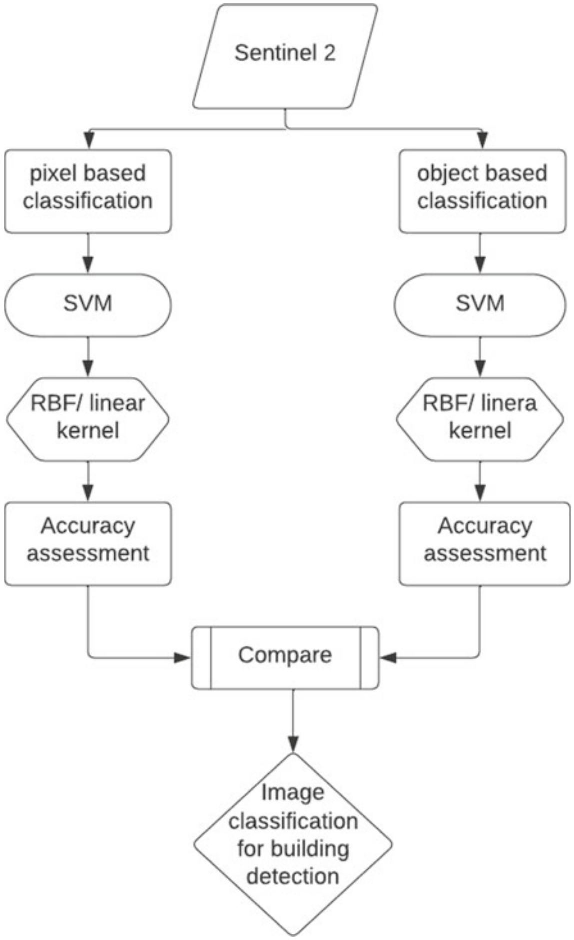


Fig. 31.2 Methodological flowchart

classes were selected. These LULC classes are 1. Waterbody, 2. Wetland 3. Built-up 4. Agriculture land 5. Vegetation. The LULC classes were selected after the reviewing some papers related to LULC analysis in KMA (Ghosh et al. 2019; Mithun et al. 2021).

Preprocessing

For the image classification, data preprocessing is a very important step. For preprocessing data, first feature extraction has performed NDVI and NDBI. NDVI and NDBI are calculated using the following formula.

$$\mathrm{NDVI} = \frac{\mathrm{NIR} - \mathrm{RED}}{\mathrm{NIR} + \mathrm{RED}} \tag{31.1}$$

Table 31.1 Sentinel-2 data specifications

Bands	Spectral bands	Spatial resolution (mm)
B2	Blue (B)	10
B3	Green (G)	10
B4	Red (R)	10
B5	Red-edge 1	20
B6	Red-edge 2	20
B7	Red-edge 3	20
B8	Near-infrared (NIR)	10
B8A	Near-infrared narrow	20
B11	Shortwave infrared 1 (SWIR1)	20
B12	Shortwave infrared 2 (SWIR2)	20

$$\text{NDBI} = \frac{\text{SWIR} - \text{NIR}}{\text{SWIR} + \text{NIR}} \tag{31.2}$$

Normalisation

Then normalise every single band and stack it as an image for image classification. The normalisation of bands has been done by using the following formula.

$$\textbf{Normalisation} = \text{Image}-\text{Image}_{\text{minimum}}/\text{Image}_{\text{maximum}} - \text{Image}_{\text{minimum}} \tag{31.3}$$

Normalisation formula has been defined as image subtracts by the respective band minimum value divided by the subtraction of respective band maximum and minimum value.

Selection of Machine Learning Algorithms

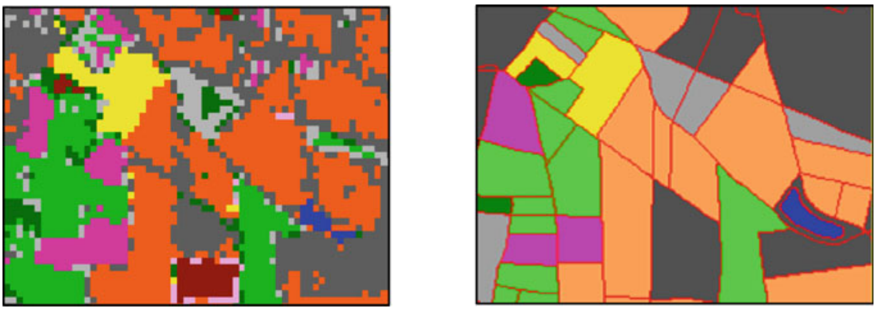
Support Vector Machine (SVM)-Linear: SVM is one of the supervised image classification algorithms used in machine learning. One of the key kernel types in the SVM ML approach is linear. When the data can be linearly separated—that is, divided along a single line—linear kernels are utilised. It is one of the most often utilised kernels. It is typically utilised when a given dataset contains a significant number of features. One instance is text categorisation, where each alphabet represents a unique feature. In these situations, linear kernels can be utilised. One benefit of this linear kernel is that it can train an SVM more quickly than any other kernel. Additionally, optimising the C regularisation SVM linear kernel when training an SVM requires the least amount of time (Creating Linear Kernel SVM in Python—GeeksforGeeks 2018).

Support Vector Machine (SVM)-RBF: In the SVM, machine learning method another important kernel is RBF. The radial basis function kernel, also known as the RBF kernel, is a common kernel function utilised in many kernelised learning algorithms. Particularly, it has been utilised frequently in classification using support vector machines. RBF kernel is the most generalised form of kernelisation and the most widely used kernel due to the similarity of Gaussian distribution. The similarity or distance between two points is generally computed using the RBF kernel function. RBF kernel also uses a K-NN-like algorithm; therefore, it benefits from K-NN advantages and solves the space complexity issue (Radial Basis Function (RBF) Kernel: The Go-To Kernel|by Sushanth Sreenivasa|Towards Data Science 2020).

Selection of Classification Approach

Pixel-based (Fig. 31.3a) and object-based (Fig. 31.3b) image classification was described.

Pixel-based image classification: Pixel-based classification technique was performed for the image classification to a pixel in one class by the spectral similarities. This pixel-based classification technique is also used to extract the low level features but in overlapping region will be misclassified due to the confusion of classes (Sibaruddin et al. 2018). Machine learning algorithms like the SVM algorithm have been used to classify pixels in images for building extraction. To begin with, gather 350 samples of each of the five classes from the map in evenly spaced intervals. This sample has been divided into two parts about 50% for equal training and test sample. Then image statistics has been calculated, and one SVM train model has been calculated.



(a) Pixel-based classification (b) Object-based classification

Fig. 31.3 Land use/cover classification approach. *Source* Aplin and Smith (2008)

Table 31.2 Training and test samples

Image classification	Training sample	Test sample
Pixel-based classification	174	174
OBIA	174	174

In machine learning, there have been created models to predict the outcome of certain events. The train/test method has been used to determine whether a model is adequate or not. In general, this technique evaluates the model's correctness (Python Machine Learning Train/Test, W3school). The training and testing sample for this study consisted of 174 people. 50% of the sample as a whole has been divided (Table 31.2).

Object-based image classification (OBIA): OBIA technique was performed by the segmentation of image data into object. It is a bottom-up region merging approach that groups the neighbouring homogeneity pixel into meaningful segments or objects. OBIA technique is highly significant for the land use classification at present day. This technique considers shape, texture and spectral information for the LULC classification. For the high-resolution land use classification, OBIA technique gives the high accuracy than the pixel-based classification (Sibaruddin et al. 2018). After segmentation on the raw image and calculate zonal statistics, 348 training samples were collected from various segment areas across the map (Table 31.2) and divided equally into two groups of 50%. The zonal statistics has been added by the location of the training sample. Following the creation of the SVM model file, object-based image classification was completed using image classification. Then the accuracy assessment was performed by using a 50% test sample.

Accuracy Assessment

The classification of image using the various classification algorithm does not give the perfect result because of many reasons like undistinguishable classes, preparing of training samples with wrong labelling and imperfect classification algorithm so the accuracy assessment is very necessary of an image classification. Various methods are available for the measurement of accuracy of image classification like omission error, overall accuracy, producer accuracy, kappa coefficient (k) in accuracy measurement this method has some merits and demerits also. In this study, for an LULC overall accuracy and Kappa coefficient were applied (Bhatta 2008).

Results and Discussions

This study assessed the most appropriate classification for building removal in the greater Kolkata area. SVM machine learning algorithm has been used to do pixel-based and object-based image analysis categorisation. The accuracy of these two methods has been compared to see which is best for accurately determining the urban footprint.

Training and Test Samples

In this study, the land use and land cover classification was done using the SVM machine learning algorithm. For this LULC analysis needs to collect the training and test sample from the satellite image. For LULC analysis in KMA, total 348 samples were collected. These 348 samples were divided into 50% using the QGIS. 174 samples were considered as training samples, and another were considered validation samples (Table 31.2).

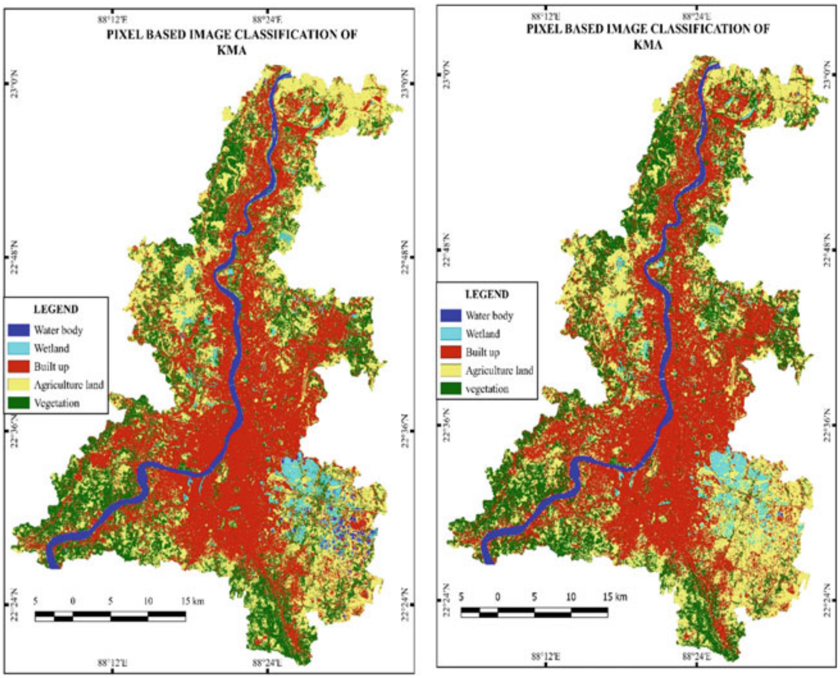
Land Use/Land Cover Classification

In this study, land use/cover analysis was done using the machine learning SVM algorithm with two different Kernels Linear and RBF. This SVM algorithm was applied on pixel-based and object-based image analysis.

Pixel-Based Land Use/Cover Classification

The most often used method for classifying images is pixel-based classification. Pixel-based image classification using the SVM machine learning algorithm has been performed for the image classification to extract the urban building. One of the more reliable ML algorithms for classifying images is the SVM method. Many different algorithms (including linear and RBF) have been used to achieve the best possible categorisation using SVM (Fig. 31.4a, b). According to the SVM linear ML algorithm, there will be 73,264 ha of built-up area in total in 2021 (Table 31.3). In the Kolkata district, there is a high density of buildings, and along the Hooghly River, there is a high density of buildings relative to the surrounding area. In contrast, the built-up area in the SVM RBF ML technique picture classification is 72,913 ha. Built-up areas have expanded more in the surrounding area in SVM RBF image classification. The overall accuracy for SVM linear image classification is 92.58%, which is quite impressive and 0.89 for the accuracy of the Kappa hat classification (Table 31.5). The SVM linear ML algorithm's picture classification accuracy in the

Kolkata metropolitan area is above 90%. On the other hand, the SVM RBF ML algorithm's overall accuracy for classifying pixel-based images is 88.31%, and its Kappa hat classification accuracy is 0.83. In contrast to SVM RBF ML algorithm image classification, SVM linear algorithm accuracy is high for pixel-based image classification in the Kolkata metropolitan area.



(a) SVM-linear image classification (b) SVM RBF image classification

Fig. 31.4 Land use/cover of KMA (2021), using pixel-based SVM

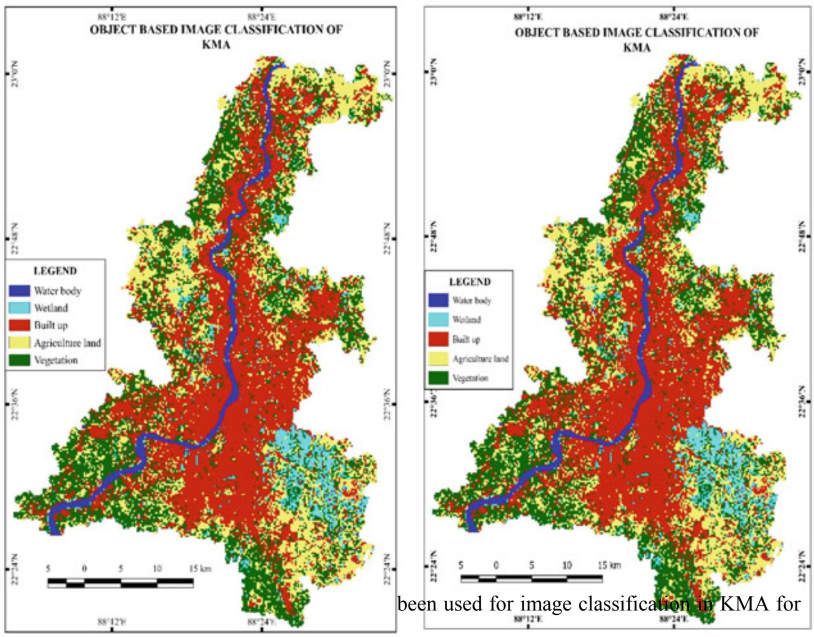
Table 31.3 Land use/cover classes (2021) using of pixel-based image classification approach (SVM-linear)

S. No	Land use/cover classes	Area (ha)
1	Waterbody	6390
2	Wetland	6540
3	Built-up	73,264
4	Agriculture land	46,693
5	Vegetation	47,040
Total		179,928

Object-Based Land Use/Cover Classification

One of the most important pictures classification methods is object-based classification. The item serves as the basis for this image classification. The majority of this image classification is vector-based. The entire image has been divided into several portions. There have been a lot of samples gathered in a point of diverse segments for OBIA image classification (Fig. 31.5a, b). Then, for image classification, use the SVM RBF and SVM linear ML algorithms. KMA's built-up area is 69,106.14 ha (Table 31.4) according to OBIA image classification. The Kappa hat classification is 0.87, and the accuracy level is 91.52% (Table 31.5). SVM RBF ML algorithm has higher accuracy than SVM linear ML technique in OBIA image categorisation. The OBIA vector classification has been converted to raster format for accuracy assessment, and accuracy assessment has been carried out.

Pixel-based and object-based image analysis has been used for image classification in KMA for building extraction. To compare the important algorithm for image classification, SVM linear and SVM RBFML have also been used. SVM linear algorithm accuracy in pixel-based image classification is much higher than the SVM RBF algorithm. In contrast, the SVM RBF method outperforms the SVM linear



(a) SVM-Linear image classification (b) SVM RBF image classification

Fig. 31.5 Land use/cover of KMA (2021), using object-based SVM

Table 31.4 Land use/cover classes (2021) using of object-based image classification approach (SVM-RBF)

S. No	Land use/cover classes	Area (ha)
1	Waterbody	5780
2	Wetland	9064
3	Built-up	69,106
4	Agriculture land	49,431
5	Vegetation	46,548
Total		179,928

Table 31.5 Accuracy assessment of land use/cover classification

Image classification	Kernel type	Overall accuracy	Kappa	Built-up area (ha)
Pixel-based	SVM linear	92.58	0.89	73,264
OBIA	SVM RBF	91.58	0.87	69,106

algorithm in object-based picture classification. Pixel-based image classification and OBIA classification provide the highest level of image classification accuracy. In comparison with OBIA classification, pixel-based image classification provides great accuracy for vast areas like the Kolkata metropolitan area. An important method for classifying images is pixel-based image classification.

Validation and Accuracy Assessment

A total of 348 samples were collected for the pixel-based image analysis and OBIA, and these samples were divided into two categories: training samples and validation samples. The Google Earth image (Fig. 31.6a) was used to validate the training samples and LULC classified image (Fig. 31.6b). Two training samples with a latitudinal range of 22°36′54″ to 22°37′ and a longitudinal range of 88°19′48″ to 88°20′06″ were visualised to relate the training sample and image classification. In the Google Earth image, this training sample represents the built-up region, and the image classification also represents the built-up area at the same latitude and longitudinal extension (Fig. 31.6).

In this study, built-up area was extracted by the LULC classification using machine learning SVM algorithm. This built-up class area was validated based on the literature review. In 2020, the built-up area of Kolkata metropolitan area was around 726.82 km^2 (Das et al. 2022). In 2021, the LULC pixel-based classification of KMA using SVM linear algorithm reveals the built-up area is 73,264 ha which represents the 732.64 km^2. So, it depicts that the pixel-based LULC classification of KMA using SVM linear machine learning algorithm is a highly accurate than the object-based image classification in this perspective area. Pixel-based and object-based

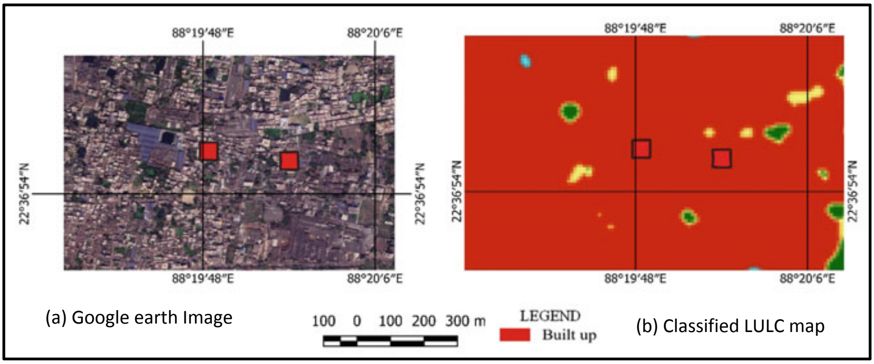


Fig. 31.6 Validation and accuracy assessment (pixel-based SVM-linear)

image classification using SVM machine learning algorithm with high accuracy was performed (Table 31.5).

Built-Up Development in Kolkata Metropolitan Area

The KMA's LULC categorisation can be used to estimate the urban footprint and determine the size of the urban area. The classification also indicates which part of KMA region is heavily urbanised as well as where the built-up area is expanding. The major cities and municipality areas on the LULC map of the KMA were labelled (Fig. 31.7), which makes it easier to distinguish between the built-up developed and built-up developing areas. The classify image shows that the areas on both sides of the Hooghly River, particularly the Kolkata district, the Haora municipality, the Bally, the South dumdum, the Dumdum, the Kamarhati, the Panihati, and the North dumdum, are highly developed municipal areas; also, it generates a compact development.

There is also a large built-up growth in the northern section of the KMA, but it is less intense than in the southern half of the region on both banks of the Hooghly River. The high-built-up municipalities in the northern section are Kalyani, Kanchrapara, Naihati, Bhatpara and Baidyabati. The map (Fig. 31.7) also demonstrates that the eastern portion of the Hooghly River has a larger built-up density than the western portion. Excluding the sides of Hooghly River built-up has grown up in the marginal area of KMA. The municipality of Barasat has grown in a condensed manner. Two cities in the peri-urban area that are developing rapidly are Rajarhat Sonarpur and Baruipur of South 24 parganas district. Rapid development in the Mahestala municipality region leads to outlying development in the peri-urban area of KMA. In the Haora district, peripheral cities and villages are also growing built-up areas. Manoharpur City, which is part of the Dankuni municipality is developing quickly, while Bansberia municipality has a highly built-up development area. Based on the growth patterns of the built-up areas in KMA, it can be prophesied that the

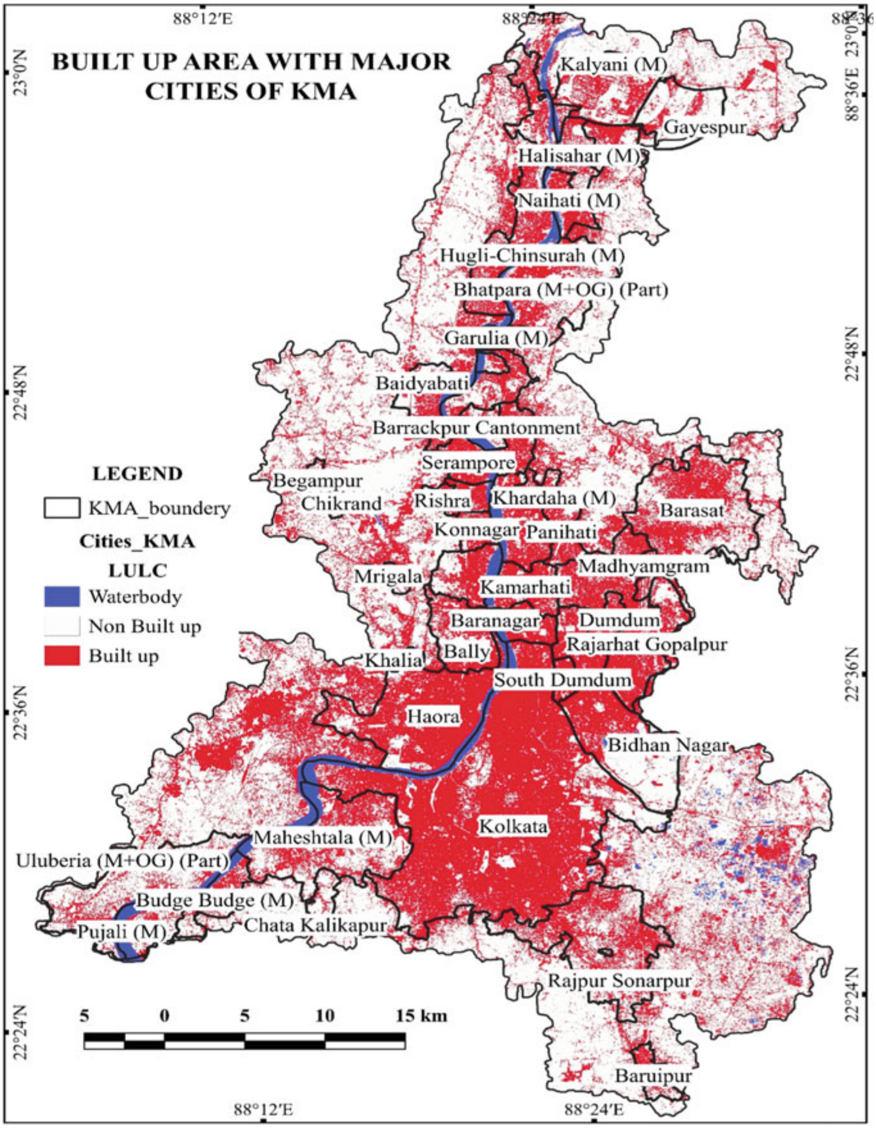


Fig. 31.7 Built-up with major cities of KMA

surrounding areas of the Kolkata district, such as Mahestala, Rajarpur Sonarpur and Baruipur, the Haora municipality and its surroundings, such as Uluberia, Krishnapur and Jagadishpur, Gayespur, Kanchrapara municipality area, and the Barasat municipality, will experience rapid growth in the near future.

Conclusion

Urban footprint mapping is a very important stage in tracking Kolkata's metropolitan area's progress. OBIA classification and pixel-based analysis play a key role in extracting buildings in metropolitan areas. There is a sizable urban agglomeration in the Kolkata metropolitan area. The built-up area has been expanding mostly in the per-urban area as the city grows day by day. So, measurement is crucial for the expanding city. Building extraction monitoring is a key strategy for comprehending urban growth. For that, pixel classification has been carried out in the greater Kolkata area. Pixel-based, OBIA, SVM linear, and SVM RBF ML algorithms have all been used for each image classification technique, making a total of two image classification techniques used here. This classification has demonstrated that SVM RBF delivers good accuracy in OBIA classification while SVM linear gives great accuracy in pixel-based classification. The result shows that the pixel-based SVM-linear (92.58% overall accuracy) outperforms the object-based SVM RBF (e.g. 91.58% overall accuracy) because object-based image classification is robust on very high-resolution satellite image (e.g. > 2 m). In addition, pixel-based image classification is robust (based on overall accuracy and quality of the map) in low-resolution image (e.g. < 2 m) because of the lower chances of producing mixed pixel in classified map and tracing out the geometry of the object from the image. The accuracy of the classification map depends on the several factors like dimensionality, number of training samples, selection of the machine learning algorithms and morphology of the land uses. The proposed land use/cover classification approach and algorithms are robust for the cities of developing countries. In addition, more investigations are required to address the challenges faced (e.g. oversegmentation, undersegmentation, etc.) in this study like to add more contextual features, training and test samples, ensembles model, etc.

Additionally, pixel-based classification delivers higher accuracy than OBIA classification in KMA's picture classification. Pixel-based classification is much more appropriate than OBIA for the classification of large-area images. OBIA can be more effective for picture classification in limited areas. It is exceedingly expensive to classify images from high-resolution data, and hence, employing an ML algorithm to classify images from medium-resolution data is ideal. It is exceedingly expensive to classify images from high-resolution data, and hence, employing an ML algorithm to classify images from medium-resolution data is ideal. The machine learning algorithm for mapping the urban extension, commonly referred to as the urban footprint, is extremely important. The map provides a general notion of the urban area's size, which provides a general concept of how urban and rural areas are divided. This study will help policymakers and planners to develop the sustainably, compact, resilient and transit-oriented city development to support Sustainable Development Goals (e.g. SDGs-11).

References

Aplin P, Smith G (2008) Advances in object based image classification. Int J Appl Earth Observ Geoinform. https://www.researchgate.net/publication/228912009

Anthony G, Greg H, Tshilidzi M (n.d.) Classification of images using support vector machines

Barnes KB, Iii JMM, Roberge MC, Lowe S, Barnes B, Morgan JM, Barnes K, Morgan J, Roberge M (2002) Sprawl development: its patterns, consequences, and measurement

Bhatta B (2010) Analysis of urban growth and sprawl from remote sensing data. https://doi.org/10.1007/978-3-642-05299-6

Bhatta B (n.d.) Remote sensing and GIS. Oxford University Press. Retrieved 1 Sept 2022, from https://global.oup.com/academic/product/remote-sensing-and-gis-9780198072393?lang=en&cc=il

Bhatta B (Basudeb) (2008) Remote sensing and GIS, pp 685

Census of India (2011a) Final population totals. http://censusindia.gov.in/2011census/censusinfodashboard/index.html. Accessed 10 Dec 2014

Chandrasekhar MC, Adithya JS, Prakash PS, Haridas B (2019) Machine learning for building extraction and integration of particle swarm optimization with sleuth for urban growth pattern visualisation for livable cities. In: PSO optimisation for SLUETH-urban growth visualisation 55th ISOCARP world planning congress Jakarta-Bogor. Indonesia International Society of City and Regional Planners

Chen W, Zhou Y, Wu Q, Chen G, Huang X, Yu B (2020) Urban building type mapping using geospatial data: a case study of Beijing, China. Rem Sens 12(17):2805. https://doi.org/10.3390/RS12172805

Creating linear kernel SVM in Python—GeeksforGeeks (2018) Retrieved 19 July 2022, from https://www.geeksforgeeks.org/creating-linear-kernel-svm-in-python/

Das S, Jain GV (2022) Assessment and prediction of urban expansion using CA-based SLEUTH urban growth model: a case study of Kolkata Metropolitan. J Indian Soc Rem Sens. 0123456789,https://doi.org/10.1007/s12524-022-01602-y

Ghosh S, Chatterjee ND, Dinda S (2019) Relation between urban biophysical composition and dynamics of land surface temperature in the Kolkata metropolitan area: a GIS and statistical based analysis for sustainable planning. Model Earth Syst Environ 5(1):307–329. https://doi.org/10.1007/S40808-018-0535-9

Gupta BM, Dhawan SM, Mamdapur GM (2021) Support vector machine (SVM) research in India: a scientometric evaluation of India's publications output during 2002–19. 57(3)

Hosseinpour H, Samadzadegan F, Javan FD (2022) CMGFNet: a deep cross-modal gatedfusion network for building extraction from very high resolution remote sensing images. ISPRS J Photogramm Rem Sens 184. https://doi.org/10.1016/j.isprs.2021.12.007

Kolkata Metropolitan Development Authority (n.d.) Retrieved 8 June 2022, from http://www.kmdaonline.org/page/cms/map_of_kma_c1fed8

Kumar JAV, Pathan SK, Bhanderi RJ (2007) Spatio-temporal analysis for monitoring urban growth—a case study of Indore City. J Indian Soc Rem Sens 35(1):11–20. https://doi.org/10.1007/BF02991829

Lata KM, Rao CHS, Vadrevu KP, Badarianath KPS, Rahgavasamy V (2001) Measuring urban sprawl: a case study of Hyderabad. Int J Appl Earth Observ Geoinform. https://www.researchgate.net/publication/285133018

Li C, Wang J, Wang L, Hu L, Gong P (2014) Comparison of classification algorithms and training sample sizes in urban land classification with landsat thematic mapper imagery. Remote Sens 6(2):964–983. https://doi.org/10.3390/rs6020964

Ma L, Fu T, Blaschke T, Li M, Tiede D, Zhou Z, Ma X, Chen D (2017) Evaluation of feature selection methods for object-based land cover mapping of unmanned aerial vehicle imagery using random forest and support vector machine classifiers. ISPRS Int J Geo-Inf 6(2). https://doi.org/10.3390/ijgi6020051

Mithun S, Chattopadhyay S, Bhatta B (2016) Analyzing urban dynamics of metropolitan Kolkata, India by using landscape metrics. Papers Appl Geogr 2(3):284–297. https://doi.org/10.1080/23754931.2016.1148069

Mithun S, Sahana M, Chattopadhyay S, Johnson BA, Khedher KM, Avtar R (2021a) Remote sensing monitoring metropolitan growth dynamics for achieving sustainable urbanization (SDG 11.3) in Kolkata Metropolitan area, India. 13:4423. https://doi.org/10.3390/rs1321442

Norman M, Mohd Shafri HZ, Idrees MO, Mansor S, Yusuf B (2020) Spatio-statistical optimization of image segmentation process for building footprint extraction using very high-resolution WorldView 3 satellite data. Geocarto Int 35(10):1124–1147. https://doi.org/10.1080/10106049.2019.1573853

Norman M, Shahar HM, Mohamad Z, Rahim A, Mohd FA, Shafri HZM (2021) Urban building detection using object-based image analysis (OBIA) and machine learning (ML) algorithms. IOP Conf Ser Earth Environ Sci 620(1). https://doi.org/10.1088/1755-1315/620/1/012010

Python machine learning train/test. Retrieved 21 July 2022, from https://www.w3schools.com/python/python_ml_train_test.asp

Rahaman M, Dutta S, Sahana M, Das DN (2018) Analysing urban sprawl and spatial expansion of Kolkata urban agglomeration using geospatial approach. In: Applications and challenges of geospatial technology: potential and future trends. Springer, pp 205–221. https://doi.org/10.1007/978-3-319-99882-4_12

Sreenivasa S (2020) Radial basis function (RBF) kernel: the go-to kernel. Towards Data Science. Retrieved 19 July 2022, from https://towardsdatascience.com/radial-basis-function-rbf-kernel-the-go-to-kernel-acf0d22c798a

Santra A, Mitra SS, Sinha S, Routh S, Kumar A (2021) Identification of impervious built-up surface features using Resourcesat-2 LISS-III-based novel optical built-up Index. In: Remote sensing and giscience. Springer, pp 113–126. https://doi.org/10.1007/978-3-030-55092-9_7

Santra A, Santra Mitra S, Sinha S, Routh S (2020) Performance testing of selected spectral indices in automated extraction of impervious built-up surface features using Resourcesat LISS-III image. Arab J Geosci 13:1229. https://doi.org/10.1007/s12517-020-06183-z

Sibaruddin HI, Shafri HZM, Pradhan B, Haron NA (2018) Comparison of pixel-based and object-based image classification technique in extracting information from UAV imagery data. In: IOP conference series: earth and environmental science. https://doi.org/10.1088/1755-1315/169/1/012098

Sinha S, Santra A, Mitra SS (2018) A method for built-up area extraction using dual polarimetric alos palsar. ISPRS Ann Photogramm Remote Sens Spatial Inf Sci 4(5):455–458. https://doi.org/10.5194/isprs-annals-IV-5-455-2018

Sudhira HS, Ramachandra TV, Jagadish KH (2013) Urban sprawl pattern recognition and modelling using GIS. Map India Conference. https://www.researchgate.net/publication/257088154

Urban Development Overview: development news, research, data | World Bank (n.d.) Retrieved July 13, 2022, from https://www.worldbank.org/en/topic/urbandevelopment/overview

Yeh G, Li X (2001) Measurement and monitoring of urban sprawl in a rapidly growing region using entropy. Photogramm Engineering Remote Sens 67(1). https://www.researchgate.net/publication/280014775

Chapter 32
The Application of CIM and BIM to the Simulation of Energy in Urban Superblocks; an Effort to Develop the Initial Digital Twins (Case Studies: Kermanshah, Iran)

Omid Veisi and Amir Shakibamanesh

Abstract The integration of Building Information Modelling (BIM) and Geographic Information System (GIS) and the suggested notion of digital twins enabled buildings to be energy-efficient in terms of consumption and generation. The study employs a real-world simulation with a low level of detail to examine several types of urban superblocks and their energy use. This research presents a unique approach for integrating urban information based on two-dimensional GIS data and a three-dimensional BIM model. The research approach used in this study is a comparison of the types of urban blocks and energy, which is considered for early energy studies instead of optimising the urban configuration. Several archetypes of blocks were modelled, analysed and then studied on three levels: electrical energy, fossil fuel and energy. The study's conclusion implies that optimisation techniques can be used in the comparative approach. While studying these various methods consumes a significant amount of time and energy, archetype evaluation consumes far less. Finally, the results reveal significant reductions in energy use in urban buildings of up to 20% compared to the ASHRAE standard model with a modest degree of detail. The results of this research may be used in the early stages of urban design in terms of superblock pattern selection.

Keywords Energy efficiency · City Information Modelling · Building Information Modelling · Archetype · Urban super-block · Digital twins

O. Veisi (✉) · A. Shakibamanesh
Faculty of Architecture and Urban Studies, Tehran Art University, Tehran, Iran
e-mail: o.veisi@student.art.ac.ir

A. Shakibamanesh
e-mail: a.shakibamanesh@art.ac.ir

U. Chatterjee et al. (eds.), *Urban Commons, Future Smart Cities and Sustainability*, Springer Geography, https://doi.org/10.1007/978-3-031-24767-5_32

Introduction

Globally, increased population and urbanisation-related constraints need new construction and the establishment of dense metropolitan areas. However, the engineer does not develop these future urban centres using Urban Energy Building Modelling tools. Numerous studies have been conducted to create new ways for modelling high-performance buildings (Arabi et al. 2022) with the least impact on the environment and the maximum level of spatial comfort at the lowest cost (Shafiei et al. 2020). Except for study and modelling, it is currently impossible to apply these methodologies to Urban Energy Building Modelling (UBEM) and proposal design for soaked structures and microclimate complexes. That is why simulation technologies are critical for guiding urban planning and optimising the environmental efficiency of buildings. Implementing simulation tools and developing master plan ideas in cities are a novel part of engineering and applied sciences which have given little attention to it in recent studies (Dogan 2015).

This broad notion resulted in developing new approaches like BIM, GIS, City Information Modelling (CIM) and software-based studies. Numerous researchers assert that legacy software and methods are unsuitable for real-time data collection and analysis, particularly when urban planners, urban designers and architects wish to explore and design for a specific city area and require a three-dimensional form with varying levels of detail (LOD) (van Treeck and Rank 2007; Pratt et al. 2012). These difficulties affect the construction of instruments based on three-dimensional dimensions, the technique for collecting data in urban development, the analysis used in planning, designing and construction and the respect for people's privacy.

Additionally, using advanced technology, simulations for the urban building's lowest level of detail may be accomplished quickly. On the other hand, simulating urban models might take days, even with parallel or cloud computing capabilities available. The different variables related to urban buildings are likewise inaccessible to modellers and architectural engineers for two reasons: first, time and objective simulation and second, mass UEBM (Cerezo Davila 2017). The method of this study uses comparison methods and simulation based on real context. The GIS is used for mapping, and the BIM is used for adding height dimensions. So, the main purpose of this study focuses on the comparison between archtype of superblock based on the energy consumption in the shortest time for urban planners. So, to achieve this aim, the research should be answered this question, how can calculating different type of energy by the lowest information in order to choose the best type of archetype of the urban block?

Aims and Originality

Nowadays, different types of energy analysis are used by engineers in various industries including urban planning, urban designer and architecture. Also, the most practical energy analysis model is utilised by academics and businesses. This method has been widely used in architectural research, notably for optimising shape to reduce energy consumption in interior areas (Omid et al. 2022). Based on a review of the scientific literature and the observed gap, more research is required on these techniques. Using the capabilities of City Information Modelling (CIM) and Building Information Modelling (BIM), it seems that speed of discovering optimal solutions and accuracy of optimal solutions may replace traditional techniques in industries and technological issues. In the early phases of urban design, reducing the computation time and enhancing the precision of calculating the ideal solution may be very useful and practical for optimising the performance of urban superblocks. The purpose of this study is to analyse and assess the ability of BIM and CIM to improve the optimisation performance of various urban superblocks, taking energy usage and degree of detail into account (LOD). This chapter presents a simple, optimal and high-precision solution for optimising multi-objective urban issues using novel techniques. Designers and engineers in different city sections are recommended to interact more during the early stages of urban block form optimisation in light of the aforementioned advantages and possibilities. This article seeks to go ahead in comparison to prior studies in the area of urban superblock design and propose an appropriate answer for the study gaps described in the previous section, based on the need that its research process has produced.

Due to the many elements in this subject, a substantial amount of time and work is required to optimise the models in this research. This realisation seeks to identify the optimal urban superblock without spending time and research costs by gathering complete data. Planners may examine the form of an urban superblock in terms of its energy usage over the shortest amount of time. The result of the initial investigation into the various forms of urban superblocks was the identification of six distinct types. An analysis of energy consumption will be conducted to expand the various types of urban superblocks with different factors and predict their energy consumption as a result. This data collection may be enhanced and extended by other researchers in order to increase the accuracy and capacity of energy consumption prediction for the different types of urban superblocks. Researchers and designers will no longer need to depend on other computational tools for model optimisation if they can calculate the amount of energy consumption at urban superblocks.

In addition to bolstering the CIM model with BIM models by combining these two methodologies, more beneficial responses may be discovered in the research-relevant study area. From the standpoint of urban design and planning, every study on urban spaces reveals that the kind of urban blocks and the researched area have a substantial effect on energy consumption (Shakibamanesh and Veisi 2021b; Veisi and Shakibamanesh 2022; Omid et al. 2022). Additionally, urban areas with a certain form of urban superblock have a dramatically lower energy use. This disregard for maximising the design of urban blocks is shown by little research on urban blocks and by this study's review of the relevant literature (Li et al. 2022). In this regard, the current research tries to find the optimal design options for common urban superblock types in terms of energy consumption efficiency.

Abbreviation	Description	Abbreviation	Description
BIM	Building Information Modelling	GIS	Geographic Information System
CIM	City Information Modelling	IFC	International Finance Corporation
UEBM	Urban Energy Building Modelling	PCA	Principal Component Analysis
EBM	Energy Building Modelling	PTC	Percentage of Thermal Comfort
EUI	Energy Use Intensity	UE	Urban Engineering
CVRMSE	Coefficient Variation Root Mean Square Error	TC	Thermal Comfort
HVAC	Heating, Ventilation and Air Conditioning	BA	Building Area
LOD	Level of Detail	DS	Design Space
DVS	Design Variables	USB	Urban Superblock
OSM	Open Street Map	LiDAR	Light Detection And Ranging
NMBE	Normalised Mean Bias Error	IoT	Internet of Things

Interaction Between CIM and BIM

Researchers have created new approaches for modelling digital cities in the twenty-first century, including CIM (Stojanovski 2013), BIM (Xu et al. 2014), Light Detection And Ranging (LiDAR) (Verma et al. 2006), CityGML as a conceptual model and exchange format for the representation (Kolbe et al. 2005). The City Information Modelling, as the most current technique based on BIM and GIS, has several disadvantages, including a lack of optimal software to generate practical output. Although a substantial percentage of the investigations were conducted globally, evaluating this approach has always been challenging. In 1970, a revolutionary technique for collecting data in computer-aided design (CAD) and Revit formats was done. The result shows that we may create models using this data, but we cannot locate a plan or a 3D model in the previous structure. As a result, we must examine both internal and exterior structures building for analysis and better understanding. This information may be utilised to have a better understanding of the structure and architectural system (Kaiser et al. 1995).

Numerous research has used urban models to study topics related to smart cities, urban management and energy saving. In 2013, Bilijecki investigated 3D urban models at many levels of detail, ranging from computer graphics to mapping. This research shows that LOD paradigms, along with CityGML, will be used for various applications. However, this approach has some fundamental limitations. For instance, because discrete surfaces and their quantity are restricted, a distinction between LODs and paradigms may exist (Biljecki et al. 2015). Also, in the other study, dubbed BIM to CIM is used to develop a digital city based on a Geographic Information System (GIS). In a small-scale project, this study comprises developing and controlling the building's physical and functional characteristics. The purpose of this research is to develop a new city model for managing and building urban zones (Xu et al. 2014). Additionally, Salminen and Hägglöf examined CIM to determine the impact of CIM's distinctive capabilities on urban management in 2015. Consequently, CIM is used as a viable alternative to developing masterplan in municipalities. In other words, by the use of CIM, procedures will improve, and CIM will become a critical instrument for planning and assisting municipal work operations. CIM enables policymakers to create projections that may be utilised to plan and govern the city (Salminen and Hägglöf 2015).

In 2016, Emine et al. conducted that the challenge for urban planning in the past was producing practical information, but nowadays, the challenge of urban planning is big data and planning based on this data. This article solves this problem by using CIM in Northumbria, England. This research is classified into four key issues: data accessibility, accuracy, integration and simulation. Also, this paper cause improves the modelling and imagination of the urban planning field. In conclusion, information production and modelling may help urban planners compete more effectively in the city's public relations market. However, caution should be used in its application since statistics alone cannot ensure the growth of a sustainable urban future (Thompson et al. 2016).

Role of Digital Twins, CIM in the Simulation of Energy in Superblocks

The IoT focused on facilitating connectivity between all objects, whether physical or virtual. The most current and accurate models of a building are preserved in shared central databases throughout the design and construction phases of a project, as well as post-construction. GIS-based systems for city monitoring and management need the synthesis of data from a variety of sources, including BIMs, city models and sensors (Isikdag 2015). The best data that can be used for modelling the city is LiDAR point clouds. Recent advances in remote sensing technology have produced precise, dense and affordable city-scale LiDAR point clouds, which may be used to represent city objects (e.g. buildings, roads and autos) for the creation of digital twin cities (Xue et al. 2020). Using LiDAR for EUBM because of the limitation of the model based on point cloud is not suitable. That is why we should develop a city based on the mesh model for analysing energy consumption.

Conzen divides urban form into three components: the ground plan (streets, plans and building blocks), the building ground and fabric and the building use. In urban design, on the other hand, Rossi typology as a physical shape represents people's lifestyles. In retrospect, Rossi's followers believe that while building a city, the urban design must always be considered. This is currently a reality in several European city centres. People's ever-changing lives have been handled suitably within unchanging urban typologies. In other words, while the physical structure of the city remains constant, the design upon which it is built does (Shi et al. 2017). As a result, the study topic is to examine the design of urban blocks using a straightforward morphological technique, with the objective of generating a varied variety of human contexts that will be generally consistent, diversified and capable of reflecting urban design principles (Duany and Talen 2002).

Historically, urban planners struggle to provide useful and timely data. However, urban planners are finding problems changing urban systems through the use of technology-based feature management. As a consequence, BIM may be used to produce CityGML and Sketchup models. This program may be used to simulate urban energy consumption using data from web visualisation (Jusuf et al. 2017). Additionally, the Energy Integrated Support System (EnerISS) may be used to model an integrated urban landscape and visualise data to assist in decision-making. The modelling of building for analysing energies includes building polygons, textures for categorised land cover forms and 3D metropolitan landscapes (Yeo and Yee 2016). Numerous scholars have used BIM and GIS to map cities in various contexts. With the BIM-CIM approach, the user may directly control and manage the city by the process of linking and integrating data. The importance of policymaking based on BIM-GIM use cases, such as smart city services and city integration models, is growing. Additionally, the chance of not acquiring the essential target information for the execution of the use cases or of performing the incorrect services due to noise can be lowered (Kang 2018). GIS is frequently used to design and manage the built environment in cities. Isikdag's et al. research focuses on the development of strategies and procedures for converting an industry-standard BIM to a GIS environment in order to give a greater degree of building-related information collection in a GIS environment. The purpose of this research is to examine how to utilise a GIS to construct an IFC model (Isikdag et al. 2004).

The European Council has endorsed a binding EU target member nations joined the Kyoto Protocol, which requires European countries to pass legislation that cuts greenhouse gas emissions by at least 40% by 2030 when compared to 1990 (Bayón-Cueli et al. 2020). In recent years, owing to a heightened awareness of climate change, there has been a heightened need for research into urban energy conservation. The energy needs for buildings in the household and non-domestic sectors surpass those for transportation and industrial activities, according to statistics from the United Kingdom. Studying and simulating the behaviour of buildings are the first stage in enhancing their energy efficiency. In recent years, several energy models and methodologies have been created for this aim. However, these models often follow the viewpoint of the building designer: they tend to see structures as self-defined entities, ignoring the significance of urban-scale events. Specifically, the influence of urban geometry on energy usage is currently understudied and contentious (Ratti et al. 2005).

A city model is necessary in order to assess heat and energy. Alhamwi et al.'s energy models aided in the strategic development of municipal energy systems by providing scientific guidance. For energy policy guidance, transparency of the tools and models used, as well as their accompanying input datasets, which are not always open source, is necessary. The purpose of this study was to simulate metropolitan energy demands, especially electricity use. This study found that a certain combination of renewable energy sources may be used to generate urban energy (Alhamwi et al. 2018). Although the previous study revealed a correlation between urban morphology and energy use, policymakers and urban planners disregarded the association between the two elements due to the complexity (Ratti et al. 2005). Numerous types of the study, such as Table 32.1, indicate that digital twins, CIM, UEBM and other approaches may be valuable and practical. Additionally, by integrating this idea across neighbourhoods, superblocks and urban blocks, CIM and digital twins are established, enabling more effective city management.

Research Methodology

The study examined the morphology of urban form and its relationship to urban energy use. Due to the scarcity of data on UEBM, this information is purely comparative. This study is comparable to that of the Center for Land Use and Form Studies at the University of Cambridge, which began in the 1960s (Martin et al. 1972). This research will examine urban energy for urban superblocks, including power, cooling and heating. During the initial phase of urban planning, urban planners examine mass urban blocks with the lowest LOD in a variety of forms (Jacoby 2016; Vidmar 2013; Akin and Moustapha 2004). Shakibamanesh and Veisi conducted research on the impact of urban blocks on various types of energy, concluding that various characteristics of urban blocks affect solar radiation absorption and that the courtyard urban block type performs better in terms of energy consumption than other types of urban blocks (Shakibamanesh and Veisi 2021b; Veisi and Shakibamanesh 2022).

The research process is divided into three stages, including archetype design and modification, evaluation and prediction and selection. The entire sequence of these three phases is detailed below and illustrated in Fig. 32.1. The first part examines a case study in which five standard types of urban superblocks are thoroughly modelled using Qgis and Revit. Design variables have been substantially changed and developed for each of these six categories to the point that this component, named archetype design, provides a limited number of design choices for examination in an exploration space. The second stage begins with sampling to prepare the dataset for detection of the design space (DS). Six examples are taken from the archetype design output and entered into the dataset production process using the Qgis program

Table 32.1 Research background

Source	Subject	Objective	Method	Tools
Loibl et al. (2021)	Effects of densification on urban microclimate	The impacts of climate change are especially tangible in dense urban areas	To assess impacts of densification on urban climate	Grasshopper Ladybug + Honeybee
Agugiaro et al. (2020)	The city of tomorrow from…the data of today	To estimate the average size in existing urban areas from available open data	Designing parameters for new urban development projects	QGIS + Rhino + Grasshopper +
Groppi et al. (2018)	Buildings energy consumption	Analysing heat, electricity, consumption	Using GIS method based on urban cell	GIS
Machete et al. (2018)	Analysing the influence of urban context	The impact of the urban context on buildings' solar energy potential	The 3D approach to evaluate solar access	3D GIS
Keena et al. (2018)	Sustainable urban ecologies	Understanding of the value and impact of speculative buildings towards sustainable design development	Considered energy, material and information flows as a system	Rhino + Grasshopper + Ladybug + Honeybee Clark's Crow
Tsirigoti and Bikas (2017)	Analysing the relationship between energy efficiency and urban morphology	The relation between geometry factors and energy efficiency	The heating and cooling loads are calculated	Ecotect
Morganti et al. (2017)	Urban morphology indicators for solar energy analysis	Identifying urban morphology indicators and the solar availability on façades	Comprises seven UMIs: (1) gross space index, (2) floor space index, (3) façade-to-site ratio, (4) average building height, (5) volume–area ratio, (6) building aspect ratio, (7) sky factor of building façades	Heliodon2 software

(continued)

Table 32.1 (continued)

Source	Subject	Objective	Method	Tools
Ramesh (2018)	Urban Energy Information Modelling	A framework to quantify the thermodynamic between the natural and the built environments	The generation and simulation of the urban microclimate	ENVI-met
Amado et al. (2017)	A cellular approach to net-zero energy cities	Urban planning driver to optimise and manage energy	Geographical urban units delimitation	Esri ArcGIS + Rhinoceros + Diva
Cerezo Davila (2017)	Building archetype calibration	Effective urban Building Energy Modelling	UBEM simulation infrastructure	ArcGIS
Mert and Saygın (2016)	Energy-efficient building block design: an exergy perspective	The suitability of the exergy analysis on the built environment	Data handling	-
Amado et al. (2016)	Energy-efficient city	A model for urban planning	A theoretical model and its practical application which relates energy consumption and solar energy	ArcGIS
Dogan (2015)	Automated building energy model	Provided a streamlined workflow: single and multi-building energy evaluation	Building performance simulation engines	Parametric scripting environment Grasshopper EnergyPlus TRNSYS
Lin (2013)	Investigating reducing building energy use at the urban scale	Understanding the energy consumption of buildings in a city	Analysing the energy performance: The top-down approach regards building units The bottom-up method in regional and national levels	Sketch up
Kanters and Horvat (2012)	Solar energy as a design parameter in urban planning	The impact of the geometry form on the potential of solar energy	Parametric design	Ecotect and DIVA

and the OSM database. This method is shown in further detail in Fig. 32.1's model generation subprocess diagram, which receives six samples as a 2D model and transforms the 2D model to a 3D model using Revit throughout the integrated simulation process. After completing the model generation section, the output, which is currently prepared as a complete 3D model, is entered into the energy analysing process. In this section, six 3D models (urban blocks of tower, courtyard, hybrid, perimeter, exist and slab) are created, and a comparison is made among these six by ASHRAE 90.1. After analysing, testing and assessing the models, courtyard is chosen as the best one for this research. Finally, this BIM and GIS model functions as a building multi-performance simulation fast engine, capable of predicting the unlimited number of design possibilities accessible in this project's design space. In the third stage, this urban block multi-performance simulation engine is integrated with Revit to provide the most optimum solutions feasible for the six key urban superblock categories. The next step is to identify the optimal solution based on the designer's priorities or project requirements. Each phase is detailed in detail, along with the actual instruments utilised throughout each phase's implementation.

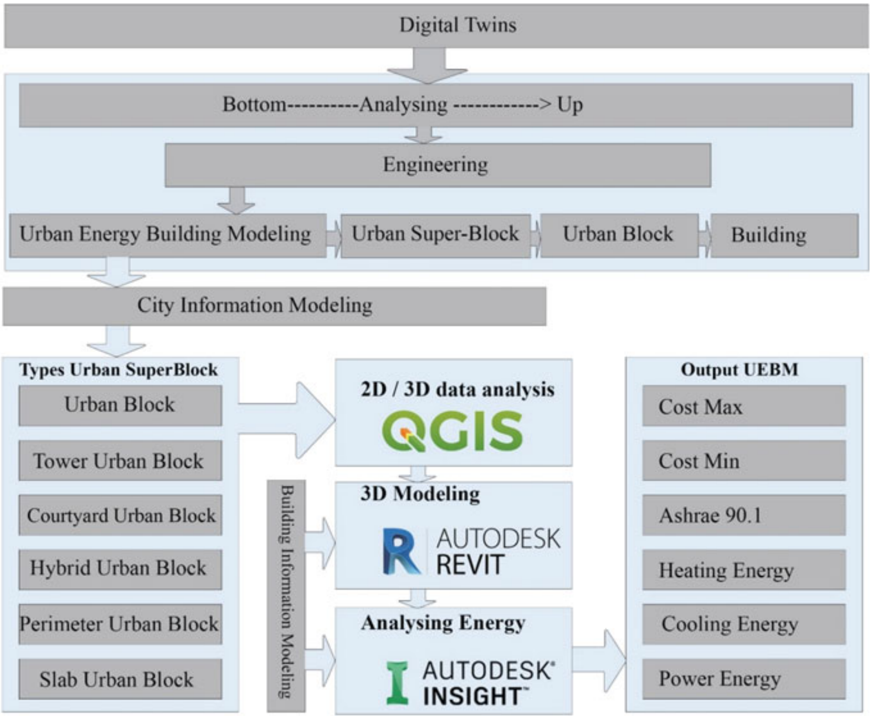


Fig. 32.1 Research framework. This framework is structured in three main phases, and all of them perform integratively in total

Step 1: Generative 2D and 3D Model

Typically, urban blocks are conceived and constructed using one of two approaches: planned and unplanned (organic) configurations. This research focused on planned configuration. An urban block is separated into numerous types in the planned configuration, including pavilions, slabs, terraces, terrace courts, pavilion courts and courts (Taleghani et al. 2013). According to Zhang et al.'s, study urban blocks are classified into six types: tower, slab, courtyard, hybrid and perimeter (Zhang et al. 2019). The six types of models produced in this research were based on metropolitan superblocks. As a result, tower typology is made up of independent tower blocks that are arranged in the form of a square or cross. Furthermore, the slab courtyard typology is made up of blocks with a completely enclosed courtyard in the centre that is uniform. In addition, hybrid typology is made up of a combination of courtyard blocks and slabs without a totally enclosed courtyard, while perimeter typology is made up of L blocks of varying heights placed around the site's perimeter.

Qgis and Revit software were used to create the geometry of these six kinds of urban superblocks (BIM and GIS software). The DVs defined by OSM data are the ultimate shapers of each of these urban superblock geometries. The range of each DV is determined by the designer's expertise. The starting value of each DV is set to a midpoint in the range, and the base case (or reference model) is then constructed. There are six varieties of urban superblocks, as seen in figure. The researchers' experiences in determining the most significant categories of urban blocks and superblocks are shown Table 32.1, which is obtained from a literature study. According to this statistic, this research, which focuses on urban design and urban planning, attempted to choose USB that included a section on design aspects. Thus, the factors chosen were totally within the limits of type of superblocks, form and geometry and mass of blocks, all of which were shown to be relevant in energy studies (Table 32.4). Another critical problem in this respect was the case study's demands and requirements. It should be noted that, as seen in Tables 32.2 and 32.3, the USB variable's floor is often taken to be 4. Additionally, the material employed in this research for mass glazing and mass skylight is double pane clear for all USB types. Additional information for various types of element blocks was included in Tables 32.2 and 32.3.

Step 2: Energy Calculation

This study used the adaptive TC model to calculate the PTC in the 12 months of the year. This model was developed based on the ASHRAE 90.1 (ANSI and Standard 2010) standard and can be used as a powerful tool in the environment of the Insight360 plugin (Stine 2015). This service was introduced in November 2015 which is used to energy modelling, cooling and heat load analysis, lighting and solar analysis and based on Cloud Energy Plus services. Using this plugin has several limitations, such

Table 32.2 General conditions for loading urban blocks in Green Building Studio and Insight360

Mass model	Constructions
Mass exterior wall	Lightweight construction—low insulation
Mass interior wall	Lightweight construction—no insulation
Mass exterior wall-underground	High mass construction—typical mild climate insulation
Mass roof	Typical insulation—cool roof
Mass floor	Lightweight construction—no insulation
Mass slab	High mass construction—no insulation
Mass glazing	Double pane clear—no coating
Mass skylight	Double pane clear—no coating
Mass shade	Basic shade
Mass opening	Air
Category	*Analytic constructions*
Roof	4 in lightweight concrete (U = 1.2750 W/(m^{2}K))
Exterior walls	8 in lightweight concrete block (U = 0.8108 W/(m^{2}K))
Interior walls	Frame partition with ¾ in gypsum board (U = 1.4733 W/(m^{2}K))
Ceiling	8 in lightweight concrete celling (U = 1.3610 W/(m^{2}K))
Floors	Passive floor, no insulation, tile or vinyl (U = 2.9582 W/(m^{2}K))
Slabs	Un-insulation solid (U = 0.7059 W/(m^{2}K))
Doors	Metal (U = 3.7021 W/(m^{2}K))

as data output, and needs internet for analysing data. After sketching 2D USB, the DVs were imported into Revit for modelling. This model should be analysed by Insight360 and on the Green Building Studio's website.

As previously indicated, an HVAC system was examined for each month of the year based on research assumptions calculating heating energy use in kWh/m. The yearly power consumption due to daylight/artificial light, on the other hand, is approximated as'lighting' in kWh/m based on the study assumptions. In this respect, the simulation settings were designed such that the bulbs only turn on when the illuminance level of daylight in the area falls below 300 lx. Finally, the heating and lighting energy (HLE) in the study building is represented by the total of heating and lighting.

Table 32.3 Significant variable for planning urban blocks

Model name	Cost max*	Cost mean*	Cost min*	Arch 2030*	ASHRAE 90.1*	EUI max**	EUI mean**	EUI min**	Building area m^2
Hybrid	7.06	6.02	4.47	1.75	11.33	85.93	75.10	58.90	256490.10
Courtyard	6.77	5.72	4.18	1.75	11.16	83.05	72.21	56.00	273465.80
Slab	7.42	6.35	4.77	1.75	7.08	80.08	68.78	52.11	303716.10
Tower	20.02	18.34	16.15	1.97	29.54	**292.75**	**275.87**	**253.63**	289575.50
Exist	9.12	7.75	5.88	4.40	12.00	99.05	85.33	66.25	331400.00
Perimeter	6.53	5.49	3.95	1.75	11.42	63.18	52.43	36.31	246868.90

*(USD/m^2/year)
**(kWh/m^2/year)

Algorithm 1. The rules for analysing 3D USB model
1. **procedure** *Name(3D USB model)*
2. *Choose "Height USB model"*
3. *in the setting*
4. *U ← 1.27 W/(m2 K) ▷ set the material of roof of USB*
5. *U ← 0.81 W/(m2 K) ▷ set the material of EW of USB*
6. *U ← 1.4 W/(m2 K) ▷ set the material of IW of USB*
Frame partition with ¾ in gypsum board
7. *U ← 1.3 W/(m2 K) ▷ set the material of Ceiling of US*
8. *U ← 2.9 W/(m2 K) ▷ set the material of Floors USB*
Un-insulation solid
9. *U ← 0.7 W/(m2 K) ▷ set the material of Slabs USB*
Passive floor, no insulation, tile or vinyl
10. *U ← 3.7 W/(m2 K) ▷ set the material of Doors USB*
Metal
▷ set the Analytic Constructions of element of USB
11. i ← hourly indoor temperature
12. j ← dset the location
13. **end procedure**

Step 3: Case Study

The urban blocks were designed and constructed by managers and planners in 1962 to meet the demands of the city of 22-Bahman in Kermanshah, Iran. Kermanshah city is characterised as having a semi-arid and wet climate, owing to its relatively wide territory and varied hilly topography, and each district has its own climate. Although it has chilly winters and hot summers in general, its western areas have a dry climate, while the central, northern and foothills have a Mediterranean climate. The municipality of Kermanshah has split the city's map into eight districts. The 22-Bahman is situated in Kermanshah's district 1 at a latitude of 34.202 and a longitude of 47.05, at an elevation of 2291 m, as shown in Fig. 32.2.

Based on 25-year records from the Kermanshah synoptic station, the average annual sunlight hours is 2906.7 h. According to these figures, the average number of snowy days was 12.7 days, and frost days were 104 days each year, and since the residential area is utilised to HVAC for thermal comfort during this time. As a result, heating systems must be turned on. On the other side, the same locations endure hot weather from May 15 to September 1, a period of 135 days. This critical time of year may be thought of as an active cooling system for the structures. This consideration implies that best design options tend to enable the building to give

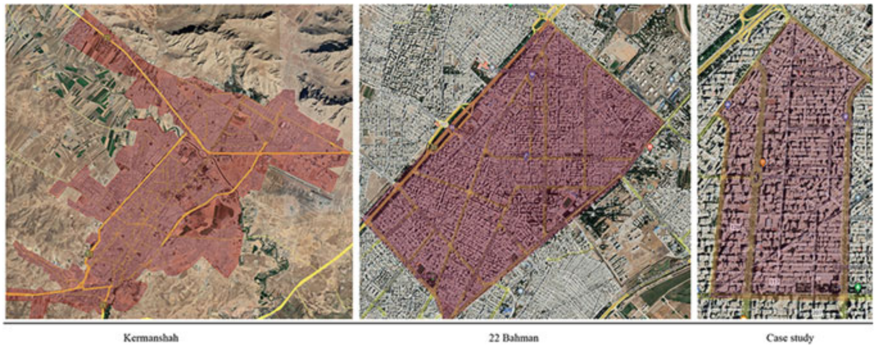


Fig. 32.2 Case study of Kermanshah

the highest PTC with an active cooling system during the warmest months of the year. It should be noted that heating in the study area is typically provided through gas resources, which is not a challenge for Iran, but cooling systems in this area are typically provided through electricity and water resources, which can be said to be relatively challenging given the conditions in Iran. As a result of the above, this research aimed to offer optimal building heating through active systems, and the design process is such that the maximum PTC is produced in the hot season of the year without the need of an active cooling system.

In this study, a highly populated 22-Bahman neighbourhood was modelled as a sample area for Kermanshah to analyse the impacts of different types of urban superblocks on energy consumption and potential adaption techniques. The example study in Fig. 32.2 looked at Kermanshah's 1st district and assessed the large-scale urban block's possible effects on cool, heat, fossil fuel and energy demand. Kermanshah is a city in Iran that is located to the west. In terms of energy consumption, this city is among the most energy-intensive. These neighbourhoods' energy requirements are critical for reducing energy consumption.

In order to define the heating system for the models, ideal air loads were selected as the HVAC system in the Insight360 settings, which can be the best choice for the early design stages, considering the cost of time in the simulation process. The occupancy and infiltration schedules were set to the same values as the default residential unit settings in the Insight360 program (these software's default settings are based on ASHRAE schedules). According to needs and standards, occupancy activities and times were deemed local, and other parameters were determined by the program using default standard information.

Results

In this study, the analytical comparative method was used to assess the influence of several types of urban superblocks on reducing energy consumption in Kermanshah's 22-Bahman area. In addition, based on the local norm of the Iran Engineering Organization, we considered a particular type of USB in the lowest LOD with 30% transparencies confronted. The blocks have been employed based on ideas of separating and integrating them, counter yard or hybrid them and other forms of urban blocks in order to achieve the best sorts of USB. The optimal form in terms of energy usage is derived after studying six kinds of urban block configurations. We will be able to figure out what forms work best in this location this way.

According to Fig. 32.3, six types of USBs in 22-Bahman neighbourhoods of Kermanshah were investigated in this study. The analysis results are shown in Fig. 32.4 according to the Green Building Studio and Insight360 sites (Stine, 2015) established by Autodesk for this program. The sole variable in this experiment is the type of block and its area, and these conditions are the same for all blocks. Three kinds of energy indicators were examined in this study: total energy, power energy and fuel energy. The original concept was thoroughly examined. The first investigation will focus on the site's current urban block, which has been uploaded and examined in accordance with the ASHRAE standard (Fig. 32.3). The present designs, as well as the anticipated analyses, are shown in Fig. 32.5:

According to Fig. 32.5, the use of fuel energy in the existing USB grew by roughly 100 W/m^{2}K between January and December. From May through August, a year's worth of energy is increased. The overall point value is greater than in January and August. This sort of urban block requires 85.3 W/m^{2}K. Numerous sources of energy are excessive per ASHRAE criteria (Fig. 32.6). The energy consumption will be raised by 59 W/m^{2}K to fulfil the ASHRAE standard. Between January and December, fuel energy climbed by around 200 k. However, between May and August, electricity energy is increased by around 50 W/m^{2}K. December and January saw an increase in total energy to roughly 4 M. The perimeter block consumes 52.4 kWh of energy each year, according to ASHRAE regulations. This value should be enhanced by at least 26.2 to meet ASHRAE standard consumption energy requirements. To summarise, municipal planners and officials should consider enacting a specific strategy to minimise energy use during the months of December and January in order

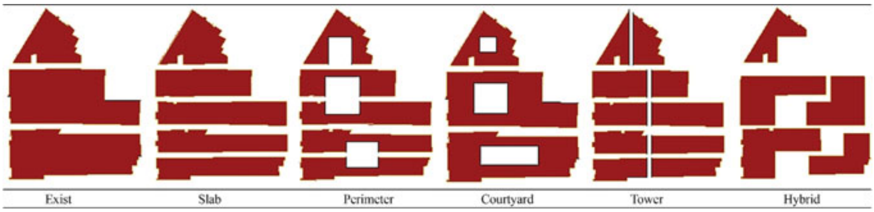


Fig. 32.3 Different shapes of USB next to each other

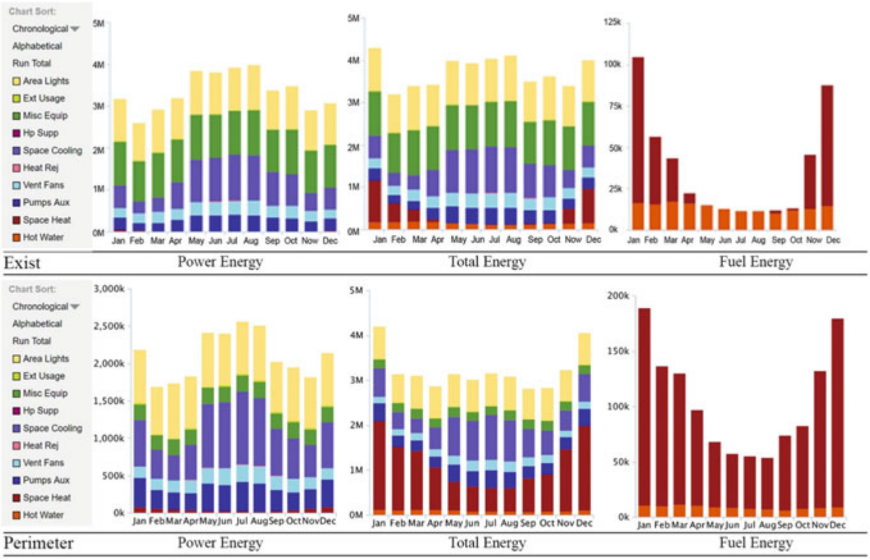


Fig. 32.4 Energy consumption for different types of an urban block in the urban block of 22-Bahman neighbourhood

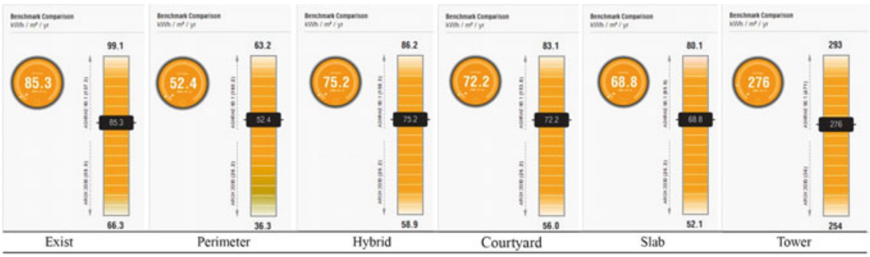


Fig. 32.5 Energy consumption for different types of the urban block based on ASHRAE standard

to save fuel. From May through August, this regulation on electrical equipment is also fairly significant.

Figure 32.7 illustrates the energy consumption of four distinct kinds of urban blocks in three distinct energy consumption categories: fuel, power and total. The first column indicates that May, June, July and August are the peak months for electrical energy use in counter-yard, hybrid, slab and tower. The last column included data on fuel energy use, with the greatest levels happening in January and December and the lowest levels occurring in May and August. According to this online research, various urban block types utilise varying amounts of energy. In December, for example, the hybrid urban block used 4 million kilowatt-hours of electricity, whereas the tower consumed 15 million kilowatt-hours. This research established a relationship between the different forms of urban blocks and energy use.

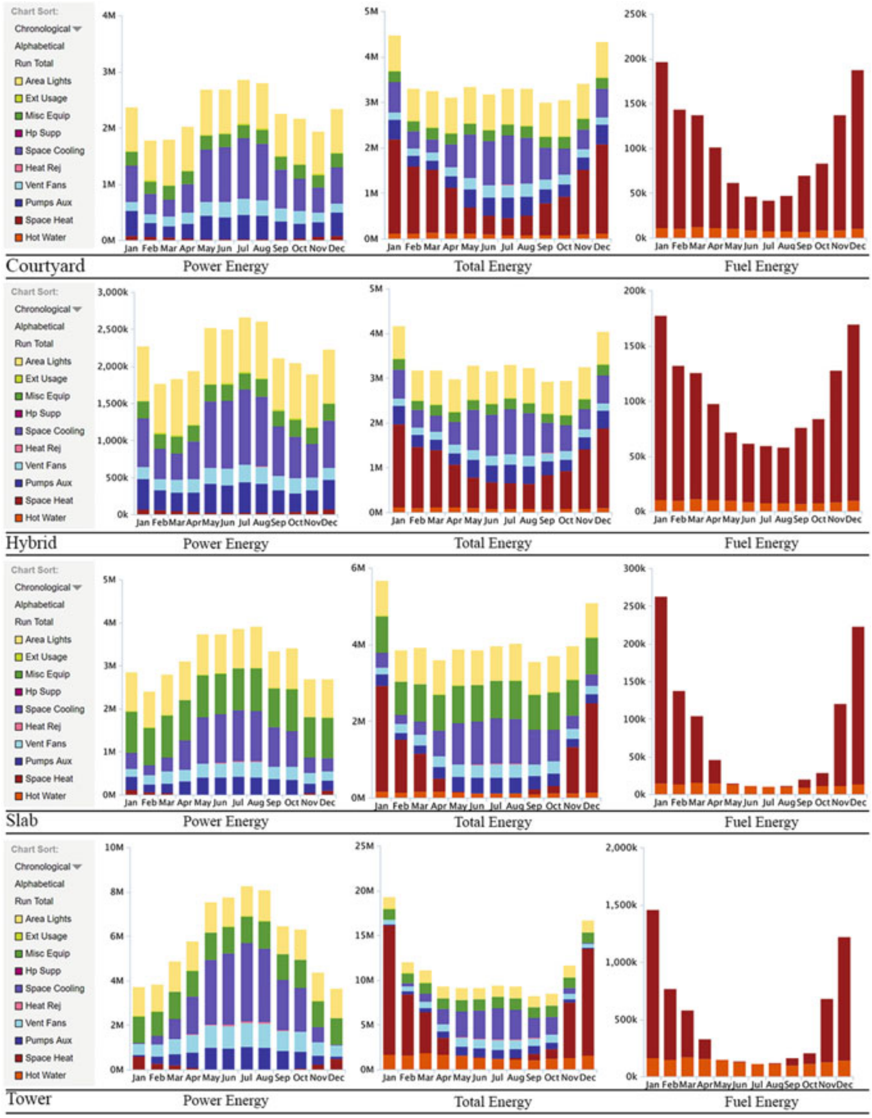


Fig. 32.6 Energy consumption for different types of an urban block in the urban block of 22-Bahman neighbourhood

In January and December, the courtyard kind of urban block consumes the most fuel energy, approximately 200 Wh/m^2/yr, while July consumes the least, around 40 Wh/m^2/yr. Data on power energy usage is collected in a variety of ways. Among May, June, July and August, the largest use of electricity energy is 3 MWh/m^2/yr, while the lowest is around 1.5 MWh/m^2/yr in February and November.

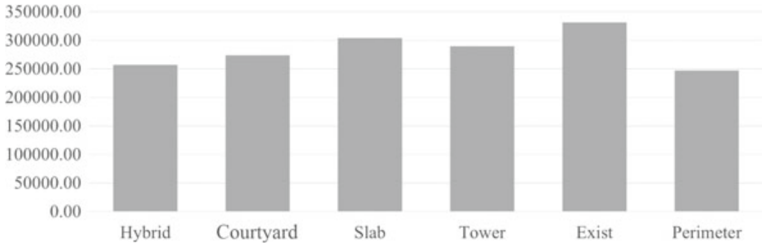


Fig. 32.7 Area of urban blocks

The monthly energy consumption of a hybrid kind of urban block is between 2500 and 2000 KWh/m^2/year, which is the ideal amount in comparison to other urban blocks.

The energy efficiency of urban slab blocks is significantly higher than that of other blocks, ranging between 250 and 5 KWh/m^2/yr. However, the electricity energy depicted in Fig. 32.7 is required in the range of 4–2.5 MWh/m^2/yr, which is a key component of this sort of super urban block's overall consumption. These sorts of tower urban blocks consume between 20 and 10 MWh/m^2/yr more energy than other blocks.

In general, simulation was used to assess the annual energy consumption of urban blocks connected to the best form of urban blocks at the district level. The greatest result connected to foul energy is the kind of exist urban blocks due to the integrated model, notably for using fuel energy in space heat about 100 kWh/m^2/yr, according to the data in the bar chart. Hybrid and perimeter urban models are the two most effusive forms of urban models.

Figure 32.8 depicts the area of various urban blocks, which has an impact on energy usage. Figures 32.8 and 32.9 show the area and EUI, respectively. On the other hand, existing urban blocks have the largest area of all urban blocks, yet their EUI is not higher than other types of urban blocks. Perimeter blocks also have a small footprint and low energy use. The measurement of EUL in the tower blocks, with a range from 293 to 254, while the area is a minimum of roughly 250,000, is a notable point in Fig. 32.9.

Table 32.3 and Fig. 32.8 reveal that EUI in all types of urban blocks ranges from 65 to 100, except for tower urban blocks, which have a EUI of around 275. Because of the connection between the face and the outside, the tower blocks, in my perspective, required substantially more energy based on ASHRAE 90.1.

The correlation is a statistical test demonstrating the relationship between variables with values ranging from −1 to 1. The number near 1 denotes a high two-factor correlation, while −1 denotes a reverse data correlation. Also, if the correlation test yields a number close to 0, this indicates that there is a weak association between variables. Table 32.4 and Fig. 32.10 indicate that cost and ASHRAE 90.1 have a good correlation of 0.97. However, there is a weak link between EUI and building area data, around 0.18, and between building area and ASHRAE 90.1 data, about 0.04.

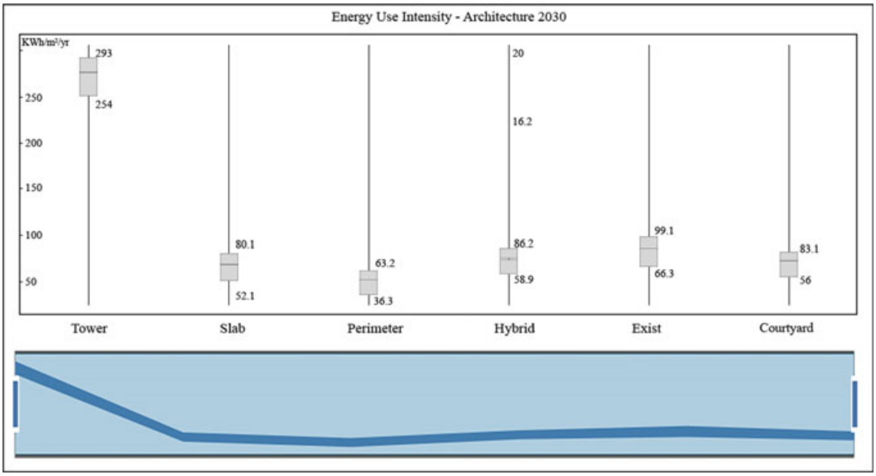


Fig. 32.8 EUI of urban blocks

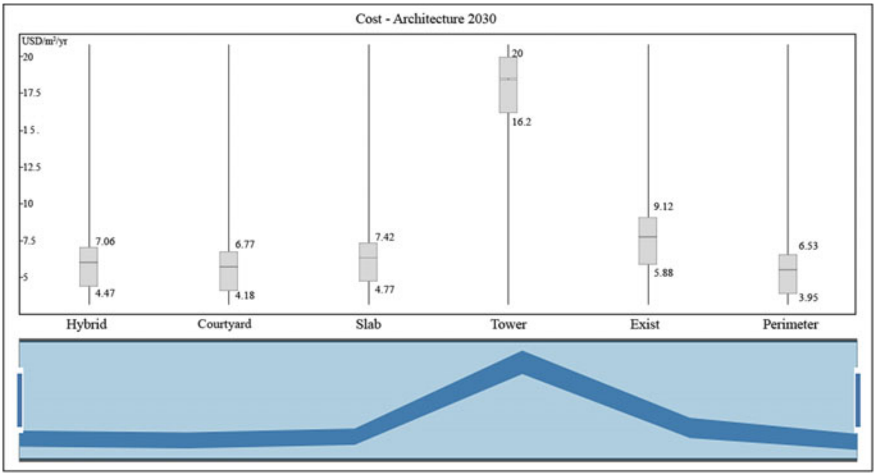


Fig. 32.9 Cost of energy consumption of urban blocks

Table 32.4 Correlation between variables

	Cost	Arch 2030	ASHRAE 90.1	EUI	Building area
Cost	1	0.03	0.97	1	0.24
Arch 2030	0.03	1	−0.03	−0.03	0.77
ASHRAE 90.1	0.97	−0.03	1	0.97	0.04
EUI	1	−0.03	0.97	1	0.18
Building area	0.24	0.77	0.04	0.18	1

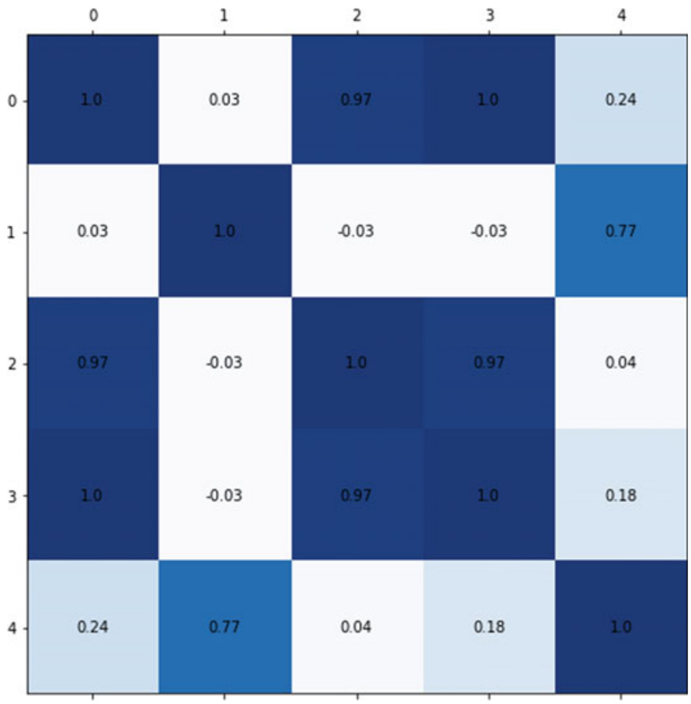


Fig. 32.10 Correlation between variables

The required monthly electric energy consumption, as well as HVAC optimisation via energy savings in different equipment, is shown in Fig. 32.11. As seen in Fig. 32.11, HVAC optimisation is only accomplished on an annual basis. As seen in this graphic, various types of urban blocks need different criteria. Figure 32.12 demonstrates that energy conservation via the use of an optimal heating system is a possible alternative, since it is difficult to attain 100% heating cover at higher densities. The electrical load efficiency of various metropolitan blocks is represented in Fig. 32.12. As seen in this graphic, monitoring efficiency may help reduce energy use.

Discussions

Significant Findings

Analysing energy consumption should be discussed for finding optimum solution in urban superblocks for reducing energy consumption in city. Because the urban superblock is the first urban feature to be built, by urban planners and urban designers.

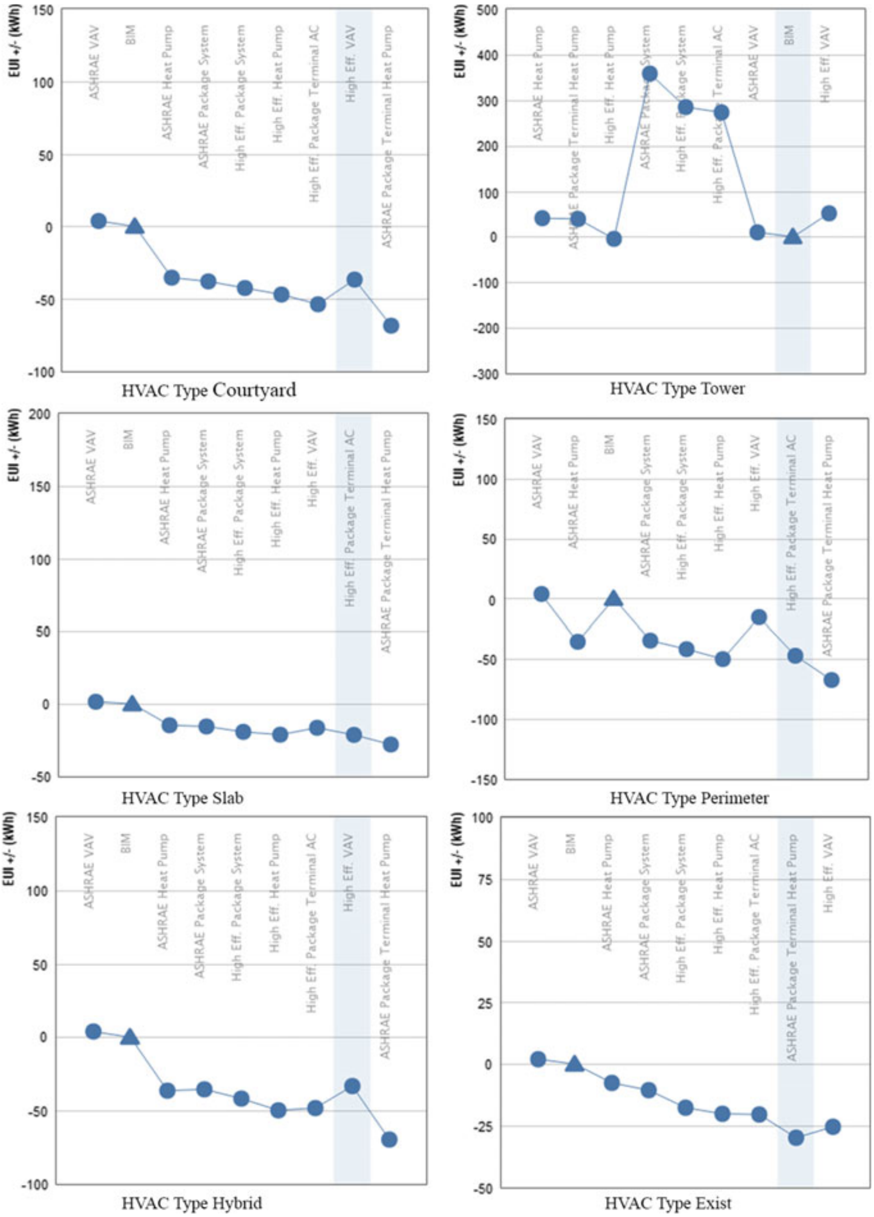


Fig. 32.11 HVAC optimisation via energy savings in different equipment

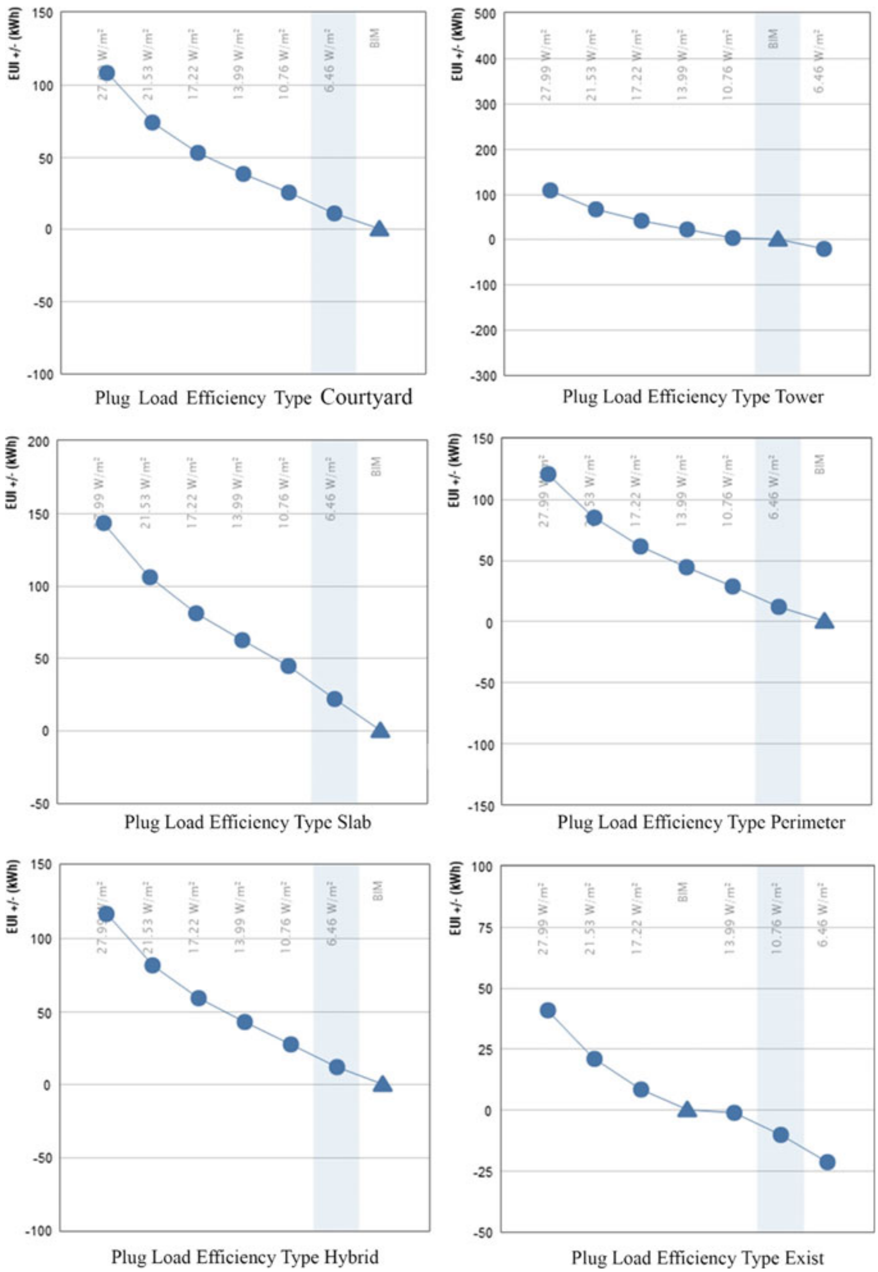


Fig. 32.12 Energy conservation via the use of an optimal heating system

Because the type of many buildings reduces the energy consumption by the interior space to a large extent. In this study, urban superblocks have been explored as an autonomous entity that is impacted by neighbouring sections. The results of this study reveal that each superblock has a varied amount of energy consumption under the impact of its component factors, including Area, and block type which is compatible with the research findings (Veisi et al. 2022; Shakibamanesh and Veisi 2021b).

The research demonstrates that various kinds of urban blocks should be chosen based on the investigated environment, location and cost of energy consumption in order to attain lowest energy consumption. In this chapter, six distinct types of urban superblocks were analysed, and according to the kind of urban superblock, each species used a distinct quantity of energy. Consequently, the surface area variable and the ASHRAE 90.1 cost standard have the highest influence on Energy Use Intensity. This is in line with current study results in the area of Energy Use Intensity in buildings and urban environments (Ghorbanian and Chehragan 2022).

The examination of six categories of superblocks demonstrates that the species of urban blocks may alter the quantity of energy consumption. As a result, urban planners and designers to effectively pick species, they must consider the kind of each species in relation to the local climate. This study is consistent with the findings of earlier studies in the area of the impacts of urban morphology type. This study aims to minimum energy consumption by using the ASHRAE 90.1 and BIM and CIM model (Morello et al. 2009; Pakzad and Salari 2018). Numerous research have been conducted on the appropriate scale for the shape of an urban block, with varying ranges of values for various kinds. However, no study has been conducted on the ideal ASHRAE model and cost function by use of CIM and BIM model for selecting best urban superblocks based on EIU; this is one of the first studies on this subject. The findings indicate that cost and ASHRAE 90.1 have good correlation with each other, and city superblock may be selected based on the ideal configuration, cost, ASHRAE 90.1 and EUI.

On the other hand, the findings of this study indicate that it is conceivable to utilise the CIM and BIM model to anticipate various types of energy consumption in different superblocks and metropolitan locations, necessitating a larger data collection comprised of climate-specific studies. Consequently, as a result of the research conducted by the researchers, the research in the aforementioned context can be expanded in terms of the species used, and more variables and patterns can be investigated in future studies, as this research is more diverse in terms of examining and implementing new methodologies (Shakibamanesh and Veisi 2021a; Veisi et al. 2022).

The Innovation

Novelty may serve as both the research topic and the research methodology in the current study. As previously stated, the major purpose of this study was to discover the most energy-efficient urban superblock type. This study analysed an alternate viewpoint based on the outcomes of prior research and divergent opinions about the most energy-efficient form of urban superblock. In order to determine the optimal limit of an urban superblock, the inverse relationship between the area of an urban block and energy consumption, the direct correlation between the ASHRAE model and cost function has been taken into account, and the research hypothesis considers the need to maintain diversity in the urban fabric in order to achieve the lowest amount of energy consumption with the smallest amount of area in various types of urban superblocks. In terms of the simultaneous use of CIM and BIM models for dataset production and development in estimating the amount of energy consumption by various superblocks in the target tissue, the research technique is both original and unique.

Conclusion and Future Work

This study highlights the importance of assessing urban blocks and energy consumption, as well as the demand and supply of building energy through integrated fuel and electrical energy. However, given the geometric complexity, it is necessary to evaluate the relationship between energy usage and the kind of urban blocks. Additionally, the approach makes use of OSM data to estimate the amount of energy used by a USB at a certain time and date and place. The suggested approach would serve as a critical reference for the annual energy usage of urban blocks, including fuel, electricity and lighting.

Because the type of urban block is often associated with a change in the degree of connection to the outside world, the need for energy consumption as a result of the type of urban block resulted in a monthly drop in energy consumption (0.20%). On the other hand, after evaluating examples in Kermanshah and determining the energy constraints of each shape, it may be considered a courtyard and perimeter kind of urban block for developing urban blocks in Kermanshah's 22-Bahman region. As previously noted, this form of central courtyard layout has been employed multiple times in this context.

The investigation's final section focuses on improving energy usage in urban areas, which results in more accurate data in various locations. As a result, this procedure has been accepted and standardised. As a result, academics can look into the subject of energy with an emphasis on BIM and CIM to tackle some issues in the initial level of design, where urban planners and policymakers lack knowledge. As a result, concerns like parametric modelling, energy efficiency, smart city regulations aimed at lowering energy consumption and how to use City Information Modelling to anticipate and design smart urban codes are topics that can aid researchers in developing this methodology.

Additional research should focus on more practical aspects of building design and construction. This might contribute to a greater understanding of the issues around building performance improvement. Thus, future research should address and propose solutions to practical and complex problems in the field of architecture through the discovery and investigation of artificial intelligence models and the use of other deep learning capabilities such as convolutional neural network (CNN), generative adversarial networks (GAN) and classification.

References

Agugiaro G, González FGG, Cavallo R (2020) The city of tomorrow from… the data of today. ISPRS Int J Geo Inf 9(9):554

Akin O, Moustapha H (2004) Strategic use of representation in architectural massing. Des Stud 25(1):31–50

Alhamwi A, Medjroubi W, Vogt T, Agert C (2018) Modelling urban energy requirements using open source data and models. Appl Energy 231:1100–1108

Amado M, Poggi F, Amado AR (2016) Energy efficient city: a model for urban planning. Sustain Cities Soc 26:476–485. https://doi.org/10.1016/j.scs.2016.04.011

Amado M, Poggi F, Ribeiro Amado A, Breu S (2017) A cellular approach to net-zero energy cities. Energies 10(11). https://doi.org/10.3390/en10111826

ANSI A, Standard A (2010) Thermal environmental conditions for human occupancy. American Society of Heating Refrigerating and Air-Conditioning Engineers, Atlanta

Arabi S, Eshtehardian E, Shafiei I (2022) Using bayesian networks for selecting risk-response strategies in construction projects. J Constr Eng Manag 148(8):04022067

Bayón-Cueli C, Barbón A, Bayón L, Barbón N (2020) A cost-energy based methodology for small-scale linear Fresnel reflectors on flat roofs of urban buildings. Renew Energy 146:944–959. https://doi.org/10.1016/j.renene.2019.07.005

Biljecki F, Stoter J, Ledoux H, Zlatanova S, Çöltekin A (2015) Applications of 3D city models: state of the art review. ISPRS Int J Geo Inf 4(4):2842–2889

Cerezo Davila C (2017) Building archetype calibration for effective urban building energy modeling. Massachusetts Institute of Technology

Dogan T (2015) Procedures for automated building energy model production for urban and early design. Massachusetts Institute of Technology

Duany A, Talen E (2002) Transect planning. American Planning Association. J Am Plann Assoc 68(3):245

Ghorbanian M, Chehragan Z (2022) The Relation between urban physical indicators and solar irradiation availability on building envelopes: using tehran as a case study. In: Advances in urbanism, smart cities, and sustainability, pp 227–239. CRC Press

Groppi D, de Santoli L, Cumo F, Astiaso Garcia D (2018) A GIS-based model to assess buildings energy consumption and usable solar energy potential in urban areas. Sustain Cities Soc 40:546–558. https://doi.org/10.1016/j.scs.2018.05.005

Isikdag U (2015) BIM and IoT: a synopsis from GIS perspective. Int Arch Photogrammetry, Remote Sens Spat Inf Sci 40:33

Isikdag U, Aouad G, Underwood J, Trodd NM (2004) Towards the implementation of the building information models in geographical information systems

Jacoby S (2016) Drawing architecture and the urban. Wiley

Jusuf SK, Mousseau B, Godfroid G, Soh JHV (2017) Path to an integrated modelling between IFC and CityGML for neighborhood scale modelling. Urban Sci 1(3):25

Kaiser EJ, Godschalk DR, Chapin FS (1995) Urban land use planning. University of Illinois Press, Urbana

Kang T (2018) Development of a conceptual mapping standard to link building and geospatial information. ISPRS Int J Geo Inf 7(5):162

Kanters J, Horvat M (2012) Solar energy as a design parameter in urban planning. Energy Procedia 30:1143–1152

Keena N, Raugei M, Etman MA, Ruan D, Dyson A (2018) Clark's crow: a design plugin to support emergy analysis decision making towards sustainable urban ecologies. Ecol Model 367:42–57
Kolbe TH, Gröger G, Plümer L (2005) CityGML: interoperable access to 3D city models. In: Geo-information for disaster management, pp 883–899. Springer
Li J, Wang Y, Xia Y (2022) A novel geometric parameter to evaluate the effects of block form on solar radiation towards sustainable urban design. Sustain Cities Soc 84:104001
Lin KY (2013) Investigating reducing building energy use at urban scale in Taipei. Cardiff University
Loibl W, Vuckovic M, Etminan G, Ratheiser M, Tschannett S, Österreicher D (2021) Effects of densification on urban microclimate—a case study for the City of Vienna. Atmosphere 12(4):511
Machete R, Falcão AP, Gomes MG, Moret Rodrigues A (2018) The use of 3D GIS to analyse the influence of urban context on buildings' solar energy potential. Energy Build 177:290–302. https://doi.org/10.1016/j.enbuild.2018.07.064
Martin L, Martin LA, March L (1972) Urban space and structures. Cambridge University Press
Mert Y, Saygın N (2016) Energy efficient building block design: an exergy perspective. Energy 102:465–472. https://doi.org/10.1016/j.energy.2016.02.121
Morello E et al. (2009) Sustainable urban block design through passive architecture. Paper presented at 26th conference on passive and low energy, Quebec city
Morganti M, Salvati A, Coch H, Cecere CJEP (2017) Urban morphology indicators for solar energy analysis. 134:807–814.
Omid V, Nastaran F, Morteza R, Hadi E (2022) Daylight optimization and energy retrofit by using proportionate automated louvers in home-based offices (case study: a house in Tehran, Iran). EnerarXiv. http://www.enerarxiv.org/page/thesis.html?id=3559
Pakzad E, Salari N (2018) Measuring sustainability of urban blocks: the case of Dowlatabad Kermanshah city. J Cities
Pratt KB, Jones NL, Schumann L, Bosworth DE, Heumann AD (2012) Automated translation of architectural models for energy simulation. In: Proceedings of the 2012 symposium on simulation for architecture and urban design, pp 1–8
Ramesh S (2018) Urban energy information modeling: a framework to quantify the thermodynamic interactions between the natural and the built environment that affect building energy consumption. Carnegie Mellon University
Ratti C, Baker N, Steemers K (2005) Energy consumption and urban texture. Energy Build 37(7):762–776. https://doi.org/10.1016/j.enbuild.2004.10.010
Salminen A, Hägglöf D (2015) City Information Model-CIM: benefits with an integrated city information model in the area of technical aspects
Shafiei I, Eshtehardian E, Nasirzadeh F, Arabi S (2020) Dynamic modeling to reduce the cost of quality in construction projects. Int J Constr Manag, pp 1–14
Shakibamanesh A, Veisi O (2021a) Designing sustainable urban blocks: an effort to optimizing 3D form and achieving maximum amount of solar radiation. In: Advances in urbanism, smart cities, and sustainability, pp 405–429. CRC Press
Shakibamanesh A, Veisi O (2021b) Designing ustainable urban blocks; an effort to optimizing 3D form and achieving the maximum amount of solar radiation. In: Sustainable urbanism in developing countries, Taylor & Francis Group/CRC Press
Shi Z, Fonseca JA, Schlueter A (2017) A review of simulation-based urban form generation and optimization for energy-driven urban design. Build Environ 121:119–129. https://doi.org/10.1016/j.buildenv.2017.05.006
Stine D (2015) Building performance analysis in revit 2016 R2 with autodesk insight 360. Retrieved from AECbytes: http://aecbytes.com/tipsandtricks/2015/issue76-revit.html
Stojanovski T (2013) City information modeling (CIM) and urbanism: blocks, connections, territories, people and situations. In: Proceedings of the symposium on simulation for architecture & urban design, pp 1–8
Taleghani M, Tenpierik M, Van Den Dobbelsteen A, De Dear R (2013) Energy use impact of and thermal comfort in different urban block types in the Netherlands. Energy Build 67:166–175

Thompson EM, Greenhalgh P, Muldoon-Smith K, Charlton J, Dolník M (2016) Planners in the future city: using city information modelling to support planners as market actors. Urban Plann 1(1):79–94

Tsirigoti D, Bikas D (2017) A cross scale analysis of the relationship between energy efficiency and urban morphology in the Greek city context. Procedia Environ Sci 38:682–687

van Treeck C, Rank E (2007) Dimensional reduction of 3D building models using graph theory and its application in building energy simulation. Eng Comput 23(2):109–122

Veisi O, Shakibamanesh A (2022) Analysis of solar radiation towards optimization and location of the urban blocks in the neighborhood units. Environ Sci Sustain Dev

Veisi O, Shakibamanesh A, Rahbar M (2022) Using intelligent multi-objective optimization and artificial neural networking to achieve maximum solar radiation with minimum volume in the archetype urban block. Sustain Cities Soc, p 104101

Verma V, Kumar R, Hsu S (2006) 3D building detection and modeling from aerial lidar data. In: 2006 IEEE computer society conference on computer vision and pattern recognition (CVPR'06). IEEE, pp 2213–2220

Vidmar J (2013) Parametric maps for performance-based urban design

Xu X, Ding L, Luo H, Ma L (2014) From building information modeling to city information modeling. J Inf Technol Constr 19:292–307

Xue F, Lu W, Chen Z, Webster CJ (2020) From LiDAR point cloud towards digital twin city: clustering city objects based on Gestalt principles. ISPRS J Photogramm Remote Sens 167:418–431

Yeo I-A, Yee J-J (2016) Development of an automated modeler of environment and energy geographic information (E-GIS) for ecofriendly city planning. Autom Constr 71:398–413

Zhang J, Xu L, Shabunko V, Tay SER, Sun H, Lau SSY et al (2019) Impact of urban block typology on building solar potential and energy use efficiency in tropical high-density city. Appl Energy 240:513–533. https://doi.org/10.1016/j.apenergy.2019.02.033

Chapter 33
Evaluating the Spatial Distribution of Thermal Comfort Conditions in a High, Elevated Lakeside City, Van

Savaş Çağlak

Abstract Thermal comfort can be defined as the state of people feeling comfortable/happy in their environment. This study is aimed to explain the distribution of thermal comfort conditions in the city of Van, which is a historical city with a high altitude established on the shores of Lake Van. In the study, the data of three meteorology stations was evaluated according to the physiological equivalent temperature (PET) index, and their spatial distribution was explained by taking into account many variables related to the field with Geographic Information Systems (GIS). As a result of the study, cold stress perceptions were dominant in the city from November to March, and "slightly warm" and "warm" stresses were dominant in the summer season. During the transition seasons, "slightly cool" stress and "comfortable" conditions are effective. Due to urbanisation, it has been observed that city centres have different thermal comfort conditions compared to the rural and semi-rural areas around them, and the thermal conditions of the city have slightly milder characteristics than the effect of Lake Van. For sustainable urbanisation, it is necessary to make urban design and planning with a geographical perspective that takes into account human, ecological and physical conditions.

Keywords Thermal comfort · Urban climate · Lakeside city · PET · Van

Introduction

Climate, which is the most important composition of the natural environment, has an impact on all human activities. Distribution of world population, economic activities, transportation, tourism, health, culture, architecture, settlement, etc. activities are under the control of the climate. Within the settlements, cities are the places where inventions that change the age of humanity are developed, socio-economic progress is recorded, and cultural interactions accelerate. Thanks to these features, cities are universal heritage areas of human history with their intangible and tangible cultural

S. Çağlak (✉)
Ministry of Education, Amasya City, Turkey
e-mail: savas_caglak@hotmail.com

U. Chatterjee et al. (eds.), *Urban Commons, Future Smart Cities and Sustainability*, Springer Geography, https://doi.org/10.1007/978-3-031-24767-5_33

features (Author, 2006). However, the migration from rural to urban areas, which gained momentum with the industrial revolution, caused the number of cities to increase and their areas to expand. As a result of this situation, urban areas have been covered with impermeable surfaces such as asphalt and concrete, green areas in the city have been destroyed, and the air quality of the cities has deteriorated with the use of motor vehicles, industrial and domestic wastes. Due to all these factors, cities have had different climatic conditions from the semi-rural and rural areas around them. This situation has been demonstrated in many studies conducted in different parts of the world (Lerner 1964; Oke 1973; Mayer 1993; Unger 1999; Çiçek and Doğan 2005; Charalampopoulos et al. 2013; Türkeş and Erlat 2017).

With the increasing level of knowledge and technological developments, many studies have begun to study thermal comfort conditions, which are the state of feeling the common effect of all climate elements, according to the specific climatic conditions of each city. In the most general sense, thermal comfort can be defined as the state of feeling comfortable or comfortable/happy in the thermal environment (air temperature, relative humidity, wind, solar radiation, mean radiant temperature, etc.) (Olgyay 1973; Sungur 1980). It can also be expressed as a state of thermally undisturbed or neutral discomfort between uncomfortable heat and uncomfortable cold (Parsons 2003). In uncomfortable conditions, there are many social, economic and physical negativities such as decrease in people's welfare and happiness, health problems and increase in energy use, decrease in work efficiency (Anderson and Bell 2009; Nastos and Matzarakis 2011; Scherber et al. 2014; Huang et al. al. 2015; Błażejczyk et al. 2018; Fallah and Mayvaneh 2012; Aboubakri et al. 2020). The first studies started in the early 1900s (Haldane 1905) in order to present the thermal comfort conditions in a concrete way, and it has become an important issue with the methods developed day by day. Today, more than 100 thermal comfort indices have been developed, and bibliographic studies have been conducted on them (Landsberg 1972; Driscoll 1992; Epstein and Moran 2006; Parsons 2014; de Freitas and Grigorieva 2015). Thermal comfort indices, which were started to be developed to increase the work efficiency of the employees, are used in areas such as the outdoor conditions of cities, tourism-climate relations, human health, climate change and energy consumption, especially in the temperate zone. Among these indices, the physiological equivalent temperature (PET) index, which is widely used to determine the outdoor thermal conditions, especially in urban areas. In addition, PET index is an ideal tool for calculating human thermal comfort in different climate types (Toy 2010). The PET index is the latitude, longitude, elevation, etc. of the studied area. The radiation model, which can be entered in information and works in all computer operating systems, is calculated with RayMan software (Matzarakis et al. 2000). Therefore, the PET index was used in the study.

With the increase in urban areas, energy transfer, specific heat, albedo, humidity, evaporation, precipitation, air pollution, anthropogenic heat, impermeability of surfaces, thermal properties of materials used on surfaces and surface geometry change the thermal comfort conditions of cities (Oke 1981). Urban areas have more burning, suffocating and suffocating thermal conditions than the surrounding rural areas. Clarke and Bach (1971) stated that the suburbs in the city of Cincinnati, Ohio, USA, are more comfortable than the city centre, and this difference is most visible in the evening hours. Mayer (1993) found that wooded environments in Munich, Germany, are more comfortable than treeless environments. It has also been revealed in Szeged, Hungary (Unger 1999), a central European city where urban areas are more uncomfortable than rural areas, and Warsaw and Łodz, Poland (Błażejczyk et al. 2016). Çiçek (2003) stated that in the capital city of Turkey, Ankara, higher temperature stresses are experienced in the urban area during the summer season. In another study conducted in Ankara, it was stated that different thermal conditions were experienced according to the land texture of the city, and these differences were more pronounced at night (Türkoğlu et al. 2011). Such unfavourable comfort conditions due to urbanisation are located in Erzurum (Toy) in the northeast of Turkey.

Location and Properties of Study Area

The city of Van is located in Eastern Turkey, in the Middle East Anatolian Region (TRB2 Level 2 Region), on the Iranian border. The city was established between latitudes 38° 36′ N—38° 25′ N and longitudes 43° 29′ E—43° 18′ E, at an altitude of 1627–2000 m, and on the shores of Lake Van, Turkey's largest lake (Fig. 33.1). Lake Van ranks fourth among the closed lakes in the world and has the distinction of being the largest soda lake in the world (Koyuncu and Karakılçık 2019).

Van city, BC, it became the capital of the Urartians between 850 and 585 years and therefore has a historical texture that reflects the Urartian heritage (Eriçok 2019). Van, which has been an important city since the past, has had a dense population due to the urbanisation movements experienced all over the world after the industrial revolution. The city of Van has metropolitan status and consists of Tusba, İpekyolu and Edremit district centres. According to the 2021 Turkey Static Institution (TSI) data, the total population is 631,827, with 163.320 people in Tusba district, 339.952 people in İpekyolu district and 128.555 people in Edremit district.

According to Köppen-Geiger (Csa) in the city of Van, which has a high altitude on the shores of Lake Van, the climate is mild in winter, very hot in summer and dry, according to De Martone; steppe—semi-humid and according to Thornthwaite; (C1) semi-arid—less humid, according to Erinç; semi-humid climatic conditions are experienced (Bölük 2016).

In the city where continental climate conditions are experienced, the annual average temperature is 9.4 ˚C, the maximum average temperature is 28.5 ˚C in August, and the minimum average temperature is −7.6 ˚C in January, according to long term (1960–2020) averages. The total annual precipitation is 392.8 mm, the highest precipitation falls in the spring and autumn seasons, and the least precipitation falls in the summer season. The annual average relative humidity is 57%, the annual average wind speed is 2.3 (m/s), and the annual average cloud cover is 3.7 (octa) (Table 33.1 and Fig. 33.2). Due to the high elevation in the east of the city and the presence of Lake Van in the west, east–west winds are effective. In addition,

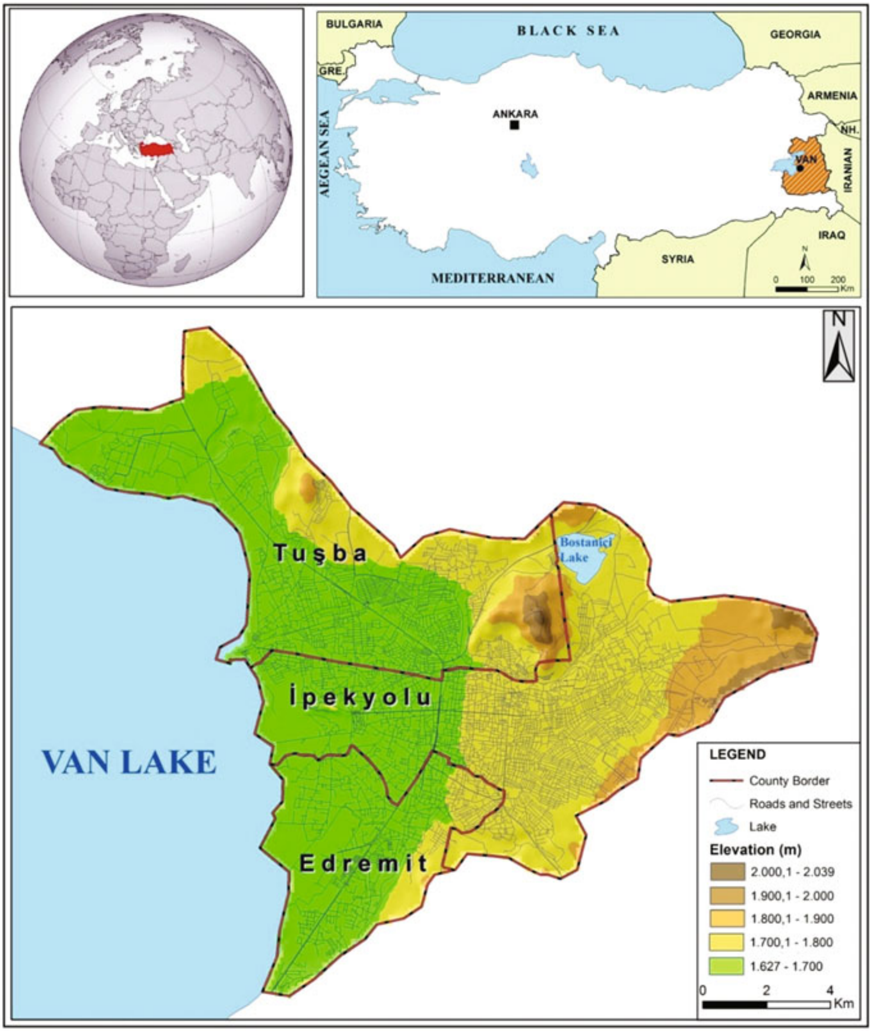


Fig. 33.1 Location map of the Van city

northeast winds from the hilly areas in the northeast of the city towards the city are also effective (Fig. 33.2).

According to the annual average values, in the city of Van, the mean temperature ranges between 7.5 and 9.6 °C, the maximum temperature ranges between 13.5 and 15.6 °C, and the minimum temperature ranges between 1.9 and 3.9 °C. While the highest values are observed along the coast of Lake Van, the values decrease with the increase in altitude from the coast to the interior. The total annual precipitation in the city ranges between 379 and 602 mm. While precipitation decreases along the coast of Lake Van, precipitation increases from the coast towards the interior. The

Table 33.1 Average and extreme meteorological values of the city of Van (1960–2020)

Months	Mean temperature (°C)	Maximum temperature (°C)	Minimum temperature (°C)	Precipitation (mm)	Relative humidity (%)	Wind velocity (m/s)	Cloud cover (octa)
1	−3.1	2.0	−7.6	35.3	68.0	2.0	5.3
2	−2.5	2.7	−7.1	32.7	68.0	2.0	5.2
3	1.6	6.6	−2.8	46.6	68.0	2.0	5.2
4	7.8	12.9	2.6	55.1	61.0	2.5	5.1
5	13.2	18.6	7.1	45.4	56.0	2.3	4.2
6	18.3	24.0	10.9	18.6	49.0	2.3	2.2
7	22.3	28.3	14.7	6.3	45.0	2.4	1.7
8	22.2	28.5	14.6	5.8	43.0	2.4	1.2
9	17.8	24.4	10.8	15.5	45.0	2.5	1.4
10	11.3	17.4	5.7	46.5	59.0	2.3	3.6
11	4.9	10.3	0.4	47.1	66.0	2.2	4.5
12	−0.4	4.5	−4.6	37.9	67.0	2.1	5.3
Annual	9.4	15.0	3.7	392.8	57.0	2.3	3.7

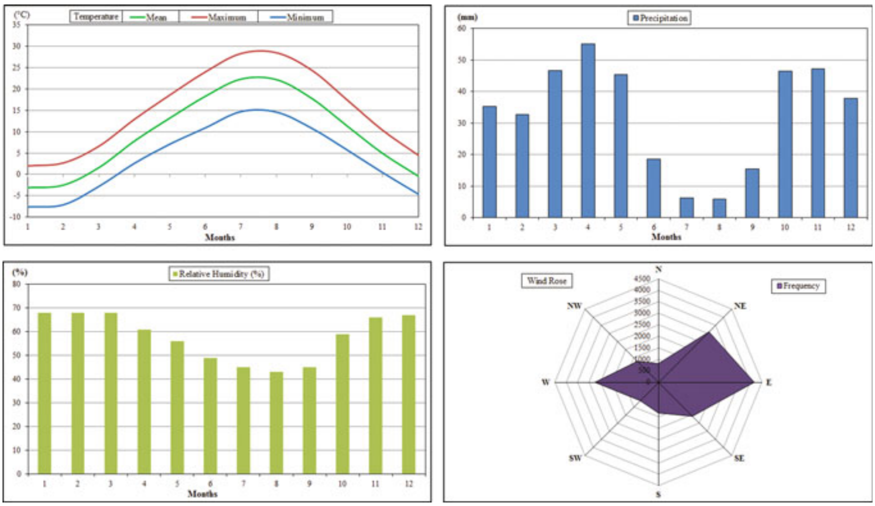


Fig. 33.2 Diagrams showing the climatic characteristics of the city of Van (1960–2020)

mean relative humidity is between 57 and 69%, while the relative humidity values are low in the urban area, and it increases in the urban peripheries. Mean wind velocity is between 0.8 and 3.6 (m/s). While the wind velocity is low due to the effect of buildings in the urban area, it increases in the city peripheries and the high areas to the southwest of the Bostaniçi Pond (Fig. 33.3).

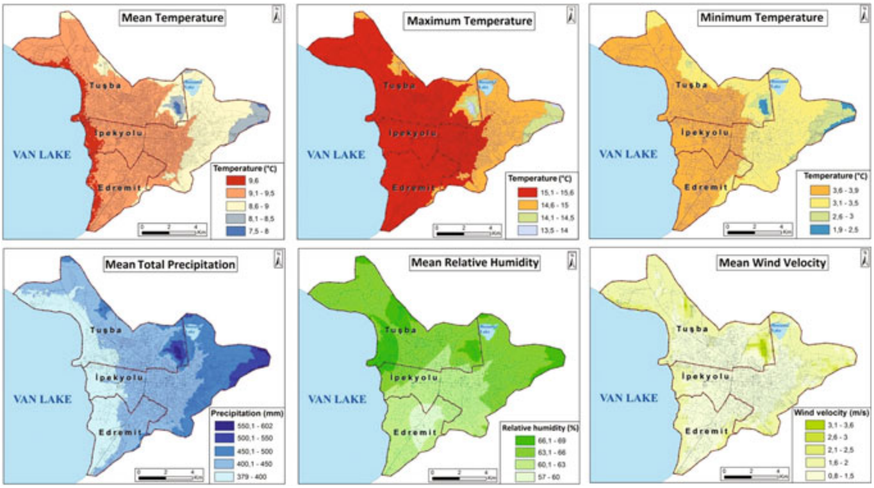


Fig. 33.3 Maps showing the climatic characteristics of the city of Van (1960–2020)

Materials and Methods

In the study, between 2015 and 2021 (7 years), hourly, temperature, relative humidity, wind speed and cloudiness data were used. Meteorology station 17170 is located at an altitude of 1665 m in the open area at Ferit Melen Airport, at an altitude of 1675 m in the urban area consisting of surfaces with built surfaces of meteorology station 17172, and meteorological station 17482 is at an altitude of 1647 m on the shore of Lake Van. Meteorology stations are located at close elevations and on different terrains (Table 33.2 and Fig. 33.4).

The first scientific approach to thermal comfort was formed by Heberden (1826) and noticed that humidity affects the temperature felt by humans as well as air temperature. But the first serious work was done by Haldane (1905). The first bioclimatic comfort index was the effective temperature index developed by Houghton and Yagloglou (1923). More than 100 indices have been developed to determine thermal comfort conditions, and bibliographic studies have been conducted on them (Landsberg 1972; Epstein and Moran 2006; de Freitas and Grigorieva 2015). Examples of indices used in thermal comfort studies are given in Table 33.3 according to their historical development.

Table 33.2 Meteorology stations used in the study

Station code	Latitude	Longitude	Altitude (m)	Surface
17170	38° 28′ 08.4" N	43° 20′ 13.2" E	1665	No structure
17172	38° 28′ 09.5" N	43° 20′ 45.6" E	1675	Structured area
17482	38° 30′ 46.0" N	43° 18′ 22.0" E	1647	Lake shore

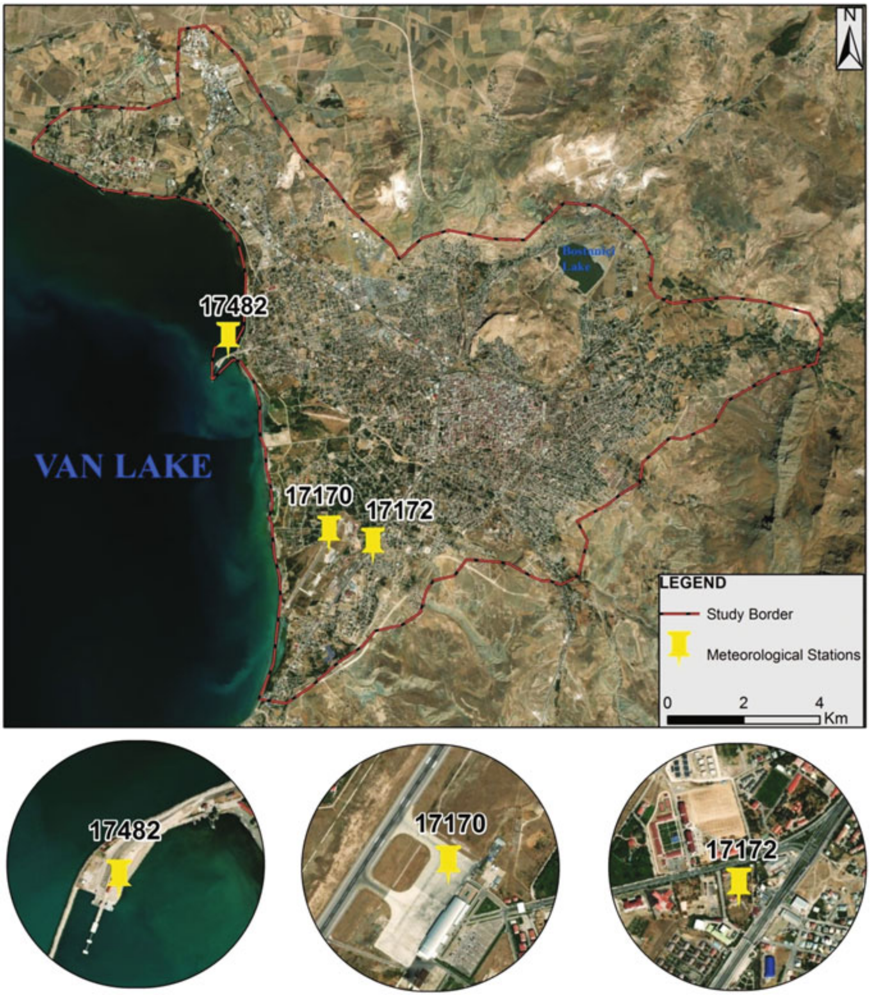


Fig. 33.4 Meteorology stations used in the study

Among these indices, the radiation model RayMan, which is widely used in the world, was used. The RayMan model calculates both atmospheric factors (temperature, relative humidity, wind speed, cloudiness and solar radiation) and personal factors (clothing, activity, metabolic processes, etc.) together in determining thermal comfort conditions (Matzarakis and Mayer 1999). The physiological equivalent temperature (PET) index obtained from the model is calculated by taking into account all the effects of the thermal environment on humans (short and long wave solar radiation, air temperature, relative humidity and wind speed) and the thermo-physiological conditions of the human body (clothing type and activity) (Höppe 1999; Matzarakis and Mayer 1999; Gulyas et al. 2006). Details about the RayMan model are given

Table 33.3 Examples of some of the thermal comfort indices

Year	Index	Short	Researcher
1923	Effective temperature	ET	Houghten and Yagloglou
1937	Operative temperature	OP	Winslow, Herington and Gagge
1945	Wind chill temperature	WCT	Siple and Passel
1959	Discomfort index	D	Thom
1970	Predicted mean vote	PMV	Fanger
1971	Standard effective temperature	SET	Gagge et al
1984	Physiological equivalent temperature	PET	Höppe
2000	Universal thermal climate index	UTCI	COST Action 730

in the studies (Matzarakis et al. 2007, 2010; Fröchlic et al. 2018). Thermal sensation levels of PET index were determined by considering a 35-year-old, 175 cm tall, 75 kg, male, healthy individual with 0.9 clothing load and 80 W workload (Höppe, 1999; Matzarakis and Mayer 1999; Table 33.4).

Geographic Information Systems (GIS) technology, which has developed in recent years, is used in the spatial distribution of thermal comfort conditions. Interpolation methods are based on station data with GIS software; IDW, Kriging, CoKriging, Radial Basis Functions, etc. (Matzarakis et al. 2010; Caliskan 2012; Daneshvar et al. 2013; Ketterer and Matzarakis 2016). However, the variables related to the land cover are not taken into account in the comfort maps produced by these techniques. Therefore, in the study, solar radiation, average radiant temperature, wind speed, aspect, etc. The newly developed model approach, which takes into account the variables related to the land cover and was found to be more than 95% reliable in the spatial distribution of thermal comfort conditions (PET), was used (Çağlak 2021). In this method approach, the distribution of PET values is determined by the ArcGIS 10.5 program (demo version) from the Geographical Information Systems

Table 33.4 Human thermal sensation and stress ranges for PET (Matzarakis and Mayer 1999)

PET (°C)	Thermal sensation	Level of thermal stress
<−4.0	Extreme cold	Freezing cold stress
−3.9–0.0	Very cold	Extreme cold stress
0.1–4.0	Moderate cold	Strong cold stress
4.1–8.0	Cold	Moderate cold stress
8.1–13.0	Cool	Cool stress
13.1–18.0	Slightly cool	Slight cold stress
18.1–23.0	**Neutral (comfortable)**	**No thermal stress**
23.1–29.0	Slightly warm	Slight warm stress
29.1–35.0	Warm	Moderate heat stress
35.1–41.0	Hot	Strong heat stress
>41.0	Very hot	Extreme heat stress

Table 33.5 Parameters affecting the spatial distribution of the PET index (Steeneveld et al. 2011; Koopmans et al. 2018, 2020; Perkhurova et al. 2019)

Parameters	Change	PET (°C)
Wind velocity	1 (m/s)	2.50
Mean radiant temperature (mrt)	1 °C	0.6
Elevation	100 (m)	0.5
Solar radiation (time 14:00)	100 (w/m^2)	0.4
Solar radiation (time 07:00)	100 (w/m^2)	1.2

software; altitude, land use, solar radiation, mean radiant temperature (MRT) and wind speed base maps (Table 33.5 and Fig. 33.5). In the method, first of all, PET values of meteorology stations in the field were distributed to the surface using Inverse Distance Weighted (IDW), one of the interpolation techniques. This technique is mostly the preferred method for generating grids by interpolation from sample point data. Then, taking into account the elevation, land cover, wind velocity, mean radiant temperature and solar radiation bases, in Table 33.4, the PET distribution obtained by the IDW technique was recalculated. Then, the values were classified according to the thermal comfort ranges of the PET index. In this calculation, the raster calculator tool in ArcGIS 10.5 software was used. Because the sun's position on the horizon changes throughout the day, the solar radiation base map time of day must be taken into account (Fig. 33.5).

Wind speed maps are arranged as 1.1 m, which constitutes the reference level of the centre of gravity of the human body (Nastos et al. 2013; Nastos and Matzarakis 2019). The wind speed data obtained from the meteorology station was evaluated according to 1.1 m using the following formula (Eq. 33.1).

$$\mathrm{WS}_{1.1} = \mathrm{WS}_h \cdot (1.1/h)^a \tag{33.1}$$

In the equation, $a = 0.12 \cdot z0 + 0.18$;
WS_h: wind speed value measured at altitude (m/s) (usually 10 m).
H: height of the station (usually 10 m).
A: an empirical exponent based on surface roughness.
$z0$: surface roughness length (Troen and Petersen 1989).
The roughness length ($z0$) value was obtained from the European Wind Atlas.

Results

The spatial distribution of the thermal comfort conditions of the city of Van was prepared monthly as mean, maximum and minimum. The distribution of thermal comfort conditions was followed in astronomical seasonal order to explain similar conditions one after another throughout the year.

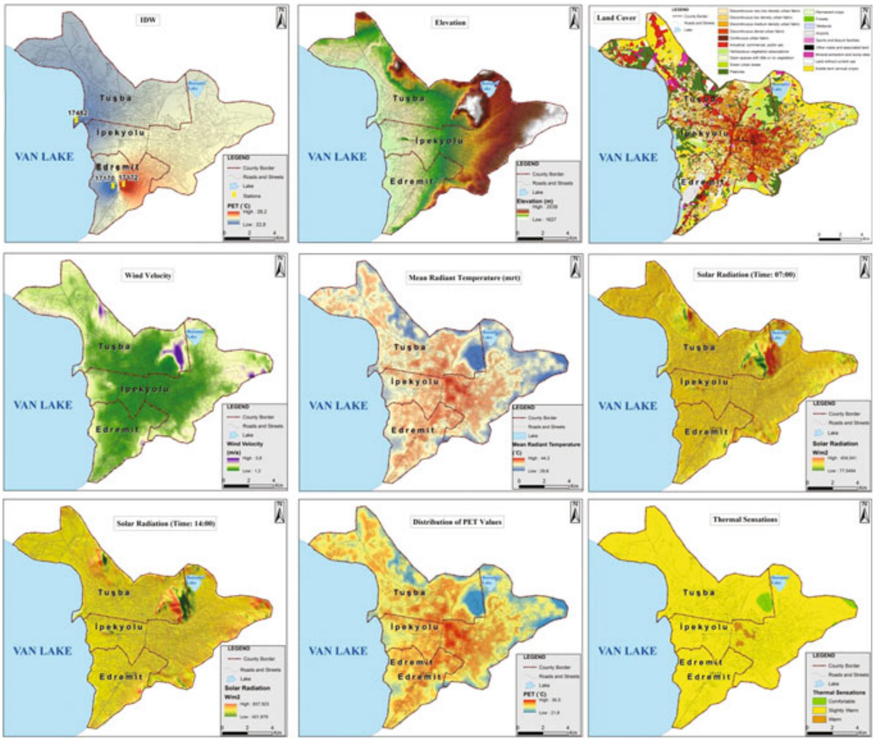


Fig. 33.5 Base maps used in the spatial distribution of thermal comfort conditions

Mean Conditions

According to the distribution of monthly average thermal comfort conditions, in December, 'very cold' stress is perceived in urban areas and 'extreme cold' stress in areas on the periphery of the city. While 'very cold' stress is perceived in the majority of the city in February, 'moderate cold' stress is perceived in densely populated areas in the city, and 'extreme cold' stress is perceived in high areas on the city periphery. In March and November, 'cold' stress is experienced in medium and dense urban areas, 'moderate cold' stress in low-density urban areas and 'very cold' stress in non-residential high areas of the city. While 'cool' stress was dominant in the urban area in April, 'slightly cool' stress was determined in dense and high-rise areas in the city, and 'cold' stress was determined in the hilly area in the Tusba district. While the 'slightly cool' stress is effective in May, 'comfortable' conditions in the densely textured urban area and 'cool' stress in the hilly area of the Tusba district are effective. 'Slightly warm' stress is experienced in the middle and densely textured urban area in June, 'comfortable' conditions on the city periphery and 'slightly warm' stress in the city in July and August, and 'warm' stress is experienced in dense and high-rise buildings in İpekyolu district. While 'comfortable' conditions are dominant in the city in September, 'slightly warm' stress is also seen in dense and high-rise buildings in the İpekyolu district. In October, 'slightly cool' stress is perceived in urban areas and 'cool' stress in urban peripheries (Fig. 33.6).

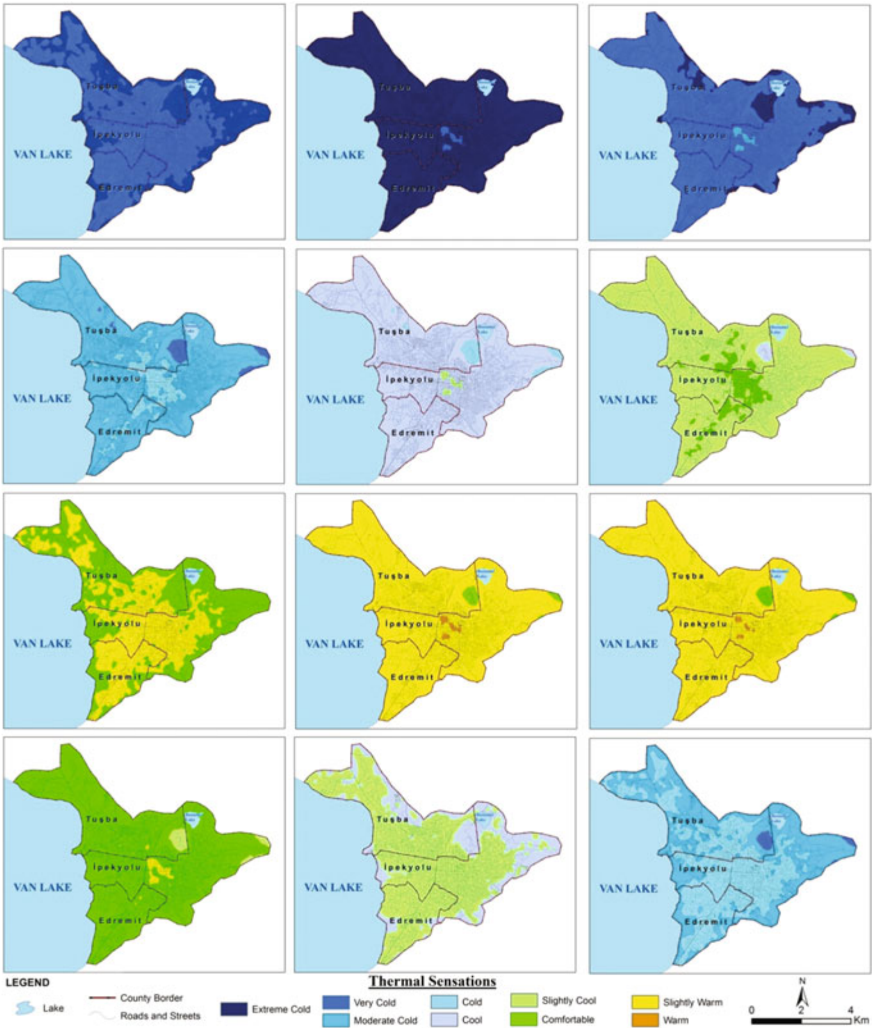


Fig. 33.6 Distribution of monthly average thermal comfort conditions of the city of Van

Maximum Conditions

According to the monthly maximum thermal comfort conditions, 'extreme cold' stress was not determined in any month in Van. In December, 'cold' stress is perceived in medium and densely textured urban areas, and 'moderate cold' stress is perceived in low-density urban areas and city peripheries. In January, 'moderate cold' stress in urban areas and 'very cold' stress in urban peripheries were determined in 'cold' stressed areas. In February, 'cold' stress is experienced in urban areas, 'moderate cold' stress is experienced in urban peripheries, and 'cool' stress is experienced in dense and high-rise buildings. In March and November, the 'cool' stress prevails in the city. In April, 'comfortable' conditions are perceived in the medium and densely textured urban area, while 'slightly cool' stress is perceived in other areas. 'Slightly warm' stress in the urban area in May, 'comfortable' conditions in the city periphery, 'warm' stress in the urban area in June, 'slightly warm' stress in the city periphery and 'hot' stress in the city in July are effective. In August, 'hot' stress is perceived in densely textured urban areas, and 'warm' stress in other areas. Although the 'slightly warm' stress was dominant in the city in September, 'warm' stressed areas were also seen. While 'comfortable' conditions are experienced in the majority of the city in October, 'slightly warm' stress is experienced in the high areas of the city (Fig. 33.7).

Minimum Conditions

According to the minimum thermal comfort conditions, from December to March in the city of Van, 'extreme cold' stress with freezing effects is experienced throughout the field. 'Moderate cold' stress in urban areas in April, 'very cold' stress in urban areas, 'cool' stress in urban areas in May, 'cold' stress in urban areas, 'slightly cool' stress in urban areas in June and 'cool' stress in urban areas were determined. 'Comfortable' conditions in the urban area in July, 'slightly cool' stress in the city periphery, 'comfortable' conditions in the medium and dense urban area in August and 'slightly cool' stress in the low-density urban area and the city periphery were determined. While the 'slightly cool' stress is experienced in the densely textured urban area in September, the 'cool' stress is experienced in other areas. In October, 'cold' stress in urban areas and 'moderate cold' stress in urban peripheries were determined. In November, 'extreme cold' stress is dominant in the city, but 'very cold' stress is effective in dense and high-rise buildings in İpekyolu district (Fig. 33.8).

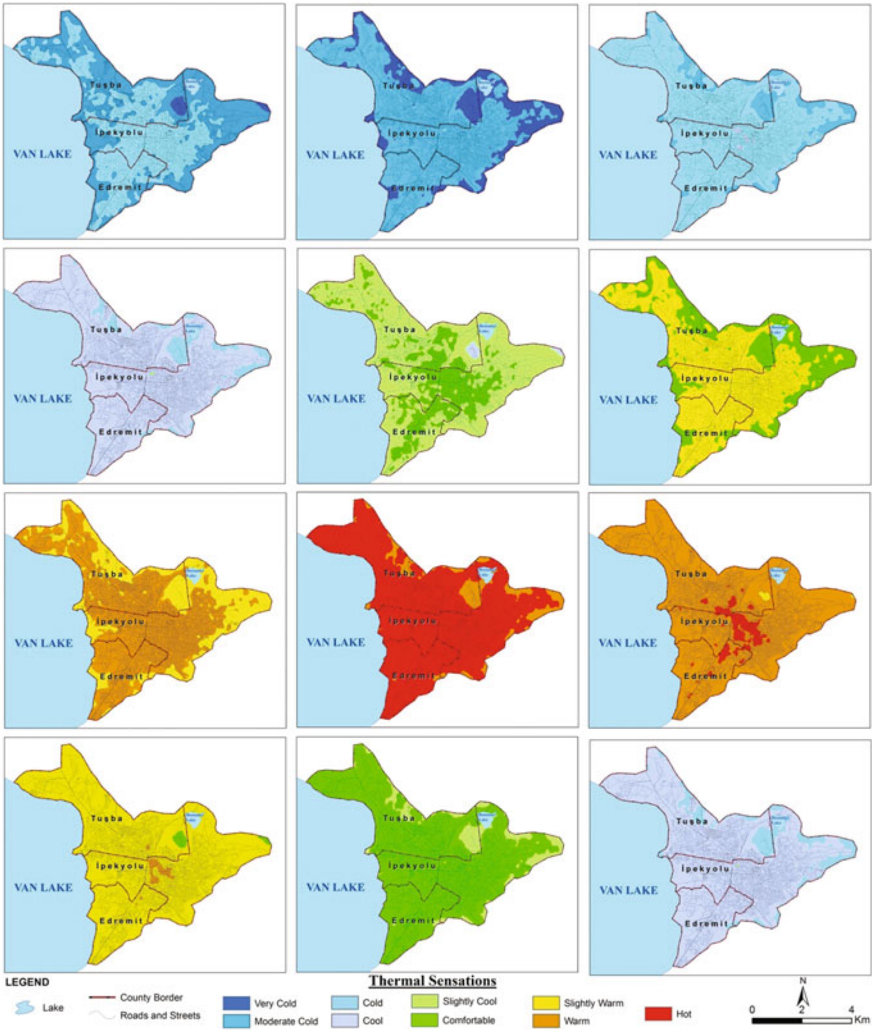


Fig. 33.7 Distribution of monthly maximum thermal comfort conditions of the city of Van

Percentages of Spatial Distributions of Thermal Comfort Conditions

The city of Van, which is the study area, consists of a total area of 133 km^2. According to the areal distributions of the average thermal comfort conditions of this area, ‘extreme cold’ stress is effective for three months in the city, in December, January and February (respectively, 37.6%, 99.1%, 10.7% of the field), and ‘very cold’ stress is effective from November to March (respectively, 1.5%, 1.5% of the field). About

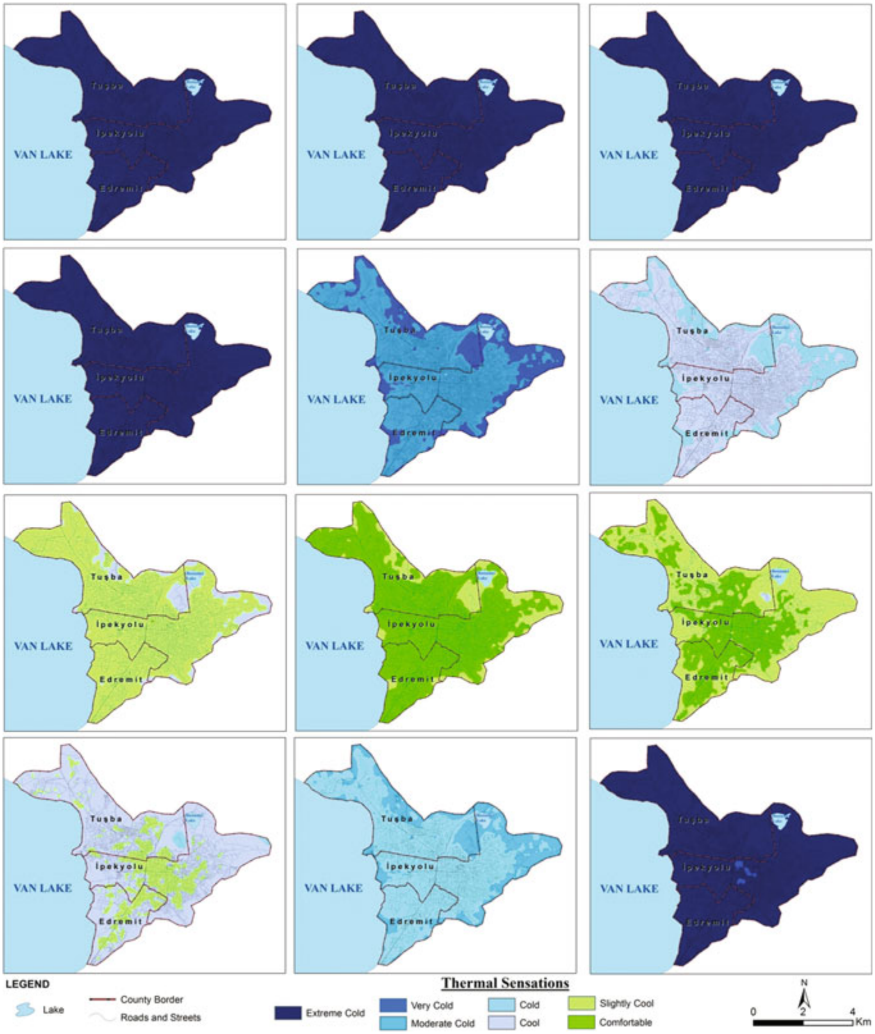


Fig. 33.8 Distribution of monthly minimum thermal comfort conditions of the city of Van

62.4, 0.9, 88.4 and 3.4% were observed to be effective for 5 months. ‘Moderate cold’ stress is in the city during the three months of February, March and November (0.9%, 87.7%, 50.3% of the field, respectively), and ‘cold’ stress is in March, April and November (respectively, 8.8%, % of the field). About 3.4, 48.2% for three months, ‘cool’ stress for three months in April, May and October (95.7%, 1.5%, 26.0% of the field, respectively) and ‘slightly cool’ stress for April, May, September and October months (0.9%, 89.6%, 2.4%, 74.0% of the field, respectively) were determined. ‘Comfortable’ conditions in the city from May to September (respectively, 8.8%, 51.8%, 1.5%, 1.8%, 95.9% of the field) for 5 months and ‘slightly warm’ stress

Table 33.6 Percentages of spatial distributions of monthly mean thermal comfort conditions

Months	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
Extreme cold	99.1	10.7										37.6
Very cold	0.9	88.4	3.4								1.5	62.4
Moderate cold		0.9	87.7								50.3	
Cold			8.8	3.4							48.2	
Cool				95.7	1.5					26.0		
Slightly cool				0.9	89.6				2.4	74.0		
Comfortable					8.8	51.8	1.5	1.8	95.9			
Slightly warm						48.2	97.6	97.7	1.7			
Warm							0.9	0.5				

from June to September (respectively, 48.2% of the field; 97.6%, 97.7%, 1.7%) are experienced for four months, and 'warm' stress is experienced in July (0.9%) and August (0.5%) (Table 33.6).

According to maximum thermal comfort conditions, the city has not experienced any 'extreme cold' stress in any month. 'Very cold' stress in December (1.5%) and January (22.1%), 'moderate cold' stress from December to February (50.3%, 77.8%, 13.1%, respectively) for three months, 'cold' stress from November to March for 5 months (10.7%, 48.2%, 0.1% 86.4%, 8.6%, respectively), 'cool' stress in February, March, April and November (0.5%, 91.4%, 1.0% 89.25%, respectively), 'slightly' 'cool' stress in March, April, October and November (0.1%, 73.1%, 10.7%, 0.05%, respectively) are perceived. 'Comfortable' conditions are in April, May, September and October (25.9%, 30.5%, 1.1%, 89.25%, respectively) for 4 months, 'slightly warm' stress is in May, June, August, September and October (69.5%, 30.5%, 0.1% 97.2%, 0.05%, respectively) for 5 months, 'warm' stress is for four months from June to September (69.5%, 10.7%, 99.3%, 1.7%, respectively), and 'hot' stress is for July (89.3%)) and in August (0.6%) (Table 33.7).

According to the minimum thermal comfort conditions, 'extreme cold' stress was determined in the entire field from December to March (4 months) and in 99.1% of the field in November in the city of Van. 'Very cold' stress is in April (26.0%) and November (0.9%), 'moderate cold' stress is in April, May and October (73.95%, 26.0%, 26.0% of the field, respectively), 'cold' stress is in April, May, in September and October (0.05%, 74.0%, 1.1%, 73.95% of the field, respectively), and 'cool' stress is perceived in May, August, September and October (10.7%, 0.3%, 76.7%, 0.05% of the field, respectively). 'Slightly cool' stress is for four months from June to September (89.25%, 17.2%, 58.1%, 22.2% of the pitch, respectively), and 'comfortable' conditions are from June to August (0.05%, 82.8%, 41.6% of the field, respectively) for three months (Table 33.8).

Table 33.7 Percentages of spatial distributions of monthly maximum thermal comfort conditions

Months	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
Very cold	22.1											1.5
Moderate cold	77.8	13.1										50.3
Cold	0.1	86.4	8.6								10.7	48.2
Cool		0.5	91.4	1.0							89.25	
Slightly cool			0.1	73.1						10.7	0.05	
Comfortable				25.9	30.5				1.1	89.25		
Slightly warm					69.5	30.5		0.1	97.2	0.05		
Warm						69.5	10.7	99.3	1.7			
Hot							89.3	0.6				

Table 33.8 Percentages of spatial distributions of monthly minimum thermal comfort conditions

Months	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
Extreme cold	100	100	100								99.1	100
Very cold				26.0							0.9	
Moderate cold				73.95	26.0					26.0		
Cold				0.05	74.0				1.1	73.95		
Cool						10.7		0.3	76.7	0.05		
Slightly cool						89.25	17.2	58.1	22.2			
Comfortable						0.05	82.8	41.6				

Discussion

Van, one of the developed cities of the Eastern Anatolia Region of Turkey, was established and developed on the shores of Lake Van, which is Turkey's largest lake with its high altitude. The city of Van, which was founded in BC, is growing in terms of population and structure by getting immigrants from the surrounding rural areas day by day.

The thermal comfort conditions of the city of Van were evaluated according to the PET index, and their spatial distribution was explained with GIS. As a result of the study, according to mean PET values, cold stress perceptions were dominant in the city from November to March (five months), and 'slightly warm' and 'warm' stresses were dominant in the summer season. In the transitional seasons (Spring and Autumn), 'slightly cool' stress and 'comfortable' conditions are effective. According to the maximum PET values, 'cool' stress in winter and 'warm' and 'hot' stress in summer are perceived. During the transition seasons, 'slightly warm' stress and 'comfortable' conditions are effective. According to the minimum PET values, 'extreme cold' stress is experienced from November to March (five months), 'slightly cool' stress and 'comfortable' conditions in summer and 'cold' and 'cool' stresses in transition seasons. In addition, Urban Heat Islands were observed in all evaluations (mean, maximum, minimum) depending on urbanisation.

When the findings are compared with the studies in the literature, it has been stated that cold stresses are experienced more and hot stresses are less experienced in Erzurum, which has altitudes close to and close to the city of Van (Toy 2010). This shows that Lake Van has a mild effect on the thermal conditions of the city. Similar findings are similar to those of Sun Moon Lake in Taiwan (Lin and Matzarakis 2008) and Ourmieh Lake in Iran (Farajzadeh and Matzarakis 2012).

Erzurum, (Toy 2010; Çağlak et al. 2022), Ankara (Çiçek 2003; Türkoğlu et al. 2011), Eskişehir, (Toy et al. 2021) where the city centre has negative thermal comfort conditions due to urbanisation.), Samsun, Bolu (Çağlak 2017; Çağlak et al. 2021), Aydın and İzmir (Kestane and Ulgen 2013; Tonyaloğlu 2019). These findings are in Athens, Greece (Charalampopoulos et al. 2013), Munich, Germany (Mayer 1993), Szeged, Hungary (Unger 1999), Cincinnati, USA (Clarke and Bach 1971). It has also been demonstrated in the Polish cities of Warsaw and Łodz (Blażejczyk et al. 2016). In this respect, the results of the study are similar to the studies in the literature.

According to the results, city centres have different thermal comfort conditions depending on urbanisation and lake, etc. It has been observed that the thermal conditions of the cities near the water have slightly milder characteristics.

Conclusion

This study evaluated the thermal comfort conditions of urban areas by taking into account many variables of the land. In this respect, the study has revealed in detail how urban land use affects thermal comfort conditions. Thermal comfort conditions of cities should be calculated by taking into account all climatic parameters. At the same time, the spatial distribution of the obtained values should be done by taking into account all the variables of the land. These studies are guiding decision-makers and planners.

Although the world population is increasing day by day, the majority of the population lives in cities. It is necessary to reduce these negative thermal comfort conditions of cities and to adapt to climate-resistant sustainable cities. In addition, to reduce the impact of climate change and prevent climate change, anthropogenic greenhouse gas emissions must be reduced very quickly and effectively. To reduce these negative thermal conditions of cities and to adapt to climate-resistant sustainable cities, environments such as green spaces, city parks, green building designs and water surfaces should be increased in urban areas. In addition, when the green areas are distributed evenly in the urban area, the 'fresh air' air circulation of the city will also be positively affected. Urban design and planning should be done from a geographical perspective (taking into account human, biotic and physical environmental conditions) to reduce the negative thermal conditions of cities and for sustainable healthy cities.

References

Aboubakri O, Kahnjani N, Jahani Y, Bakhtiari B (2020) Thermal comfort and mortality in a dry region of iran, kerman; a 12-year time series analysis. Theoret Appl Climatol 139:403–413. https://doi.org/10.1007/s00704-019-02977-8

Anderson BG, Bell ML (2009) Weather-related mortality: how heat, cold, and heat waves affect mortality in the United States. Epidemiology 20:205–213. https://doi.org/10.1097/EDE.0b013e318190ee08

Blażejczyk K, Kuchcik M., Dudek W, Kręcisz B, BLażejczyk A, Milewski P, Szmyd J, PaLczyński C (2016) Urban heat ısland and bioclimatic comfort in Warsaw. In: Musco F (ed), Counteracting urban heat Island effects in a global climate change scenario, pp 305–321. https://doi.org/10.1007/978-3-319-10425-6_11

Blazejczyk K, Baranowski J, Blazejczyk A (2018) Climate related diseases. Current regional variability and projections to the year 2100. Quaestiones Geographicae 37(1): 23–36

Bölük E (2016) Turkish climate according to Köppen climate classification. MGM Publications, Ankara. https://www.mgm.gov.tr/FILES/iklim/iklim_siniflandirmalari/koppen.pdf

Charalampopoulos I, Tsiros I, Sereli AC, Matzarakis A (2013) Analysis of thermal bioclimate in various urban configurations in Athens, Greece. Urban Ecosyst 16:217–233. https://doi.org/10.1007/s11252-012-0252-5

Clarke JF, Bach W (1971) Comparison of the comfort conditions in different urban and suburban microenvironments. Int J Biometeorol 15:41–54

Çağlak S (2017) Investigation of samsun's bioclimatic comfort conditions and the effect of urbanization on bioclimatic comfort conditions.(Unpublished Master's Thesis) Ondokuz Mayıs University/Social Sciences Institute, Department of Geography, Samsun

Çağlak S (2021) Effects and possible consequences of climate change on bioclimatic comfort conditions. Doctoral Thesis. Ondokuz Mayıs University

Çağlak S, Aydemir KPK, Kazancı G (2021) Effects of urbanization on bioclimatic comfort conditions Bolu example. City Health J 2(2):47–55

Çağlak S, Toy S, Esringü A (2022) An approach to evaluate the effects of cities on bioclimatic conditions: the sample of Erzurum city. J Kesit Acad 8(31):220–239

Çalışkan O (2012) Analysis of Turkey's bioclimatic conditions and ınvestigation of the effect of urbanization on bioclimatic conditions on Ankara scale. Doctoral Thesis. Ankara University

Çiçek İ (2003) The effect of urbanization on bioclimatic conditions in Ankara. In: Prof. Dr. Climatology Workshop in Memory of Sirri Erinç 2002, 11–13 April 2002, Ege University. Ed. fac. Arrow. No:121: 145–157

Çiçek İ, Doğan U (2005) Investigation of the city heat Island in Ankara. J Geog Sci 3(1):57–72

de Freitas CR, Grigorieva EA (2015) A comprehensive catalogue and classification of human thermal climate indices. Int J Biometeorol 59:109–120

Driscoll DM (1992) Thermal comfort ındexes. Current uses and abuses. Nat Weather Digest 17(4): 33–38

Daneshvar MRM, Bagherzadeh A, Tavousi T (2013) Assessment of bioclimatic comfort conditions based on physiologically equivalent temperature (PET) Using the RayMan model in Iran. Central Eur J Geosci 5:53–60

Epstein Y, Moran DS (2006) Thermal comfort and the heat stress indices. Ind Health 44:388–398

Eriçok AK (2019) Investigation of the urban tourism possibilities of the city of van in the context of globalization. J Soc Sci Inst 44:171–191

Fallah Ghalhari G, Mayvaneh F (2012) Effect of air temperature and universal thermal climate index on respiratory diseases mortality in Mashhad Iran. Arch Iran Med 19(9):618–624
Farajzadeh H, Matzarakis A (2012) Evaluation of thermal comfort conditions in Ourmieh Lake, Iran. Theor Appl Climatol 107: 451–459. https://doi.org/10.1007/s00704-011-0492-y
Fröhlich D, Gangwisch M, Matzarakis A (2018) Effect of radiation and wind on thermal comfort in urban environments—application of the RayMan and SkyHelios model. Urban Clim 27:1–7
Gulyas A, Unger J, Matzarakis A (2006) Assessment of the micro climatic and human comfort conditions in a complex urban environment: modelling and measurements. Build Environ 4:1713–1722
Haldane JS (1905) The influence of high air temperature. J Epideomology Infect 5(4):494–513
Heberden W (1826) An account of the heat of July 1825, some remarks on sensible cold. Phil Trans 2:69–75
Houghton FC, Yaglou CP (1923) Determining equal comfort lines. J Am Soc Heat Vent Engrs 9:165–176
Höppe P (1999) The physiological equivalent temperature—a universal index for the biometeorological assessment of the thermal environment. Int J Biometeorol 43:71–75
Huang F, Zhao A, Chen RJ, Kan HD, Kuang XY (2015) Ambient temperature and outpatient visits for acute exacerbation of chronic bronchitis in Shanghai: a time series analysis. Biomed Environ Sci 28:76–79. https://doi.org/10.3967/Bes2015.008
Kestane Ö, Ülgen K (2013) Determination of bioclimatic comfort zones for İzmir Province. Süleyman Demirel Univ J Tech Sci 5(3):18–25
Ketterer C, Matzarakis A (2016) Mapping the physiologically equivalent temperature in urban areas using artificial neural network. Landsc Urban Plan 150:1–9
Koopmans S, Ronda R, Steeneveld GJ, Holstlag AM, Tank AMG (2018) Quantifying the effect of different urban planning strategies on heat stress for current and future climates in the agglomeration of the Hague (The Netherlands). Atmosphere 9(3):1–20
Koopmans S, Heusinkveld G, Steeneveld GJ (2020) A standardized physical equivalent temperature urban heat map at 1-M spatial resolution to facilitate climate stress tests in The Netherlands. Build Environ 181:1–13
Koyuncu B, Karakılçık Y (2019) A theoritical study on administrative problems of Van Lake watershed. Mehmet Akif Ersoy Univ J Soc Sci Inst 11(27):170–187. https://doi.org/10.20875/makusobed.515600
Landsberg HE (1972) The assessment of human bioclimate, a limited review of physical parameters. World Meteorological Organization, Technical Note No. 123, WMO-No. 331, Geneva
Lerner D (1964) The passing of traditional society modernizing the middle east. The Free Press, New York
Lin TP, Matzarakis A (2008) Tourism climate and thermal comfort in Sun Moon Lake, Taiwan. Int J Biometeorol 52:281–290. https://doi.org/10.1007/s00484-007-0122-7
Matzarakis A, Mayer H, Iziomon MG (1999) Applications of a universal thermal ındex: physiological equivalent temperature. Int J Biometeorol 43:76–84
Matzarakis A, Rutz F, Mayer H (2000) Estimation and calculation of the mean radiant temperature within urban structures. In: de Dear RJ, Kalma JD, Oke TR, Auliciems A (eds) Biometeorology and urban climatology at the turn of the millenium, Selected Papers from the Conference ICB-ICUC'99, Sydney, WCASP-50, WMO/TD No. 1026, pp 273–278
Matzarakis A, Rutz F, Mayer H (2007) Modelling radiation fluxes in simple and complex environments—application of the RayMan model. Int J Biometeorol 51:323–334
Matzarakis A, Rutz F, Mayer H (2010) Modelling radiation fluxes in simple and complex environments—basics of the RayMan model. Int J Biometeorol 54:131–139
Mayer H (1993) Urban bioclimatology. Experientia 49:957–963
Nastos TP, Matzarakis A (2011) The effect of air temperature and human thermal indices on mortality in Athens, Greece. Theor Appl Climatol 3(4):591–599

Nastos PT, Giaouzaki KN, Kampanis NA, Matzarakis A (2013) Acute coronary syndromes related to bio-climate in a Mediterranean area. The case of IeraTHIra, Crete Island, Greece. Int J Environ Health Res 23(1):76–90

Nastos PT, Matzarakis A (2019) Present and future climate—tourism conditions in Milos Island, Greece. Atmosphere 10(3):97–107

Oke TR (1973) City size and the urban heat island. Atmos Environ 7(8):769–779

Oke TR (1981) Canyon geometry and the nocturnal urban heat island: comparison of scale model and field observation. J Climatol 1:237–254

Olgyay V (1973) Design with climate, bioclimatic approach to architectural regionalism. Princeton University Press, New Jersey

Parsons KC (2003) Human thermal environments: the effects of hot, moderate, and cold environments on human health, comfort and performance. Taylor & Francis, London, New York

Parsons K (2014) The effects of hot, moderate, and cold environments on human health, comfort, and performance, 3rd edn. CRC Press, Singapore. ISBN 9781466595996

Perkhurova AA, Konstantinov PI, Varentsov MI, Shartova NI, Samsonov TE, Krainov VN (2019) Real-time microscale modeling of thermal comfort conditions in Moscow Region. IOP Conf Ser: Earth Environ Sci, 386: 1–8

Scherber K, Langner M, Endlicher W (2014) Spatial analysis of hospital admissions for respiratory diseases during summer months in Berlin taking bioclimatic and socio-economic aspects into account. DIE ERDE—J Geog Soc Berlin 144(3–4):217–237. https://doi.org/10.12854/erde-144-16

Steeneveld GJ, Koopmans S, Heusinkveld BG, Hove LWA, Holstlag AAM (2011) Quantifying urban heat island effects and human comfort for cities of variable size and urban morphology in The Netherlands. J Geophys Res 116:1–14

Sungur KA (1980) An essay on monthly distribution of suitable and unsuitable heat values for human life in Turkey. J Istanbul Univ Inst Geogr 23:27–36

Tonyaloğlu EE (2019) The evaluatıon of the ımpact of urbanısatıon on urban thermal envıronment in the case of Aydın. Turk J Landscape Res 2(1):1–13

Toy S (2010) Investigation of Eastern Anatolia region recreational areas in terms of bioclimatic comfort values. (Unpublished PhD Thesis), Atatürk University/Institute of Science and Technology, Department of Landscape Architecture, Erzurum

Toy S, Çağlak, S, Esringü A (2021) Assessment of bioclimatic sensitive spatial planning in a Turkish City, Eskisehir. Atmosfera. Early Onlıne Release. https://doi.org/10.20937/ATM.52963

Troen I, Petersen E (1989) European wind atlas. National Laboratory Roskilde, ISBN 87-550-1482-8

Türkeş M, Erlat E (2017) A scientific evaluation of changes and trends observed in the world and Turkey in extreme weather and climate events. In Ucal M (ed), Climate change and the green dimension: green economy, green growth, pp 5–38. Heinrich Böll Stiftung Association Turkey Representative, Istanbul

Türkoğlu N, Çalışkan O, Çiçek İ, Yılmaz E (2011) The analysis of impact of urbanization on the bioclimatic conditions in the scale of Ankara. Int J Hum Sci 9(1):932–955

Unger J (1999) Urban-rural air humidity differences in Szeged, Hungary. Int J Climatol 19(13):1509–15015

Part V
Urban Governance, Smart Solutions, and Sustainable Cities

Chapter 34
The Application of Geospatial Artificial Intelligence, Geo Internet of Things and Geostatistical Visual Analytics for Urban Recovery Planning and Management Due to the Eruption of Mount Semeru, Indonesia

Adipandang Yudono, Herry Santosa, Sukir Maryanto, Sujarwo, Nurjannah, Nurul Sri Rahatiningtyas, and Osmar Shalih

Abstract Disaster management essentially encompasses measures for safeguarding people from disasters and reducing the possibility of hazards arising. On 4 December 2021, Semeru Volcano experienced increased volcanic activities and produced hot clouds and lava with a sliding distance of up to 16 km towards Besuk Kobokan in the southeast sector, resulting in human casualties and damage to property and infrastructure. The hot cloud bed and shouts on 4 December 2021 expanded to the Supiturang and Sumberwuluh villages, 11–16 km from the summit. The assessment was carried out by aerial photography using drones. Furthermore, due to the vast affected

A. Yudono (✉)
Department of Urban and Regional Planning, Brawijaya University, Malang, Indonesia
e-mail: Adipandang@ub.ac.id

H. Santosa
Department of Architecture, Brawijaya University, Malang, Indonesia
e-mail: herrysantosa@ub.ac.id

S. Maryanto
Department of Geophysics, Brawijaya University, Malang, Indonesia
e-mail: sukir@ub.ac.id

Sujarwo
Department of Agribusiness, Brawijaya University, Malang, Indonesia
e-mail: sujarwo@ub.ac.id

Nurjannah
Department of Statistics, Brawijaya University, Malang, Indonesia
e-mail: nj_anna@ub.ac.id

N. S. Rahatiningtyas
Department of Geography, University of Indonesia, Depok City, Indonesia
e-mail: nurul.sr@ui.ac.id

O. Shalih
National Disaster Management Authority (BNPB-RI), Bogor, Indonesia

U. Chatterjee et al. (eds.), *Urban Commons, Future Smart Cities and Sustainability*, Springer Geography, https://doi.org/10.1007/978-3-031-24767-5_34

coverage area and limited human and financial resource from the authorities, the damage and loss assessment processes adopted the geospatial artificial intelligence method in detecting rapidly damaged urban facilities. To facilitate communication among stakeholders for a rapid response, this study utilised the Internet of Things method for urban recovery planning and management. At the end of the activity, a smart emergency dashboard was built to support decision-making by the local and national governments. This study showed that the use of GeoAI, IoT and geostatistical visual analysis accelerates evacuation processes compared to conventional methods for minimising the number of disaster victims.

Keywords Disaster management · Urban recovery planning and management · Geospatial artificial intelligence · Internet of Things · Geostatistical visual analytics

Introduction

Urban planning management is carried out based on an understanding of the potential and limitations as well as sustainable development based on socio-economic activities in a space where humans live, along with nature conservation activities in the future (Hall 2002). So, ideally, land for development with environmental conservation needs to be defined holistically at the level of the spatial planning system at all levels of government from the national level to the local government and vice versa.

In the process of urban planning and management, various aspects of human interaction involving political, social, economic, historical and cultural goals can be understood through maps or spatial visualisation, because these media can describe abstract phenomena into visual images (Dühr 2007; Stephenson 2010). Furthermore, spatial visualisation can minimise potential conflicts in spatial planning activities (Healey 1997), setting the planning agenda (Forester 1982) and collaborating with all stakeholder perspectives in spatial planning activities (Robbins and Cullinan 1997).

Spatial planning activities that pay attention to nature conservation cannot be separated from the context of disaster mitigation. Disaster mitigation plays a significant factor in minimising the number of victims and impacts of a disaster. Disaster mitigation can work well if applying the applicable disaster management. A disaster can be defined as 'an event or series of events that threatens and disrupts people's lives and livelihoods impacted, either by natural factors and/or non-natural factors as well as human factors, resulting in human casualties, environmental damage, property losses, and psychological impact'.

A disaster can occur if there are two main aspects, which are the hazard itself and the vulnerability of people's lives. If a community's social structure is damaged but does not experience vulnerability, it indicates that the community is able to overcome the disaster. However, if a community is harmed and experiencing vulnerability, then the community is experiencing a disaster. A disaster can occur if disaster management in a community is lacking so that it can harm the community itself. The loss itself depends on the resilience of society. In short, the risk of disaster can be formulated as follows (Wisner et al. 2004; Shahid and Behrawan 2008).

$$\left[\textbf{Risk} = \textbf{Hazard} \times \textbf{Vulnerability}\right]$$

Indonesia is known as a ring of fire country, which means that its position is in a volcanic circle. The ring of fire zone was formed due to the movement of three active plates flanking the Indonesian archipelago. One of the catastrophic impacts caused by the ring of fire zone is a volcanic eruption. According to records from the Center for Volcanology and Geological Hazard Mitigation (2021), Indonesia has 127 active volcanoes that continuously erupt. In East Java alone, there are about 7 active volcanoes of type A that must be monitored continuously, one of which is Mount Semeru (Fig. 34.1).

Based on historical records, the eruptions produced by Mount Semeru have been frequent since 1818, where recording is carried out every 3–4 h each day with vulcanian and strombolian types of eruption. The eruption of Mount Semeru is characterised by an explosive eruption that destroys the dome, and there is a presence of lava tongues that have formed in previous eruptions. Furthermore, the occurrence of strombolian-type explosions was characterised by the development of fresh domes and the growth of lava tongues. During an explosive eruption, the visible phenomenon is the flow of volcanic ash rains flowing into the valleys. Currently, based on the monitoring of the Indonesian Geological Agency, the direction of the lava of Mount Semeru is to the southeast at the upstream of Besuk Kembar, Besuk Bang, Besuk Kobokan (PVMBG 2021). In December 2021, Mount Semeru experienced a powerful eruption that claimed human lives (PVMBG 2021). A total of 46

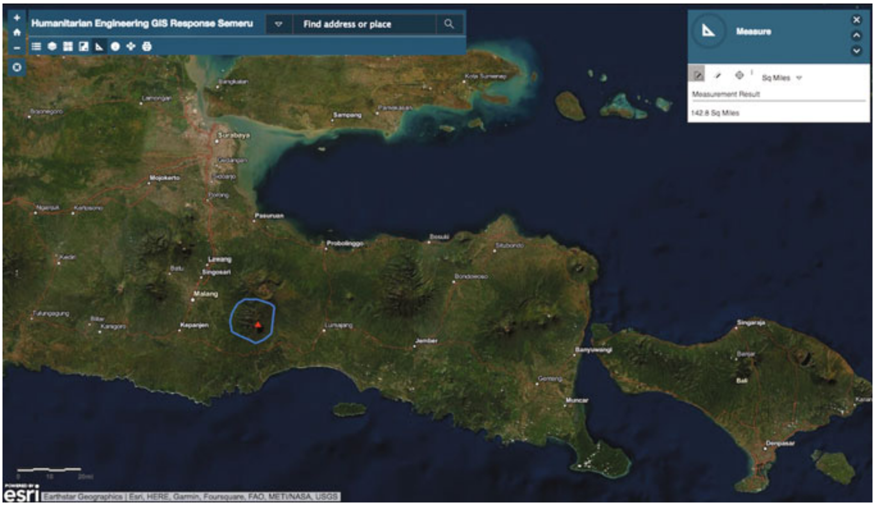


Fig. 34.1 Map of the location of Mount Semeru marked in the blue circle. *Source* Created by Researchers, 2021

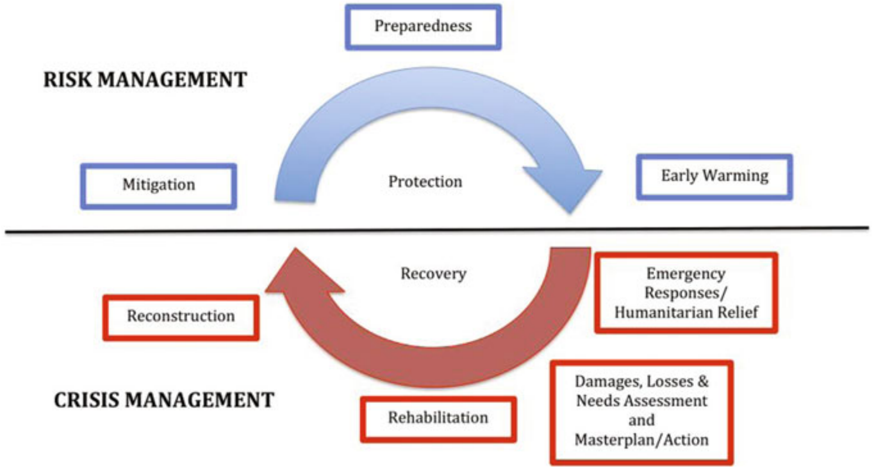


Fig. 34.2 Disaster management scheme. *Source* Lemmens, M, 2006

people were identified as victims of Mount Semeru's hot clouds, and 9 people are still in the search stage (BNPB 2021).

The high number of casualties and losses, both material and non-material, signifies that Indonesia still needs to improve its governance performance in terms of disaster management. Disaster management is basically the act of preventing the community from disasters and reducing the possibility of hazards arising. Disaster management itself can be applied to 5 basic models (Fig. 34.2), namely:

1. Disaster management continuum model, which includes the following stages: emergency, relief, rehabilitation, reconstruction, mitigation, preparedness and early warning.
2. Pre-, during and post-disaster model, which involves activities carried out before the disaster, during the disaster and after the disaster.
3. Contract-expand model, which emphasises more the emergency and relief stage in Model 1.
4. The crunch and release model, which emphasises efforts to reduce vulnerability to overcome disasters. If the community is not vulnerable, the disaster will also less likely occur even though the hazard still takes place.
5. Disaster risk reduction framework that emphasises disaster management efforts on identifying disaster risks in the form of vulnerabilities and hazards and developing the capacity to reduce these risks.

The development of science and technology as part of the Industrial Revolution 4.0 has discussed the field of disaster, with one of its implementations being the concept of artificial intelligence, or AI. The implementation of AI, as well as other concepts such as big data and cloud computing, is an effective way to support disaster risk reduction through technological innovation (Pribadi et al. 2021).

The application of AI as done by Prasetio et al. (2012) used the Strategic Environmental Assessment (SEA) framework with the Spatial Multi-Criteria Evaluation (SMCE) method to create various types of geospatial analysis in determining flood-safe areas in Padang City. The use of ICT in improving the disaster resilience of rural communities was carried out by Firdhous and Karuratane (2018) by optimising the use of social media and big data, resulting in an effective decision system in the stages of prevention, mitigation and preparedness.

Another study by Inan et al. (2018) used a Decision Support System (DSS) with a Meta Object Facility (MOF) mechanism with the output in the form of a work system mechanism pre-disaster and during the disaster. In addition, there is Knowledge Management for Earthquake Resilient Infrastructure System (KERIS), which was used by Pribadi et al. (2021) to support efficient and effective coordination of multi-level and multi-sectoral parties in earthquake disaster mitigation.

Meanwhile, to optimise mitigation measures and state resilience to disasters, the Community Resilience Cost Index (CRCI) is used. Through CRCI, direct and indirect losses and vulnerabilities from various sectors can be identified (Yu et al. 2016). The studies conducted so far are in the form of partial advancement of technology in disaster risk reduction, and there were seldom combinations of the use of technological advancement in disaster management. To fill this gap, this study was conducted to explore the combination of advancements in geospatial technology in managing disasters effectively and efficiently.

Research Framework

The main objective of this study is to explore advancements in geospatial technology to create urban recovery, planning and management as an answer to the eruption of Mount Semeru, Indonesia. This framework considers geospatial artificial intelligence for rapid object detection for settlements through aerial imageries, Geo Internet of Things for collecting massive information to support emergency support systems and geostatistical visual analytics to select the prioritised urban recovery planning and management actions by the decision-makers.

Many studies have been carried out concerning the disaster management area with partial steps, such as by only considering AI or IoT. Therefore, this study attempts to merge different advancements in geospatial technological methods to create a quick response to urban recovery planning and management through three major steps in the framework, namely:

- Step 1: GeoAI for rapid object detection for settlements before and after the eruption
- Step 2: GeoIoT for collecting massive information correlating with emergency situations
- Step 3: Geostatistical visual analytics to select the prioritised urban recovery planning and management (See Fig. 34.3).

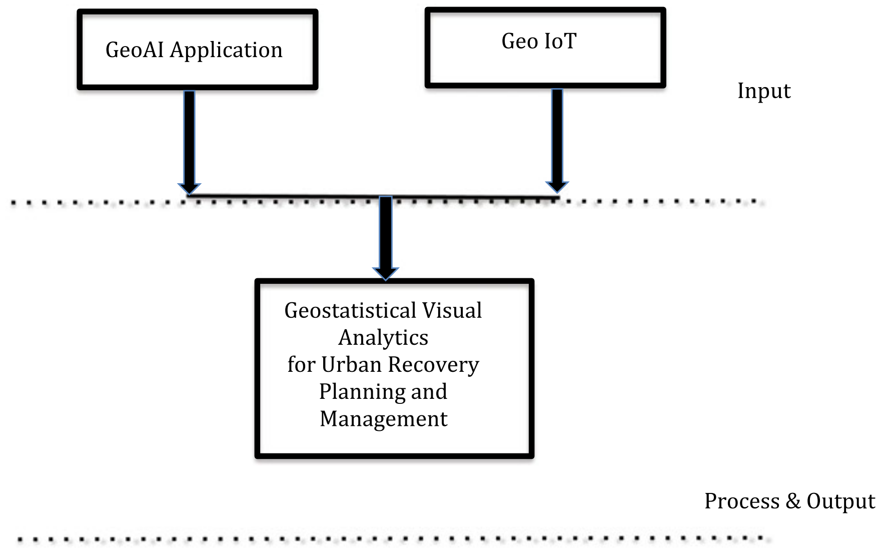


Fig. 34.3 Research framework. *Source* Created by Researchers, 2022

The Role of Geospatial Information and Technology in Urban

To figure out how to bridge the context of urban planning and management with disaster management, it is necessary to have data that provides a visual geographic picture that includes both contexts, and, for that reason, spatial data is needed. Spatial data plays a role in spatial planning by presenting thematic geospatial information and analysis at all planning and development hierarchies (Vincent 2008). Moreover, geospatial data and information are essential for encouraging planning consideration in assisting the creation of general agreements on planning agendas (Campbell and Masser 1995). Currently, geospatial data and information are used to establish correspondence with all stakeholders (i.e. government, private sectors and communities) concerned in planning proposals to decide on the planning implementation of a local geographic area (Dühr 2007).

As Vincent (2008) alludes to, geospatial information is comprised in spatial planning in two ways:

1. Geospatial data and information as an illustration of an area, which can notify the public who places an interest in planning projects by visualising the project in a 3D format as a beneficial capital in decision-making.
2. Geospatial data and information can demonstrate the spatial planning issues of all participants and assist them to be wise of the long-term future spatial consequences of their current public consensus.

In addition, Haque (2001) discusses that geospatial data and information have crucial points for governance processes in three approaches:

1. Geospatial data and information contribute substantial information for addressing land conflicts that have an impact on local government tax revenues.
2. Sympathetic data and information can present the characteristics of the socio-economic population on a map that provides an overview of the condition of local governments in proposing development costs to the central government.
3. By highlighting detailed and trustworthy socio-economic geographic data and analysis using maps and charts, resulting from GIS applications, decision-makers can take crucial decisions to determine planning programs and planning regulations.

As significant factors in planning, geospatial visualisation and geospatial information can assist in achieving spatial planning consensus by identifying pertinent spatial issues, corresponding strategic planning reports and commencing planning programs by the government at various administrative levels, as well as in the private sector and among neighbourhoods (Dühr 2007). Geospatial visualisation has an essential contribution in accommodating various perspectives of authorities so that planning objectives can be achieved from the national level to the local level.

The study of geospatial information has a very broad scientific context, including the production and management of geospatial data and information. Production and management activities in general can be obtained through two approaches, namely the top-down approach and the bottom-up approach. The top-down approach in the form of production and management of geospatial information carried out by the government is then disseminated among governments with different levels of authority and the community. In other words, a series of production activities and the management of geospatial data and information from the government to the community are also known as spatial data infrastructure. Meanwhile, the bottom-up approach is in the form of producing and managing geospatial information carried out by the community for their own circles, but it is possible that the government will use it in making decisions. In other words, the series of production and management activities of geospatial data and information from the community or between communities, even to limited use by the government, is called Volunteered Geographic Information (VGI).

Furthermore, regarding the connectivity of spatial data openness and spatial planning related to the current issues occurring in Indonesia regarding disasters, this chapter will examine the role of crowdsourcing geographic information in an effort to restore urban area planning after the eruption of Mount Semeru in Indonesia using Geospatial Internet of Things and visual geostatistical analytics.

GeoAI

Geospatial artificial intelligence is a new term that has become widely known since 2017 when the Association of Computing Machinery (ACM) held an international seminar titled 'International Workshop on GeoAI: AI and Deep Learning for Geographic Knowledge Discovery at the inauguration of the Special Interest Group on Spatial Information or SIGSPATIAL' (VoPham et al. 2018).

The term geospatial artificial intelligence is further defined by VoPham et al. 2018, as:

> '… a scientific discipline that combines innovations in spatial science, artificial intelligence methods in machine learning (e.g. deep learning), data mining, and high-performance computing to extract knowledge from spatial big data'.

According to the definition above, geospatial artificial intelligence (abbreviated: GeoAI) is a multidisciplinary field of science that is the result of the merger of several fields of science, including spatial science, data mining, artificial intelligence and high-performance computing. The main goal of GeoAI is to extract knowledge from spatial big data. The interesting thing is that the field of geospatial artificial intelligence emerged at the right time when several supporting technologies have reached a high level of progress, such as deep learning as a branch of AI, computer-based Graphics Processing Units (GPU) and big data analytics based on a distributed computing framework. Thus, the technology becomes an enabler and reinforcer of the development of AI methods in the field of large-scale geospatial data analysis.

A large number of study reports in the last five years show that the field of GeoAI is developing rapidly thanks to the support of various parties, for instance, academia, professional associations/communities and industry. The results of research in the field of GeoAI have produced, among others: (i) a number of large-scale remote sensing data that can be used as research materials, (ii) large-scale remote sensing data analysis methods based on deep learning that have been published in various scientific journals and (iii) technology for analysing spatial big data has now become a part of the Geographic Information System (GIS) software system.

Remote sensing data processing such as semantic segmentation and object segmentation is two functions of Geographic Information Science (GIS) in which deep learning technology as a branch of artificial intelligence can be applied.

Geospatial Internet of Things (GeoIOT)

Internet of Things (IoT) technology is a cyber-physical system or a network of networks consisting of many objects/things and sensors that are connected to each other in a very large internet network and are used as a means to stream data generated by sensors/things. Through IoT, data will be collected, exchanged and analysed to obtain valuable information related to the relationship between these things.

A 'thing' is a connection item or body that can associate soon or through a connection portal to the internet. It demonstrates a connection paramount for the IoT viewpoint in which an array of the network of 'things' can make correspondence with one another to transport new functions and facilities (Atzori et al. 2010), contrary to the connection item viewpoint, which focuses on the transmission devices used. The IoT can be examined from a genuine thing-fundamental viewpoint in which the facilities accomplice with the things are critical. These facilities will be responsible for managing the big data collected by smart items or 'things' as an outcome of communication with the surroundings.

In general perspectives, the description of the concept 'thing' is vast and contains a broad range of physical matters: (i) personal gadgets such as tablets, smartphones and smartwatches are an illustration of the matters; (ii) regular items and appliances in daily habit, for example vehicles, lights, microwaves and doors are an illustration of these items; (iii) alternative identifiable items equipped with quick response (QR) codes, near-field communication (NFC) or radio frequency identification (RFID) tags are examples of these items; (iv) items equipped with mini microcontrollers are examples of these items.

There is no concession among academics regarding 'thing' because of the variety of technological devices. Various international standardisations of items and organisations have suggested definitions, which lead to differing perceptions of things and IoT concepts that sometimes alter only slightly. As a result, each academician may have a different interpretation to describe the IoT and things.

The Institute of Electrical and Electronics Engineers (IEEE) defines a thing as an item with programmable prospects. Furthermore, IEEE interprets that things are guided by two specific features:

1. Things may correspond technologically.
2. Things may integrate into existing connected circumstances.

For implementing the network performance, microcontrollers such as Raspberry Pi, Arduino and PCDuino can be used in real cases.

The European Research Cluster on The Internet of Things (IERC) defines a thing as 'physical and virtual items with identities, physical attributes, virtual personalities, and smart user interfaces that are seamlessly integrated into the information network'. (IERC 2014).

The ITU describes IoT as 'a worldwide infrastructure for the information communities, contributing sophisticated facilities by linking things (physical and virtual) that developed on existing and thriving applicable information and transmission technologies' (ITU-T 2012). Furthermore, ITU demonstrated Adapted IoT with three independent dimensions, which are thing, time and place (See Fig. 34.4).

The goal of geospatial information is to replicate the real world within the digital atmosphere. Myriad attempts have been made to discover and capture the earth from space as well as from the ground using in situ sensors. In the last statement, advancements in geospatial information technology have closed significant scientific gap by utilising these sensors and their networks with the help of geographic position as a key component.

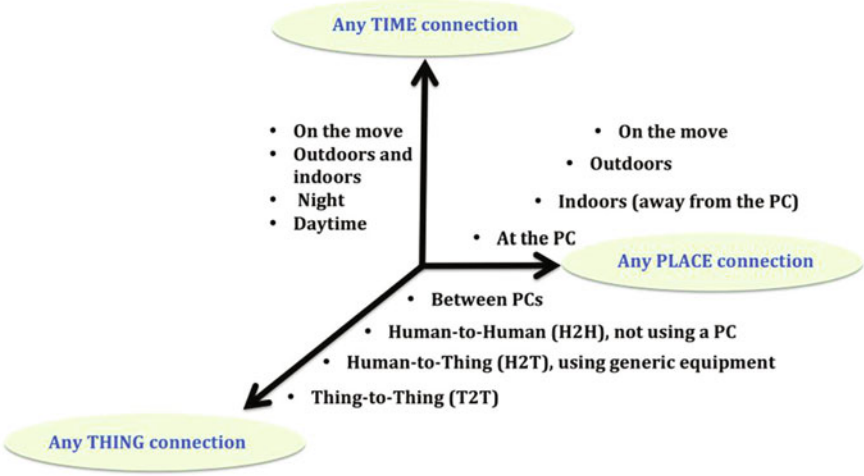


Fig. 34.4 Dimensions of the IoT. *Source* (ITU 2012)

Considerable geographic pictures have been transformed into digital data over the last two decades to be analysed and visualised through digital tools, like virtual globes (Butler 2006). The traditional geospatial information encompasses the following functions:

1. Geospatial data acquisition.
2. Spatial analysis for understanding spatial patterns.
3. Geospatial modelling and simulation.

(Lü et al. 2019)

In terms of the current geospatial technological trend, these functions help to fill scientific gaps. In this case, the researchers are bridging the gap between Geographic Information (GI) and IoT. Furthermore, the researchers will examine each of the traditional geospatial technology correlating with IoT in the next paragraphs.

To begin, geospatial data acquisition is a critical function in the Internet of Things because things and smart devices discover and capture earth phenomena in order to collect substantial measurements. The discoverability of things and the correspondence of capturing geospatial data become intensely significant for data acquisition through the IoT viewpoint. The ability to discover and capture, the two main capabilities of things, is the fundamental mechanism for providing data on earth phenomena, which are then transformed into geospatial information.

Furthermore, geospatial analysis and geospatial statistics are well-known geospatial methods for investigating the patterns, distributions and relationships of the earth's behaviours (Worboys and Duckham 2004; de Smith et al. 2018). Analytical methods are an important step for examining earth phenomena. Furthermore, in the current trends, analyses during the occurring event or real time and cloud computing lead to the shift of massive analytical power to devices, allowing captured data to be processed directly on gadgets. This trend suggests that analytical items in the IoT will have a significant impact on geospatial information.

The latest geospatial modelling and simulations are needed to investigate both physical and social earth phenomena in order to achieve a new scientific insight and knowledge to create effective and efficient action for decision-makers. Understanding spatiotemporal behaviours and then creating modelling and simulations will aid in the construction of a detailed yet broad picture of the complex and multidimensional relationships that take place in the existing world.

Geostatistical Visual Analytics in the Dashboard

Visualisation aims to facilitate observation and provide more understanding of phenomena. Geospatial information or visualised spatial data is better known as geovisualisation. Geovisualisation is a term used in the field of cartography as a tool or method that supports geospatial data analysis using visualisation methods. According to Kraak (2003), geovisualisation is the use of geospatial data display that is useful for various purposes, such as data exploration in making hypotheses, solving problems and developing knowledge.

One of the geovisualisation techniques currently being developed is the storytelling method. The storytelling method provides convenience in communicating geospatial information equipped with additional 4 W elements, namely where, what, why and when. In addition to being represented using story texts, the storytelling method is also equipped with communicative and interesting visualisations. Conceptually, geovisualisation with the storytelling method has 3 main activity characteristics, which are data exploration, telling and publication. Data exploration is carried out to collect data to be presented, including textual data and spatial data and their attributes. Furthermore, the data is arranged to become a structured story. The final product will be published in the form of a web page so that it can be widely used by the public. The concept of geovisualisation with the storytelling method is described in Fig. 34.5.

The storytelling method has an important role and includes a medium of communication to bring together different ideas (Crawford 2005). In another sense, to communicate ideas and experiences, the storytelling method is widely used to convey information and messages in entertainment, communication, education and other areas in the form of oral, written or other visual stories (Laurel 1991; Mateas and Sengers 2003). According to Aditya (2007), an atlas with a storytelling method is an atlas equipped with a narrative or story structure in it. In other words, a storytelling-based atlas is one way of visualising spatial aspects by adding narration to the atlas according to the atlas theme.

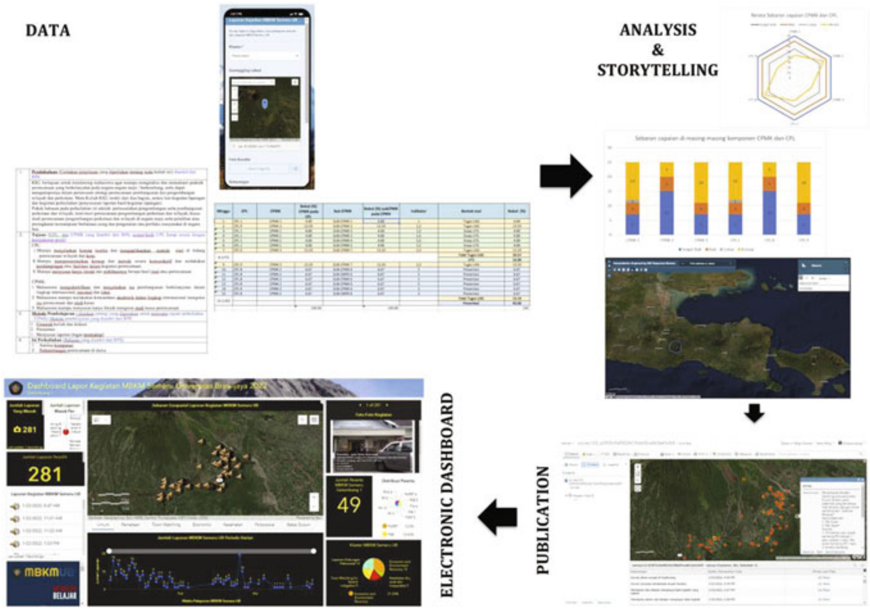


Fig. 34.5 Geovisualisation concept with the storytelling method. *Source* Created by Researchers, 2022

The Development of GeoAI, GeoIoT, Geostatistic Visual Analytics for Urban Recovery Planning and Management Due to the Eruption of Mount Semeru

The Application of GeoAI in an Effort to Accelerate the Emergency Response to the Mount Semeru Eruption as the Basis for Urban Recovery Planning and Management

The initiation of the application of GeoAI in disasters was implemented due to the experience in conducting the evacuation process and the collection of data on houses buried by mudflow as a result of the eruption of Mount Semeru on 4 December 2021. At the time of the incident, settlement areas around the lava flows of Mount Semeru were affected and submerged. For 2 days, the disaster evacuation team had searched for victims by only relying on land roaming on foot.

Furthermore, efforts to evacuate and collect data on disaster-affected areas are constrained by the weather, which, throughout December 2021, is the rainy season in Indonesia. The latest satellite imagery cannot capture a clear visual of the area affected by the eruption due to the dense and extensive cloud cover. Thus, on the third day, a proposition was put forth by the Indonesian drone pilot community, which was to take aerial photographs of the Semeru eruption disaster site via drones in an effort to accelerate evacuation and data collection on the affected areas.

On 7 December 2021, the Mount Semeru Eruption Quick Response Geospatial Team was formed to procure the latest geospatial data and information, which was divided into 3 divisions:

1. Drone Division
   A team containing drone pilots tasked with taking aerial photographs
2. GIS Division
   A team consisting of GIS experts tasked with processing GIS data from the aerial photographs obtained by the drone crews
3. Advocacy Division
   A team comprising administration staff, negotiators and mediators in the delivery of geospatial information to the authorities

The initial inventory activity carried out was georectifying aerial photographs taken through drone media. Then, a visual interpretation with the naked eye was performed concerning the object of the house with the categories consisting of 'intact', 'lightly damaged' and 'badly damaged'. This activity was carried out for 5 days. The evaluation of this activity concluded that the visual interpretation activity had slow progress due to limited human resources. As a result, on 11 December 2021, there would be changes to the visual interpretation method using GeoAI.

This GeoAI aerial photograph interpretation activity was undertaken on the Mapflow platform. Mapflow means that the geospatial application is based on the internet platform for automated mapping using satellite imagery or aerial photograph powered by deep learning image recognition algorithms. The process of visual interpretation of disaster-affected house objects was conducted through the use of high-resolution satellite imagery prior to the disaster incident, which was entered on the Mapflow platform. In the selection of data for the GeoAI process, GeoTiff is selected (See Fig. 34.6).

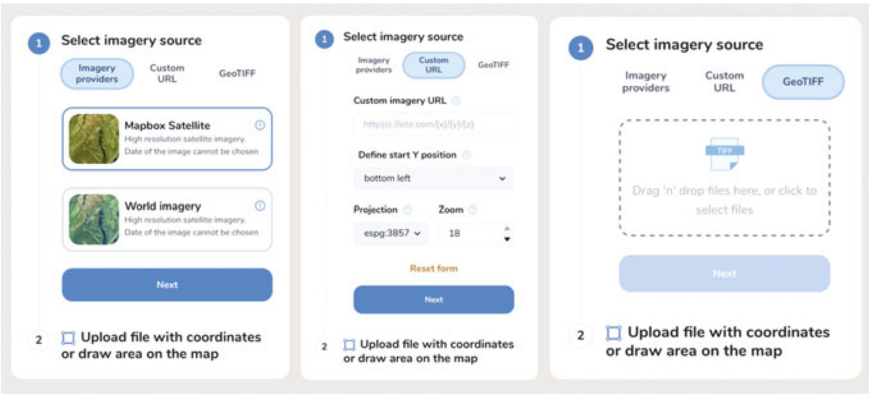


Fig. 34.6 Selection of provider. *Source* Mapflow, 2021

The next process was the selection of area of interest (AoI) objects to be observed by GeoAI (See Fig. 34.7).

Furthermore, the next stages consisted of the selection of the GeoAI algorithm for automatic and fast recognition for house objects and the selection of post-processing in the form of simplification, i.e. the process of refining objects (See Fig. 34.8).

The duration of the object recognition process on Mapflow depends on the computer's specifications, AoI extent and internet speed. The results of house object recognition using GeoAI on Mapflow can be seen in Fig. 34.9.

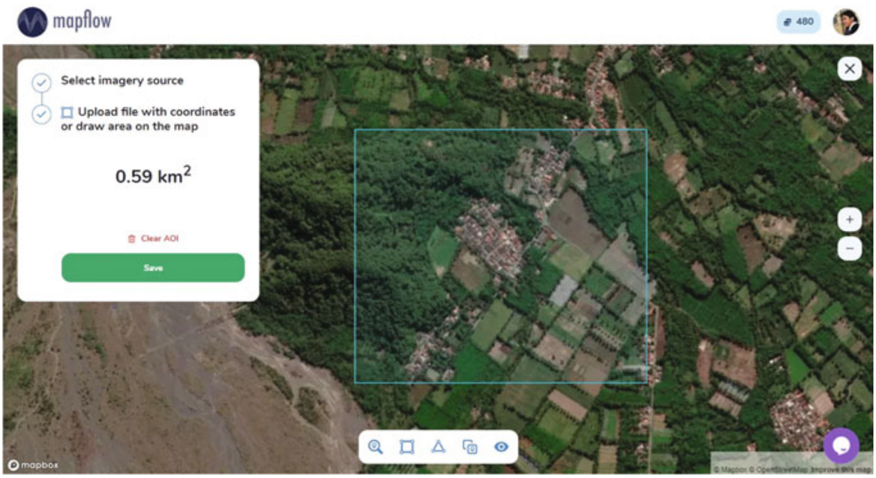


Fig. 34.7 Selection of area of interest (AoI). *Source* Mapflow, 2021

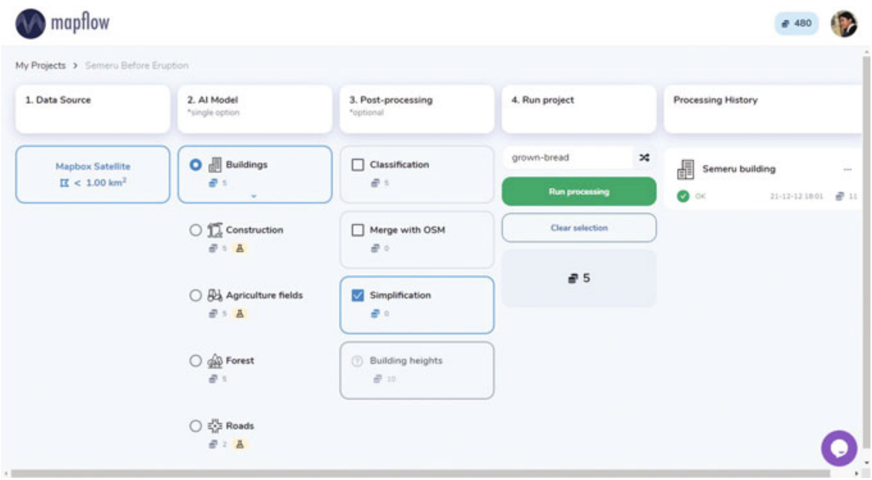


Fig. 34.8 GeoAI algorithm selection and post-processing type. *Source* Mapflow, 2021

Fig. 34.9 Result of residential object recognition through GeoAI on the Mapflow platform. *Source* Mapflow, 2021

Moreover, the process of identifying houses not affected, affected with light damage and affected with heavy damage was able to be done by comparing GeoAI results from high-resolution satellite images before the Semeru eruption to aerial photographs taken via drone media after the Semeru eruption (4 December 2021) (See Figs. 34.10 and 34.11).

The Development of GeoIoT in an Effort to Accelerate the Mount Semeru Eruption Emergency Response and Urban Recovery Planning and Management

GeoIoT development is divided into 2 parts, namely:

1. GeoIoT development during the emergency response process of the Semeru eruption (4 December 2021–25 December 2021).
2. GeoIoT development during urban recovery planning and management (25 December 2021–today).

The GeoIoT context, as described in Chapter 34.2.2 Geo Internet of Things, is an activity that is interconnected between all stakeholders through sensors, where the sensors in one place can be in the form of electrical sensors that automatically perform geospatial-based measurements or sensors in the form of reporting information submitted by humans based on geospatial conditions, where the scope of activities includes the collection, exchange and analysis of valuable information.

In this study, GeoIoT development includes the development of 2 applications, namely GIS data collector and WebGIS. This GIS data collector was built on the

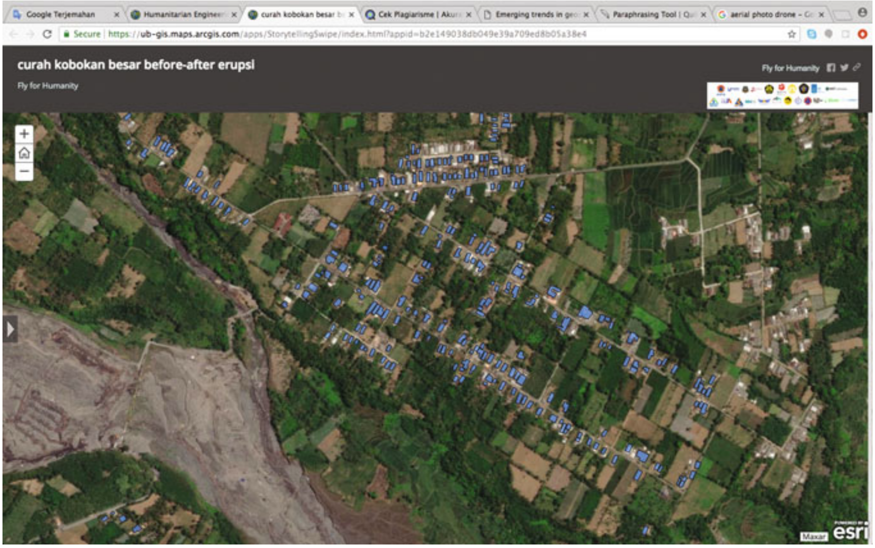


Fig. 34.10 Settlement surrounding Mount Semeru before the eruption on 4 December 2021. *Source* Created by Researchers, 2021

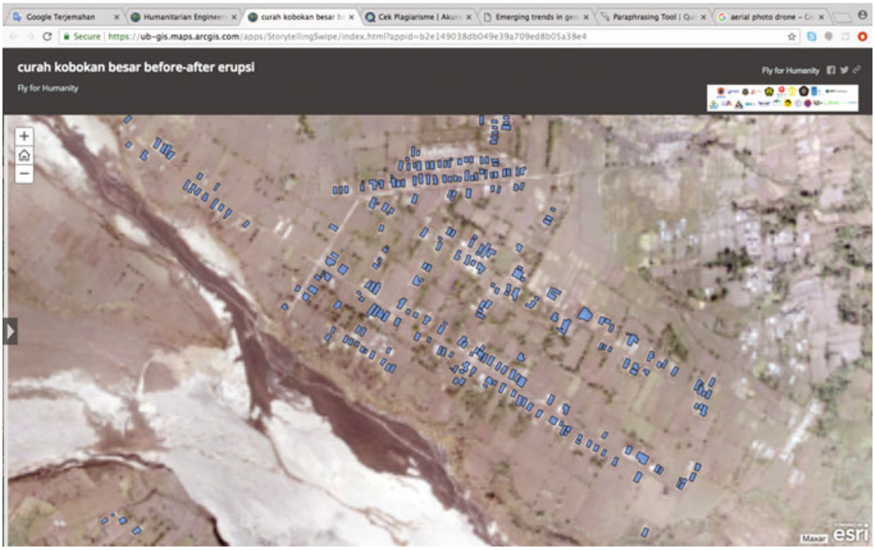


Fig. 34.11 Settlement surrounding Mount Semeru after the eruption on 4 December 2021. *Source* Created by Researchers, 2021

Table 34.1 Variables and parameters for reporting food and medical logistics

No	Variable	Type
1	Name	Text
2	Location	Geographical coordinates
3	Date	Number
4	Picture	Graphics
5	Things	Text

Table 34.2 Variables and parameters for reporting aerial photographs

No	Variable	Type
1	Name	Text
2	Institution	Text
3	Area of interest	Number
4	Location	Geographical coordinates
5	Picture	Graphics
6	Date	Number

ESRI platform under the name Survey123. During the emergency response period of the Semeru eruption, the development of this GeoIoT was focused on reporting the distribution of food and medical logistics for the victims of the Semeru eruption and taking area of interest by obtaining aerial photographs via drones by the drone pilots.

The development of the reporting application started with determining the variables and parameters as the basis for data input to be processed as information (Tables 34.1 and 34.2).

As for the development of reporting applications in the urban recovery planning and management period, the substance of the reporting contains reporting on post-eruption conditions for each theme (i.e. agriculture, animal husbandry, tourism, economy, health, education) for data collection as the basis for planning and managing settlements based on disaster mitigation and volcanic eruption. Variables and parameters for reporting on urban recovery planning and management can be seen in Table 34.3.

The next stage was the development of a reporting application on Survey123. On the ESRI platform, ArcGIS Survey123 is a survey application for data collection activities using simple but high-performance forms that make geospatial-based survey creation, sharing and analysis possible.

In the Survey123 application, a question form is made with the types of answers in the form of essay, multiple choice, geolocation data collection, photograph or date. Filling in the form is tailored to the needs of the user. Furthermore, users can access field survey reporting via smartphones, laptops or tablets.

Reporting on food and drug logistics can be seen in Fig. 34.12. Reporting for drone pilots' coordination can be seen in Fig. 34.13. Meanwhile, for urban recovery planning and management reporting fields, this can be seen in Fig. 34.14.

Table 34.3 Urban recovery planning and management reporting variables and parameters

No	Variable	Type	Parameter
1	Theme	Multiple choices	• Agriculture • Tourism • Husbandry • Health • Education • Economic
2	Location	Geographical coordinates	
3	Date	Number	
4	Picture	Graphics	
5	Things	Text	

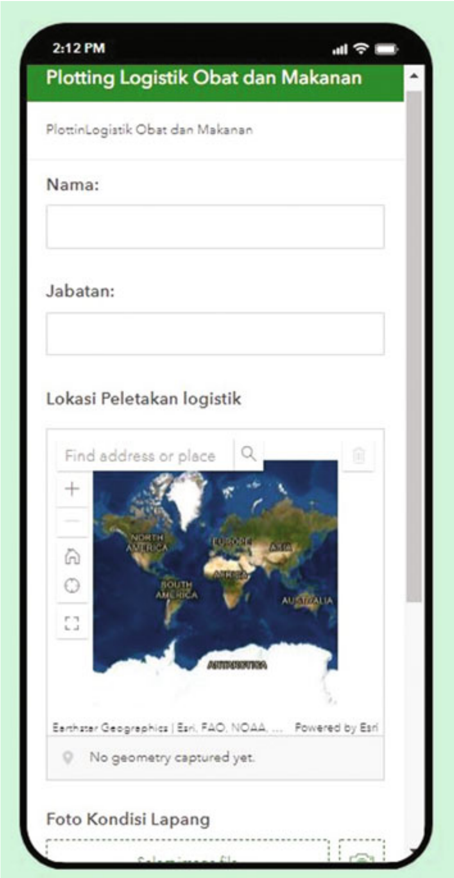


Fig. 34.12 Drug and food logistics reporting application

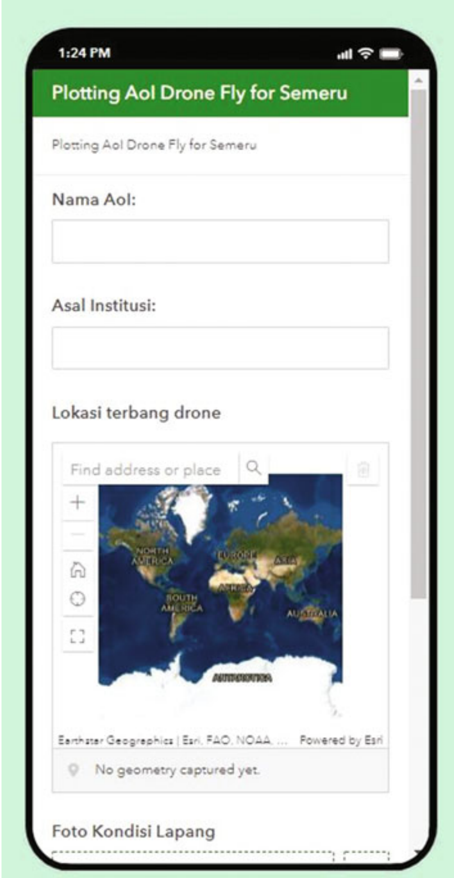


Fig. 34.13 Drone pilots' coordination reporting application. *Source* Created by Researchers, 2021

For exchanges of information, users who have provided information can access the existing situation in WebGIS as follows (Fig. 34.15).

The Development of Geostatistical Visual Analytics to Support Decision-Making Processes for Urban Recovery Planning and Management due to the Mount Semeru Eruption

A Geostatistical Analytics Dashboard is a type of electronic dashboard that is used to monitor and manage the performance of a regional phenomenon within a given time period and geographic position. Previously, the data summarised in information was still built in partial ways, whether it was the presentation of maps, statistical charts, descriptions or numbers. Today, advancements in IoT technology have combined all

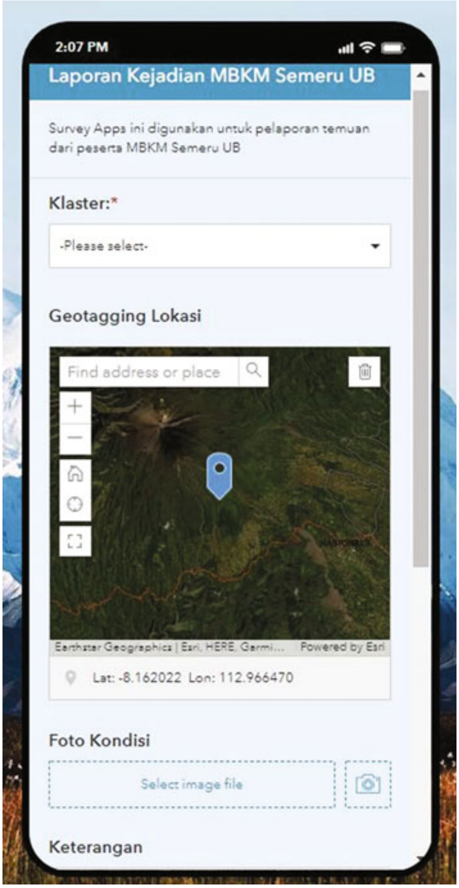


Fig. 34.14 Urban recovery planning and management reporting application. *Source* Created by Researchers, 2021

types of data into an infographic. This is very helpful for supporting decision-makers to immediately take the right decisions on the activities of regional phenomena.

The Geostatistical Analytics Dashboard designed in this study was used to monitor and analyse community activities in settlement areas affected by or near volcanic eruption hazard zone. Furthermore, this dashboard can also be used as a warning for communities living in disaster-prone areas based on real-time data. The information conveyed through the previously described GeoIoT will generate operational reports that provide an interactive infographic display. This dashboard will ultimately help planners and decision-makers design urban recovery planning and management agendas and programs.

The development of this Geostatistical Analytics Dashboard was built on the ESRI platform under the name ArcGIS Operational Dashboard. The ArcGIS Operational Dashboard features visual analytical information delivery with real-time data updates that are connected to GeoIoT built on the Survey123 platform, and it can correlate geospatial data with statistics intuitively and interactively.

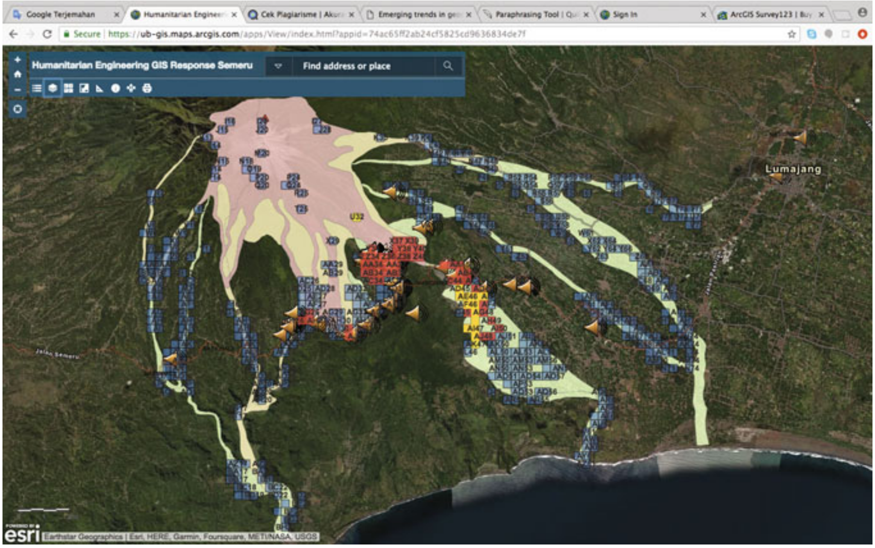


Fig. 34.15 WebGIS food and medical logistics reporting and aerial photograph plotting (URL link https://s.ub.ac.id/gisresponsemeru). *Source* Created by Researchers, 2021

Further development of Geostatistical Analytics Dashboard for urban recovery planning and management after the Mount Semeru eruption was connected with GeoIoT application reporting urban recovery planning and management (See Chapter 34.3.2 and Fig. 34.5). Applications built on the Survey123 platform will be connected in real time on the ArcGIS Dashboard platform (See Fig. 34.16).

The initial stages of the development of the Geostatistical Analytics Dashboard for urban recovery planning and management in the ArcGIS Dashboard were the preparation of the dashboard concept in the form of variables, parameters and visualisation forms that would be displayed, such as maps, charts, pictures, numbers and texts. Afterwards, the ArcGIS online platform was opened to build a dashboard with a drag-and-drop system for selecting widgets on the system. Furthermore, synchronisation and interoperability of data and information were carried out for data transactions in real time from Survey123, which was a GeoIoT application reporting urban recovery planning and management, to ArcGIS Operational Dashboard as Geostatistical Analytics Dashboard for urban recovery planning and management was carried out (See Fig. 34.17).

Challenges/Limitations of the Study

A catastrophic natural disaster, which has a detrimental impact, requires rapid handling and effective and efficient work, both during the emergency response period and during the recovery period of the affected area. One of the alternative solutions

Fig. 34.16 Data integration and synchronisation between Survey123 and ArcGIS Dashboard. *Source* Created by Researchers, 2022

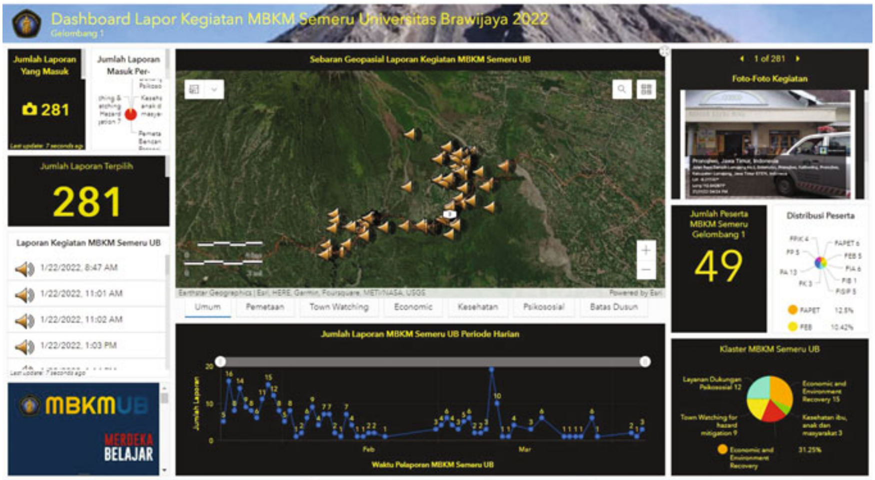


Fig. 34.17 Geostatistical Analytics Dashboard for urban recovery planning and management after Mount Semeru eruption (URL link https://s.ub.ac.id/dashboardmbkmsemeruub1). *Source* Created by Researchers, 2022

provided is the use of technology, specifically the use of GeoAI, GeoIOT and Geostatistical Analytics Dashboard. However, it is undeniable that the use of this technology is very dependent on the availability of an internet network between the location of the disaster and the location of the command centre for disaster response and urban recovery planning and management. This is an obstacle because, during a disaster, telecommunications networks, especially internet provider stations, are affected by the damage caused by the disaster. However, this issue can be solved through the mobilisation of mobile internet imported from other cities.

Conclusions

Emergency response situations and urban recovery planning and management require fast, effective and efficient work in order to accelerate the evacuation of victims as well as to create an inventory of disaster-affected areas for urban planning based on disaster mitigation. The studies conducted so far are in the form of partial advancement of technology in disaster risk reduction; there were seldom combinations of the use of advanced technologies in disaster management. To fill this gap, this study was conducted to explore the combination of advancements in geospatial technology in managing disasters effectively and efficiently.

One of the alternative solutions provided is the use of technology, specifically the use of GeoAI, GeoIOT and Geostatistical Analytics Dashboard. Although, in practice, there are obstacles, especially the availability of internet networks, the provision of mobile internet is able to provide an answer. Furthermore, it is undeniable that the use of GeoAI, GeoIOT and Geostatistical Analytics Dashboard helps all decision-makers in taking systematic steps for disaster management and carrying out area recovery processes more quickly thanks to rapid and massive updating of regional data and information.

Acknowledgements This chapter is a part of the authors' research under ***Hibah Penelitan Utama (HPU),*** The Principal Research Grant, with **The University Contract Number: 975.45/UN10.C10/PN/2022** and ***Merdeka Belajar Kampus Merdeka Semeru Universitas Brawijaya (MBKM Semeru UB)*** university-community outreach for Semeru recovery with **The University Contract Number: 113/UN10/KP/2022** under Brawijaya University Agenda. Within this consideration, the authors would like to express their thanks to Brawijaya University Fund in supporting this financial research and university-community outreach.

References

Aditya T (2007) National atlas as a metaphor for improved use of a national geospatial data infrastructure. PhD Thesis, Utrecht University

Atzori L, Iera A, Morabito G (2010) The internet of things: a survey. Comput Netw 54(15):2787–2805

Badan Nasional Penanggulangan Bencana (BNPB) (2021) Pemetaan dan Evaluasi Bencana Awan Panas Guguran (APG) Gunung Semeru, Kabupaten Lumajang, Provinsi Jawa Timur, 5–16 Desember 2021, BNPB Report, Jakarta. National Board for Disaster Management (2021) Mapping and evaluation of mount semeru hot avalanche disaster (APG), Lumajang Regency, East Java Province, 5–16 December 2021

Butler, D., 2006. Virtual globes: The web-wide world.

Campbell H, Masser I (1995) GIS In organizations: how effective are GIS in practice? CRC Press, London, UK

Crawford TW (2005) Spatial fluctuations as signatures of self-organization: a complex systems approach to landscape dynamics in Rondonia, Brazil. Environ Plann B 32:857–875

de Smith M, Longley P, Goodchild M (2018) Geospatial analysis—a comprehensive guide. 6th edn. The Winchelsea Press

Dühr S (2007) The visual language of spatial planning. Routledge, Oxford, UK

Firdhous MFM, Karuratane PM (2018) A model for enhancing the role of information and communication technologies for improving the resilience of rural communities to disasters. Procedia Eng 212:707–714. https://doi.org/10.1016/j.proeng.2018.01.091

Forester J (1982) Planning in the face of power. J Am Plann Assoc 48(1):67–80

Hall P (2002) Urban and regional planning, 4th edn. Routledge, London, UK

Haque A (2001) GIS, public service, and the issue of democratic governance. Public Adm Rev 61(3):259–265

Healey P (1997) Collaborative planning: shaping places in fragmented societies. UBC Press, Vancouver, Canada

IERC (2014) Internet of Things. http://www.internet-of-things-research.eu/about_iot.htm. (Accessed: 20 July 2022)

Inan DI, Beydoun G, Pradhan B (2018) Developing a decision support system for disaster management: case study of an Indonesia volcano eruption. Int J Disaster Risk Reduction 31:711–721. https://doi.org/10.1016/j.ijdrr.2018.07.020

ITU-T (2012) Recommendation ITU-T Y.2060. Overview of the Internet of Things. ITU-T Study Group 13

Kraak MJ, Ormelling FJ (2003) Cartography: visualization of geospatial data. Prentice Hall, New York

Laurel B (1991) Computers as theatre. Addison-Wesley, Reading, MA, USA

Lemmens M (2006) Planetary emergency. GIM Int, vol 20

Lü G, Batty M, Strobl J, Lin H, Zhu A-X, Chen M (2019) Reflections and speculations on the progress in Geographic Information Systems (GIS): a geographic perspective. Int J Geogr Inf Sci 33(2):346–367. https://doi.org/10.1080/13658816.2018.1533136

Mateas M, Sengers P (2003) Narrative intelligence (advances in consciousness research). John Benjamins Publishing Company, New York

Prasetio EA, Arifianti Y, Hardjakaprabon B, Agustin F (2012) Triple helix in disaster management: case study of strategic environmental assessment (SEA) for government office relocation planning of Padang City, Indonesia. Procedia—Soc Behav Sci 52:150–159. https://doi.org/10.1016/j.sbspro.2012.09.451

Pribadi KS, Abduh M, Wirahadikusumah RD, Hanifa NR, Irsyam M, Kusumaningrum P, Puri E (2021) Learning from past earthquake disasters: the need for knowledge management system to enhance infrastructure resilience in Indonesia. Int J Disaster Risk Reduction 64(June):102424. https://doi.org/10.1016/j.ijdrr.2021.102424

Pusat Vulkanologi dan Mitigasi Bencana Geologi (PVMBG) (2021) Press Release Aktivitas Vulkanologi Gunung Semeru—Jawa Timur, 4 Desember 2021. Center for Volcanology and Geological Hazard Mitigation (2021) Press release volcanological activity of Mount Semeru—East Java, 4 December 2021. https://translate.google.com/?sl=id&tl=en&text=Press%20Release%20Aktivitas%20Vulkanologi%20Gunung%20Semeru%20%E2%80%93%20Jawa%20Timur%2C%204%20%20Desember%202021&op=translate. (Accessed: 15 July 2022)

Robbins E, Cullinan E (1997) Why architects draw. MIT Press, Cambridge MA

Shahid S, Behrawan H (2008) Drought risk assessment in the western part of Bangladesh. Nat Hazards 46(3):391–413

Stephenson J (2010) People and place. Plan Theory Pract 11(1):9–21

Vincent MM (2008) Governance and geography explaining the importance of regional planning to citizens, stakeholders in their living space, Boletin de la A.G.E.N, No. 46, pp 77–95

VoPham T, Hart JE, Laden F, Chiang YY (2018) Emerging trends in geospatial artificial intelligence (geoAI): potential applications for environmental epidemiology. Environ Health 17(1):40

Wisner B, Davis I, Cannon T, Blaikie P (2004) At risk second edition: natural hazards, people's vulnerability and disasters. Routledge, New York.

Worboys MF, Duckham M (2004) GIS: a computing perspective, 2nd edn. CRC Press, Boca Raton

Yu S, Yoon SM, Choi EK, Kim SD, Lee YJ, Lee Y, Choi KH (2016) Quantitative assessment of national resilience: a case study of mount Paektu eruption scenarios on South Korea. Int J Disaster Risk Reduction 19(September 2001):118–132. https://doi.org/10.1016/j.ijdrr.2016.09.002

Chapter 35
Rethinking 'Heritage' Based on Urban Space Transformations in the Colonial Town of Chandernagore, India

Lina Bose, Anindya Basu, and Adrija Bhattacharjee

Abstract Heritage is not just something associated with the past but also something that connects us with our present and accompanies us into the future. Heritage always calls for inclusion, but the inclusionary aspect of heritage is often underpinned when it comes to development. In the colonial town of Chandernagore, the urban expansion and fast rise of multi-storey buildings have begun to threaten the existence of urban-heritage structures at an alarming rate. In Chandernagore, one of the oldest municipal corporations of West Bengal, the urban and historic realms are inextricably linked. The study will attempt to map the co-existing colonial heritage units within the urban space and will try to explore the underlying causes of the conflict between heritage and urban planning. The major goals of the chapter are to find out ward-wise changing density of population on the basis of prior literature, decadal census data; delineate of spatio-temporal change of land use and land cover (LULC) over a span of almost 40 years (1982–2022) using supervised image classification approach with maximum likelihood classification and corroborating it with corresponding Google Earth images; and understand citizen's perspective about the recent trend of urbanisation involving qualitative methods like key informant interviews, transect walk, passive observation and contextual interviews. If urban concerns are adequately addressed, the city has every chance of becoming a viable, sustainable heritage city. The action plan formulated on the basis of the study findings hopes to offer interesting insights to the planners and conservations to rethink and recognise the plurality of the heritage values through comprehensive up-scaling heritage initiatives.

Keywords Heritage scape · Urban-heritage · Urban space · Colonial town · Action plan

L. Bose
Department of Humanities and Social Sciences, Indian Institute of Technology Kharagpur, Kharagpur, West Bengal, India

A. Basu (✉) · A. Bhattacharjee
Department of Geography, Diamond Harbour Women's University, Sarisha, West Bengal, India
e-mail: basu_anindya2004@yahoo.com

U. Chatterjee et al. (eds.), *Urban Commons, Future Smart Cities and Sustainability*, Springer Geography, https://doi.org/10.1007/978-3-031-24767-5_35

Introduction

India has a rich heritage that includes both tangible and intangible elements. The concept of heritage has evolved from a narrow focus on buildings to a broader scope that includes all urban spaces and their contents (Taylor 2015). Heritage is not just something associated with the past but also something that connects us with our present and accompanies us into the future. Heritage always calls for inclusion, but the inclusionary aspect of heritage is often underpinned when it comes to development. Heritage in the era of development emerged as an interconnected network of diverse modes of living and creating rather than a monochrome monolith, connecting different social actors with the policymaking processes in the context of heritage preservation. The neoliberal paradigm alienates heritage from the mainstream notion in the modern era. Heritage is typically thought as something that binds us to our past; however, one needs to rethink, reconceptualise and re-orient the perspective and ask themselves, 'What does heritage mean to us?'. Today, heritage has become intertwined with the various hues of new urbanity and its socio-cultural idiosyncrasies and is frequently viewed as something individuals can live without. The urban sprawl deliberately ignored and underpinned the rich cultural values of the city. In the twentieth century, with the growing globalisation trend, a significant shift occurred where cultural practices and ethos became necessary to preserve locational uniqueness apart from objects and buildings. Arjun Appadurai, with the help of five scapes or flows: ethnoscapes, technoscapes, ideoscapes, finance scapes and mediascapes, explained how cultures around the world influence each other de-localised power structures (Rantanen 2006). Based on that, the concept of heritage scape was introduced by Garden (2004), where heritage sites were not viewed as a singular entity but existed within a wider physical and social spectrum. Di Giovine (2008) further popularised this, who views heritage scape as 'an authentic social structure constructed through the juxtaposition of unrelated, but similarly designated…heritage sites'. Thus, the urban-heritage scape became not only limited and concerned with the past and present but also a future-oriented, contingent and creative endeavour in which the values of intangible objects are given equal weight. In urban-heritage scapes, both human and non-human boundaries got blurred. Both are equally implicated, attached and embedded in a complex process that binds them across space and time. Heritage is thus viewed as a collaborative process where various actors and communities work together to make the past more vibrant and accessible. Cultural heritage is a multi-layered palimpsest of history, society and a way of life that manifests in the form of the urban built fabric, spatial planning, architecture, materials, construction techniques and life rituals. As a result, to achieve long-term growth, it is critical to safeguard and conserve the town's historic fabric, which will also help to promote its unique identity in the future. Thus, heritage has emerged as a coherent overarching concept in which the past, present and future are entangled as a process that requires special attention (Cathrine 2006).

Historicising Chandernagore

Hugli river, a significant tributary of the Ganges, is interwoven into a network of cultural and regional interactions and exchanges (Ivermee 2020). The crescent-shaped Chandernagore, located on the western bank, is the jewel in this spatial crown, drawing the limelight as a potential heritage site. Chandernagore, or the *Ville du Bois de Santal* or *Ville de la lune* in French (Land of Sandalwood) (Seth 1963), is a former French colony in Bengal. The entire stretch of the Hugli River connecting the dots, starting from Bandel and continuing through Chinsurah, Chandernagore, Serampore and Barrackpore, is known as 'Mini Europe' (Das and Chattopadhyay 2014) (Fig. 35.1). European powers such as the Portuguese, French, Dutch, Danes and British all left their imprints on the stretch, transforming it into an important commercial centre in the eighteenth century. This cultural mingling is the foundation of contemporary Bengali culture, as seen in the region's architecture, town planning, literature and art. The five towns share the same water linkage with Calcutta (now Kolkata), yet all have different stories. Upstream from her renowned cousin – Kolkata, Chandernagore has been preserving elements of Indo-European heritage in public places, architecture and culture. European culture and town planning principles influenced the development of Chandernagore during the 250 years of possession by the French rulers. The French settlement in Bengal began in 1673 when Ibrahim Khan (a diwan) granted Du-Plessis, a French trader, permission to occupy a parcel of land on the northern bank of the Hugli River, today known as Chandernagore. Different papers and old historical documents produced uncertainty concerning the foundation of the French colony in Chandernagore, and thus, the actual date of the French presence in Chandernagore remained unknown. The enclave of Chandernagore was most likely created in 1690 (Annoussamy 2004).

Around 1687, a French commander named Andre Bourreau Deslandes began doing business at Bandel in Hooghly, but after many difficulties, he moved to Chandernagore by paying the Mughal government Rs. 40,000. In a letter from the collector of Hooghly, Mr. E Sterling, it was revealed that after a year, in 1688, the French

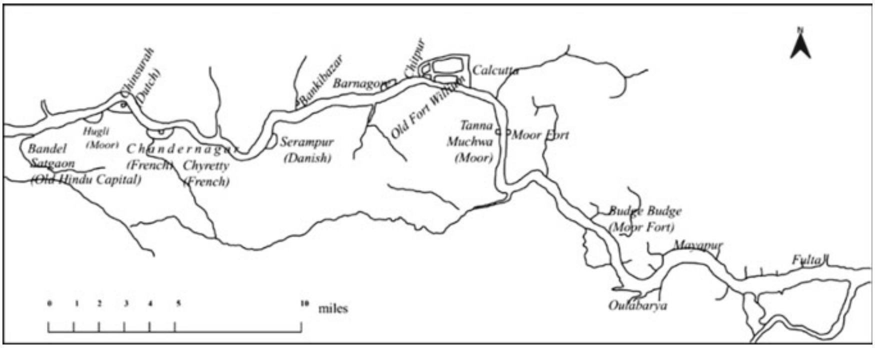


Fig. 35.1 Tracing the Hugli corridor on the basis of Hill (1903)

permanently occupied Chandernagore under an edict of Aurangzeb, the then Mughal Emperor of India (Hill 1903). By 1700, Chandernagore came under the control of the French. Hooghly was their major business centre in Bengal until 1711 (*Comptoir principal dans Bengale,* translated as Principal Counter in Bengal). The French East India Company gained substantial property rights in Chandernagore in 1688, which can be regarded as the beginning of French supremacy in India. The city under French rule outperformed all of Bengal's overseas colonies in trade and business. Chandernagore gradually transformed from a cluster of small villages to a vibrant city and became part of the more significant Calcutta urban agglomeration.

Farasiganj, formerly known as French Ghiretti in Chandernagore, was a 120-bigha stretch of land on the bank of Hugli River. The city witnessed many struggles; several times, a power transfer occurred between the British and the French. Throughout the eighteenth century, the city encountered a dynamic turn of political events, interrupting periods of English occupation between 1757 and 1763, 1778 and 1783, and again in 1793 and 1802. During the era of the Anglo-French conflict, many significant promenades and structures in the town were destroyed by the British (Ukil 1996). By 1800, the town's prior commercial prominence had faded, becoming a sleepy Calcutta suburb (ICOMOS 2017). However, despite everything, it is noted for its clean, wide thoroughfares with many elegant residences and structures along the river bank. When the whole of Bengal was under British rule as a province of British-administered India, Chandernagore, being part of it, created an independent tradition under French control. Because of its separate identity, Chandernagore developed and became a total of its own, even with its small area. Even though the town is geographically distinct from other Bengal townships, its inner linkage with others is intricately tied.

The river Hugli was vital to the growth and development of the city of Chandernagore and became Bengal's first urban riverine location. Aside from many heritage structures, the existence and identity of many lives are also rooted in the banks, which got intertwined with many stories, memories and ethos. The stretch along the river Hugli is a perfect example of a riverfront heritage scape, where the river simultaneously connects and reconciles both the past and the present by re-establishing the connection between the built heritage and the river and serving as a catalyst for economic and cultural revitalisation. Because of urban sprawl, the entire riverine portion along the Hugli stretches of Chandernagore underwent massive changes. Urban expansion is considered one of the significant threats to the heritage structures of the city. The ecological aspect also gained prominence in Chandernagore, along with hard (tangible) and soft (intangible) components. The Hugli stretch reflects the entwined realities of the river and space and tells the story of the river's coproduction and coexistence with the city. The city is rich in heritage structures, and only a suitable planning system can bring the city's decaying heritage elements back to life.

Trajectories of Urban Growth in Chandernagore

Chandernagore was proclaimed a free city in 1947 even though the French administration remained in place, holding a symbolic force. The de facto occurred in 1949, when G. H. Tailleur, the last French administrator, left Chandernagore, leaving it completely independent of French control. De'Jure (formal) transfer took place in 1952 (Rai 2007). Finally, the administration of Chandernagore was handed over to the West Bengal Government on October 2, 1954, following which Chandernagore Municipal took charge of it as a municipal town in February 1956 (Seth 1961). It became a municipal town within the ambit of the Calcutta Metropolitan District. The city is under Chandernagore Municipal Corporation, an autonomous local government body supported by the Government of West Bengal; Chandernagore Municipal Corporation is responsible for the city's upkeep and management. Chandernagore's diverse and vibrant heritage feature has created and shaped its Indo-French cultural identity. The urban plan and built heritage of the French period, subsequent British period and elite landlords of Indian origin characterise various layers of the urban history of Chandernagore (Ghosh 1998).

The town's first phase of development occurred between 1673 and 1687. Before the arrival of Governor-General Dupleix, its early history was hardly documented. The early settlements grew and developed by the side of the river Hugli from north to south and for a little more than a mile from east to west (Bandhopadhyay 2003). The town's first phase of urbanisation began to the north of Chandernagore and subsequently spread to the south (Gondolpara). By 1744, Chandernagore emerged as a nerve centre for trading activities in Bengal (Crawford 1902). The most incredible preserved feature of the city of Chandernagore is its urban fabric. Throughout the eighteenth century, the town saw several ups and downs. The town's natural morphology was affected due to the long conflict between the English and the French. During the French administration, the city had the unique advantage of experiencing a blend of indigenous and French culture; this blending gave Chandernagore a distinct cultural character that set it apart from other metropolitan centres. The arrival of rail networks in 1854 accelerated the town's expansion. The East India Railway (Eastern Railway) traversed the city from the western end during 1854–55. Thus, the town's growth extended to the west, i.e. to Khalisani (Ghosh and Siddique 2018). From the initial phase to till the early twentieth century, the municipality covered an area of 9.5 km^2 with 27 municipal wards (Ukil 1996); from 1994 onwards, six more wards were added to the western part covering 12.5 km^2 (Ghosh and Mistri 2015) (Fig. 35.2). From a mere trading centre, Chandernagore progressed into a compact urban identity. Despite losing the colonial sheen, it still serves as a subdivisional headquarter (Basu et al. 2020).

The intrinsic values and assessment of the city include not only the built structures but also the intangible heritage assets that shape and define city life. The cultural aspect is severely being ignored when it comes to development. India is arguably one of the most popular destinations of cultural centres, with a rich and diverse history that allows for the exploitation of opportunities offered by the cultural heritage

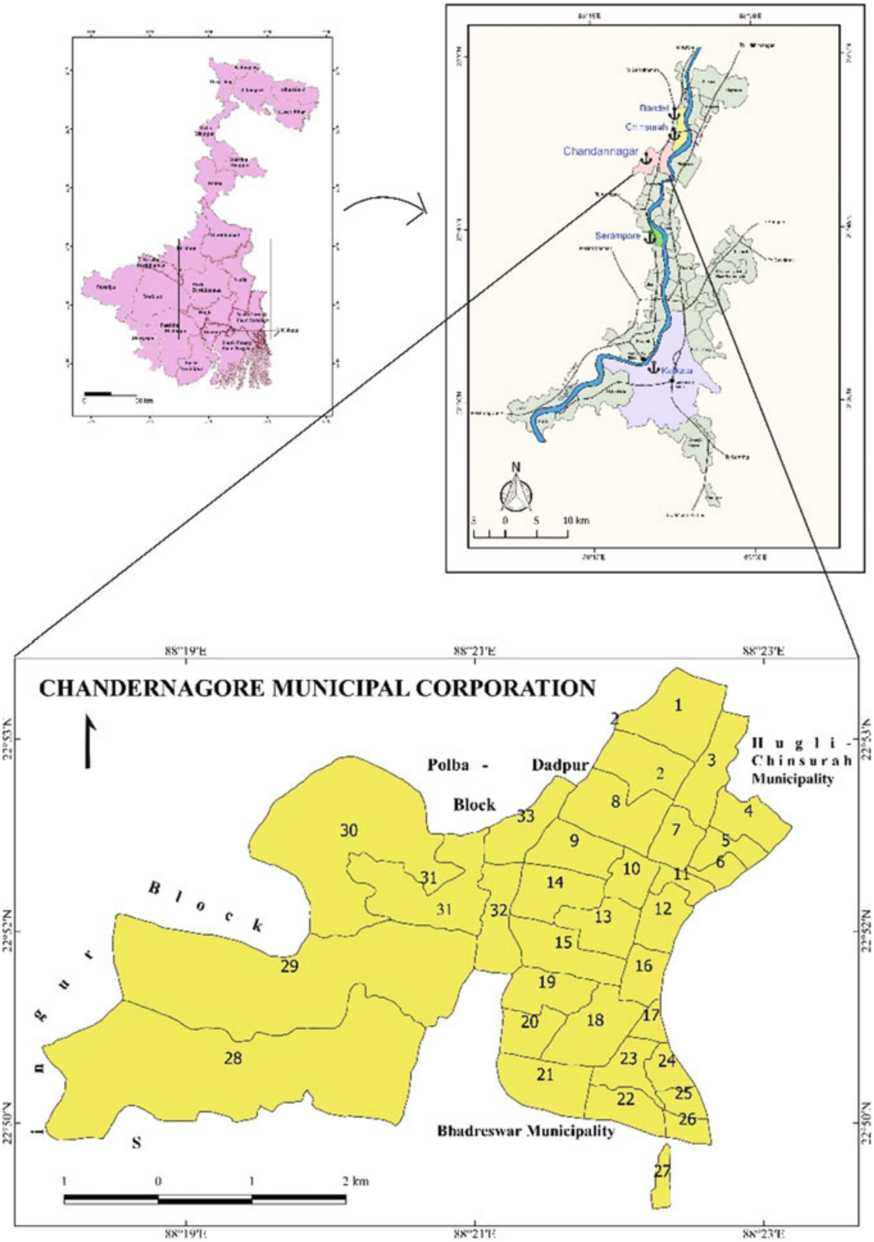


Fig. 35.2 Introducing the study area—Chandernagore city, a former French Colony in West Bengal, India, an important part of the urban-heritage tourism circuit 'Little Europe of Bengal' developed along the river Hugli

(Menon 2014). The city of Chandernagore, like others, has several heritage assets. However, in today's context, the town's rich cultural heritage is getting overshadowed by the construction of multi-storied buildings facilitated by the forces of transnational capital and real-estate speculation.

Objectives

Chandernagore is one of the oldest municipal corporations of West Bengal, the urban and historic realms are inextricably linked. The study will attempt to map the co-existing colonial heritage units within the urban space and explore the underlying causes of the conflict between heritage and urban planning. The primary goals of the paper are to find out the ward-wise changing density of population-based on prior literature and decadal census data; delineate the spatio-temporal change of land use and land cover (LULC) over almost 40 years (1982–2022) using supervised image classification approach with maximum likelihood classification and corroborating it with corresponding Google Earth images; and understand citizen's perspective about the recent trend of urbanisation qualitative methods like key informant interviews, transect walk, passive observation and contextual interviews.

If urban concerns are adequately addressed, the city has every chance of becoming a viable, sustainable heritage town. The action plan formulated based on the study findings hopes to offer exciting insights to the planners and conservations to rethink and recognise the plurality of the heritage values through comprehensive up-scaling heritage initiatives.

Materials and Methods

Since the chapter focuses on two aspects, i.e. presence of heritage sites and the gradual urban expansion of the colonial town of Chandernagore, mixed method approaches have been followed. The Census of India data (1901–2011) has been used to gauge the rate of increase in total population in the municipal area and to compare the inter-ward population densities too with the help of mapping (Fig. 35.3). From USGS Earth Explorer Landsat imageries, (Path 148, Row 44) and (Path 138, Row 44) acquired in March for the years 1982 and 2022 from Landsat 4 (MSS) and Landsat 8 (OLI_TIRS) missions having a resolution of about 79 and 30 m, respectively, have been downloaded and supervised classification using maximum likelihood has been carried out to bring out the spatio-temporal variations in land use and land cover involving ARC GIS v10.2.2. To corroborate the findings, corresponding Google Earth images of 1984 and 2022 have been used too. Through a review of past literature, oral interviews and intensive field visits important heritage sites have been identified along with the presence of modern, urban residential units alongside them with the

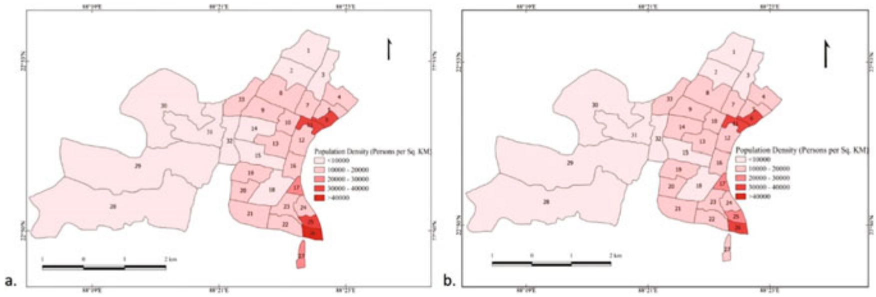


Fig. 35.3 Varying ward-wise population density (**a** 2001 and **b** 2011) of Chandernagore Municipality Corporation, West Bengal

help of g GPS Garmin Etrex 10 handheld receiver and plotted on the map using Q-GIS v3.16.

Cutting-edge research was conducted using various methods, including historical and ethnographic methodologies, multi-stakeholder participation and exchanges, and audio-visual strategies and techniques. There were brainstorming focus group sessions with stakeholders involved in preserving the city's heritage elements, where participants discussed laws that needed to be mobilised, funding avenues and ways to overcome the apathy of private heritage property owners towards conservation. The transect walk method through modified Participatory Rural Appraisal (PRA) was used on the city's major road network to formulate an understanding of the perceptions of the residents and tourists on the street networks and heritage demolition along the roadside (Table 35.1).

Table 35.1 An overview of qualitative method of analysis

Approaches involving primary sources		Secondary sources
Open-ended interviews with different stakeholders	Key informants: • Academicians • Government officials • Owners/Custodians • Heritage activists • Project volunteers • Citizen historians • Student community • Real-estate developers	Books
Focus group discussions		Journals
Ethnographic observations		Census reports
Action research		Newspaper articles
Transect walk		
Observation through photo survey		

Source Compiled by authors, 2022

Changing Spatial Dynamics

The city of Chandernagore, which is located approximately 40 km north of the megacity of Kolkata, is a part of the Kolkata Metropolitan Development Authority, and due to its proximity to the state capital and availability of transportation alternatives like roadways, railways and waterways, Chandernagore has been a viable alternative for the middle-class residents. In today's context, the city of Chandernagore is urbanising rapidly to keep pace with the demands of development. From the data of Census of India, this growing concentration of urban population becomes pretty clear from 26,831 persons in 1901, it rose to 49,909 in 1951 and in 2011 it touched 166,867. However, an interesting fact is that the population growth rate from 1991–2001 was 34.73% while that for 2001–2011was 2.88%; so, this probably indicates that Chandernagore has already reached its demographic peak and resultant urban expansion. Interestingly, 9 wards (5, 6, 7, 9, 11, 17, 25, 26 and 27) have shown an adverse change in total population and consequently in population density too; ward 26 has maintained its leading position in terms of population density though faced a sharp decadal slump. The older municipal wards (1–27) and especially the ones on the eastern side, along the river Hugli which houses most of the heritage sites though smaller in areal dimension, have higher population density (Fig. 35.3), highlighting that the chances of urban renewal and transformation in those.

To understand the changing nature of land use and land cover of the study area, supervised classification has been used on the basis of maximum likelihood by means of spectral signatures with the help of training output creation through creation of region of interest (ROIs) and the resultant output is based on conventional colour coding having four macro-classes (waterbody, open space, vegetation and built-up area). Over the span of 40 years (1982–2022), there has been a vast change in the categories. Over the years, the settlement (built-up area) has increased from 36.50% in 1982 to 79.5% in 2022 allowing more residential space in expense of open spaces and vegetated areas mostly, which faced a sharp decline of 14.29 and 24.29% in the said period. With the increasing trend of real-estate development, water bodies decreased from 9.66 to 5.16% (Table 35.2 and Fig. 35.4). So, this changed LULC of the region reflects that in contemporary times many residential and development projects are coming up indicating rapid urbanisation.

Table 35.2 Area and percentages of LULC classes for the period 1982–2022 for Chandernagore municipal corporation (Wards 1–27)

Years	LULC classes							
	Waterbody		Open space		Vegetation		Built-up area	
	(km^2)	(%)	(km^2)	(%)	(km^2)	(%)	(km^2)	(%)
1982	0.92	9.66	2.34	24.61	2.78	29.24	3.47	36.50
2022	0.49	5.16	0.98	10.32	0.47	4.95	7.56	79.58

Source Computed by authors from satellite imageries of Landsat 4 and 8 for 1982 and 2022, respectively

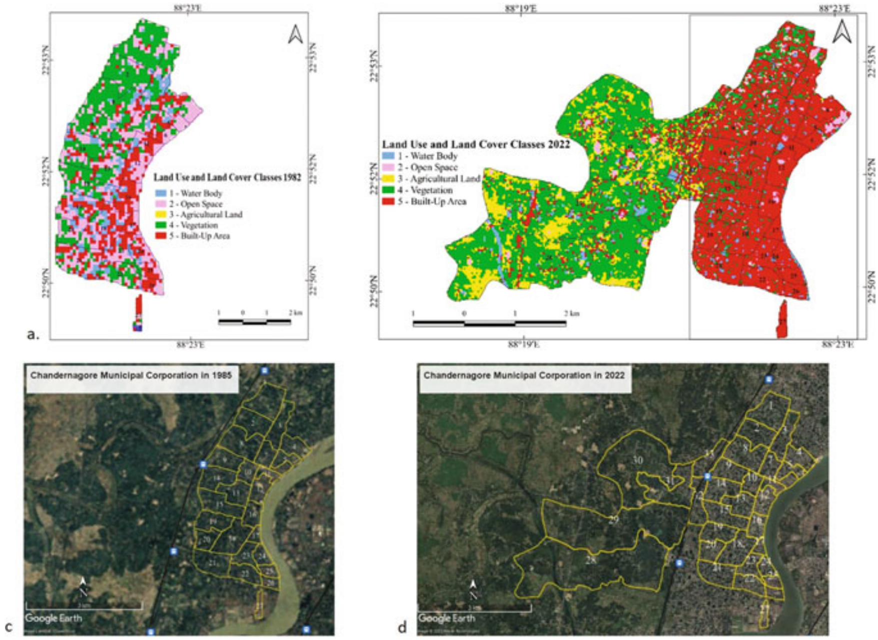


Fig. 35.4 Marked change in land use and land cover of Chandernagore, West Bengal. The LULC maps (**a** and **b**) with the help of satellite imageries of Landsat 4 and 8 for 1982 and 2022, respectively. The corresponding Google Earth images (**c** and **d**) of 1985 and 2022 also corroborate the same

To ensure the quality of classification, accuracy check has been done—the overall accuracy of 87.92% and kappa coefficient of 0.83 were obtained from the 1982 map while the accuracy was 91.82% for the 2022 map with a kappa coefficient of 0.89.

The newly added wards in the western part are less concretised till now but with the continuous rising graph of population pressure and urbanisation it is very likely that these open spaces will soon be converted into residential plots with mixed-uses. Apart from horizontal expansion, the city is also growing vertically with introduction of multi-storied buildings (Siddique et al. 2020). According to Ghosh and Sarkar (2021), because Chandernagore is one of the important Urban Local Bodies of the Kolkata Metropolitan Area (KMA), the city's urban scape will gradually replace colonial structures with modern flat culture, as with the other units of the KMA.

Reality Check: Status of Heritage Sites

Chandernagore has diverse and vibrant built heritage structures that have created and shaped the city's cultural identity (ATA 2012). However, when planning goals are taken into account, urban-heritage preservation is not seen as a priority, and thus, established heritage buildings around the city of Chandernagore continue to be relegated to the periphery of the urban plans. Chandernagore's built fabric reflects the powers that have historically dominated and influenced the city, including the Hindus, Portuguese, French and British. Chandernagore has an established heritage with a diverse portfolio of tangible heritage assets. Although the city does not have a UNESCO World Heritage site, only one site, Institut de Chandernagore, is maintained by the Archaeological Survey of India (ASI). As mentioned earlier, most of the heritage building units are in the older municipal wards (1–27) and the concentration is highest in the two adjoining wards of 12 and 16. Some prominent built heritage structures of the city include Institute de Chandernagore, St. Joseph's Convent, Registry Building, Sacred Heart Church, French Administrative Building, Hotel De France, French Jail, Liberty Gate, College Dupleix, Nandadulal Temple, Bura-Shiv Temple, Moran Saheb's Bungalow, Patal Bari, Jora Ghat, Nritya Gopal Smriti Mandir, Lal Dighi, Thistle Hotel or the Chandernagore Subdivisional Court and French Cemetery, among many others (Kar et al. 2020).

Earlier the settlements in Chandernagore flourished along the river Hugli, the presence of the Grand Trunk (G. T.) Road, Strand Road and Burrabazar Main Road, as well as the railway line, aided in the city's gradual urbanisation. Das et al. (2020) divided the city into three zones: (a) Zone-I (Residential Area) covers parts of wards 15, 17 and 18, having significant colonial imprint and at the same time bearing the brunt of modern transformation, (b) Zone-II (Administrative Hub) has the iconic colonial administrative buildings bearing French legacy, which are located in the neighbourhood of Burrabazar area, predominantly covering ward 13, and (c) Zone-III (Mercantile Zone) was once where Fort d'Orleans' (later destroyed by British) was located and now the Urdi Bazar area. The ward 11 has become a prominent commercial hub for the city. Taking into account the population density, distribution of houses, road layout, distribution of open spaces and other socio-economic parameters Chandernagore can be divided into three morphological zones (Table 35.3).

The rise in the real-estate market has increased the land value in certain areas, resulting in unaffordable housing for low-income groups. Developers are buying land in the town's main areas, demolishing heritage buildings and replacing them with

Table 35.3 Morphological divisions of Chandernagore, West Bengal

Zones	Characteristics
Zone-I: River-side area along the bank of River Hugli	• Historical core • Administrative buildings • Old residential houses • Industrial belt
Zone-II: The Inland Zone along G. T. Road, in the east and the Eastern Railway in the west	• Old historical buildings • New residential complex • Commercial areas
Zone-III: The Outer Zone along the city's western periphery	• Newly developed residential houses • Squatter colonies

Source Computed by the authors based on literature review and Field Survey, 2022

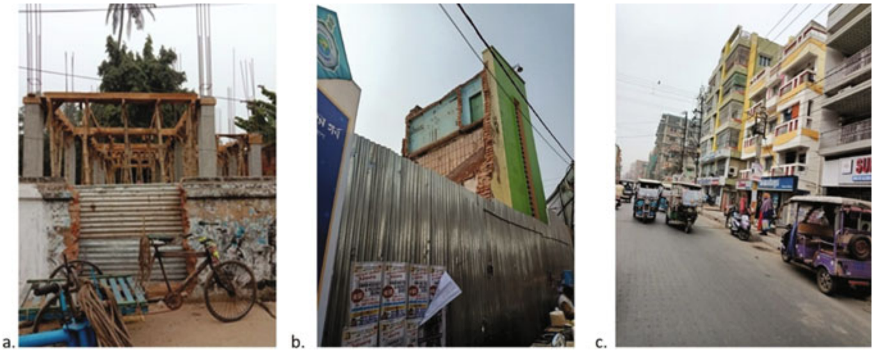


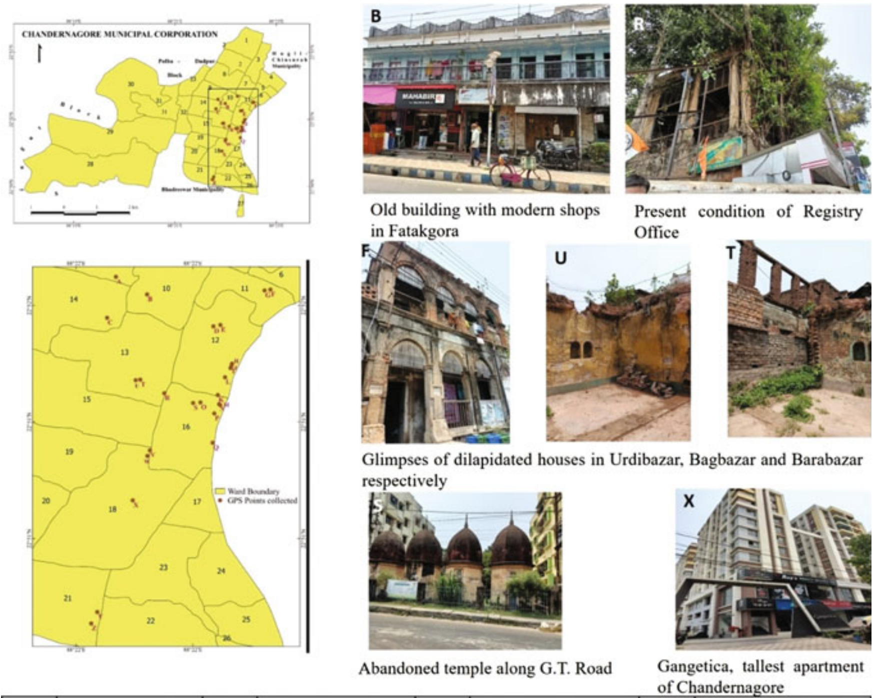
Fig. 35.5 Fading history—**a** A historically significant building in Gondolpara is being demolished to make way for an apartment; **b** Chabighar (Cinema Hall) in Chandernagore, West Bengal is being razed to make way for a mall; **c** Several flat complexes have sprung up along the whole stretch of Grand Trunk Road. *Source* Field Survey, 2022

modern housing with higher density to increase the land value (Fig. 35.5). Significant changes have occurred in the town's main street networks (like Strand Road, G. T. Road, Bagbazar Road and Burrabazar Road).

The present scenario demands a detailed examination of ground reality rather than merely mapping the heritage units to bring out the gradual transformation the small town is going through to keep pace with the changing times. The area along the G. T. Road has good connectivity, and the land price is relatively high. For this, the real-estate developers have eyed this area for urban regeneration, and a host of old villa-type buildings are being demolished, giving way to swanky apartments for residential and commercial purposes, resulting in mixed land use. Due to the scenic beauty of the riverfront, the land price is highest along the Strand Road. Since most of the stretch has several important colonial structures and the promenade is a dedicated public space, land or building conversion has been very limited, and the local administration has been highly proactive in maintaining the colonial public realm. Another sprawling area is along the Burrabazar Road, which is almost the city's centre, buzzing with several activities – administrative, judiciary, educational, etc. Here, the land price is also within reach of the middle class, and thus, many new apartments with modern amenities are replacing the old architectural charm (Fig. 35.6).

Understanding People's Perceptions About Town's Heritage Values

Extensive qualitative research was conducted to ascertain how residents and custodians perceive the town's heritage assets. During the interviews, it was observed that many owners of the present generation (fourth to the seventh generation from the



GPS Point	Location	GPS Point	Location	GPS Point	Location	GPS Point	Location
A	Fatakgora Thakur Bari	H	Government Women's Polytechnic College	O	Sacred Heart Catholic Church	V	Juxtaposition of an old house beside a residential apartment, G.T. Road
B	Old buildings housing shops	I	Chandernagore Court	P	Chandernagore Municipal Corporation	W	Shopping complex near Barasat Gate
C	Modern residential apartment replacing old house	J	Chandernagore Sub-Correctional Home	Q	Bhasha Shahid Smarak	X	Gangetica, tallest building of Chandernagore
D	Kuthir Math, Urdi Bazar	K	Chandernagore Government College	R	Registry Office	Y	Old house under demolition beside G.T. Road towards Barasat Gate
E	Old building still in use for residential purpose	L	Rabindra Bhavan	S	Abandoned temple in Barabazar	Z	A well-maintained old house (Deb Udyan), along G.T. Road
F	Dilapidated house in Urdi Bazar	M	Jora Ghat, Strand Road	T	Dilapidated house in Bagbazar		
G	A well-maintained old house (Garib Khana), Urdi Bazar	N	Tunnel opposite Jora Ghat, Strand Road	U	Dilapidated house in Barabazar		

Fig. 35.6 Distribution and status of various heritage sites across Chandernagore, West Bengal. *Source* Field Survey, 2022

original owner/s) of old homes consider their buildings as liabilities rather than assets. Many owners do not have the funds or adequate economic resources to restore their old properties. The old buildings are often not suitable for the type of accommodation required by the present-day nuclear family structure (broken away from the traditional joint-family system), dissatisfying the present owners. Some family members relocate to new apartment buildings with modern amenities whenever the opportunity and affordability arise. Legal issues occur with buildings that have multiple owners. Buddhadeb Dutta (heritage enthusiast and the Key Informant Interview person) rightly informed that ownership issues centred around the old historic homes. The majority of the mansions are multi-tenanted or contested among families, resulting in a lack of upkeep and maintenance and strife, which has led to many of them being taken to court. As a result, the lawsuits have been pending for years, and many families have relocated. Instead, they would rather sell their properties to real-estate brokers than appear in court regularly. For the last twenty to thirty years, many people from the adjacent towns have come to settle here in Chandernagore. The city's urban fabric has severely altered the original morphology of the entire cityscape. Mr. K. P. Jana (former Chandernagore Education Minister) is well versed in the city's rich heritage buildings and monuments. He moved here fifteen years ago, living in Kolkata, and stated that the city has recently experienced a new flat culture growth. The loss of historic buildings and construction was not as quick as some twenty years ago. Another person, Mr. Biswajit Roy (Officer of the Superintendent in Chandernagore Municipal Corporation), rightly stated that it is difficult to find any physical evidence linked to the reminiscences of French colonisation. Over time, the city saw several changes that weakened the diverse culture that previously subdued its homogeneous character. As a result, a routine commercial or ceremonial visit to Chandernagore without any intention of the investigation will easily ignore the French history of the city. Although the administrative bodies in Chandernagore implemented many plans and initiatives to restore the old historic buildings around the city, the issue remains as to why the city is losing its old historical structures. Mr. Kamal Banerjee of the Indian National Trust for Art and Cultural Heritage (INTACH) said that the town's population has increased in the last ten years because many individuals from Kolkata could not afford to live there settled here. People prefer to purchase a two-room flat than land, which is more expensive. This prompts real-estate brokers to give loans and discounts, and, as a result, vacant land and old historic homes become easy targets for construction.

Chandernagore is home to a diverse collection of heritage structures, including private and public ones. The power that has always ruled and impacted the city is reflected in the private mansions (including French, Portuguese and Natives). Similarly, architectural aspects of public historic sites across the city reflect components and themes that tell their own unique stories. However, public structures are always given precedence over private arrangements. Interviews and focus groups were conducted to gain a better understanding of two essential aspects: I. How rapid urbanisation stimulates the property market to produce more housing, resulting in replacing older buildings with newer buildings with higher densities and II. How the replacement of newcomers weakens the affection that local communities still have for their local heritage since newcomers are often not aware of the heritage value and regional identity.

- *Chandernagore is experiencing rapid urban growth. This creates significant problems in creating heritage awareness and identifying and awaiting opportunities* (Commissioner CMC, Expert Interview).
- *Urbanisation is a threat because many younger generations have left the city, and new owners have been replaced by traditional owners, who find old housing unsuitable for modern lifestyles* (Official of Chandernagore Municipal Corporation, Expert Interview).

- *To save heritage buildings and structures around the city, one needs to have a proper long-term plan involving the citizens and the owner-custodian of the house rather than conducting a day-long walk and talk* (Official WBHC, Expert Interview).
- *With its vibrant edifices and tangible and intangible facets, the city has the potential to become a heritage city* (Official WBHC, Expert Interview).

The city of Chandernagore has diverse and vibrant built heritage structures that have created and shaped the city's cultural identity. However, when planning goals are considered, urban-heritage preservation is not seen as a priority. Thus, old heritage buildings around the city of Chandernagore continue to be relegated to the periphery of urban planning plans (Bose and Mukherjee 2022). The replacement of ancient buildings with new ones destroyed the city's social and cultural character and people's sense of place and identity (Vecco 2010; Yung et al. 2017). Today, it is not easy to find any physical evidence linked to the reminiscences of French colonialism. Over time, several changes occurred in the city that weakened the diverse culture that had previously subdued its homogeneous character. The majority of those who can afford to buy apartments are from the middle class. Those from the wealthy class maintain the old fabrics of their homes through regular renovation and restoration work. The social strata's uniformity is actually a hindrance to the overall system and mindset. The economic set-up further complicates the dichotomies between 'public' and 'private' spaces. On the one hand, the opens up private homes and spaces for heritage exploration and casual visits, creating a newer category of consumerist publics who devour on the distinct consumption of romance and nostalgia around the past. On the other hand, previously public properties that had been part of the city's collective memory have become exclusive elite spaces that are no longer open to the public. The economic strata significantly altered the social and economic structure of the town. The majority of the population is unaware of the significance of the old homes and thus sells them to real-estate brokers for a few rupees. As a result, a routine commercial or ceremonial visit to Chandernagore without any intention of the investigation will easily ignore the French part of the city. Today, the lack of convergence and conflict between multiple actors and networks is a severe hindrance to preserving heritage structures in and around Chandernagore. The dynamic stories related to the house have created and shaped the cultural identity of the city of Chandernagore. It is primarily understood that there is, in fact, no standard classification and valorisation approach towards the declared heritage houses in Chandernagore. The question is still left unanswered as to what type of heritage should be preserved, for what reason, and by whom.

The formal mapping often does not have a connection with the common man and for that involvement of them is much needed. So, while strolling through the city's lanes and byways, interactions with residents and tourists from nearby areas who frequented the city were made and requested few interested ones to draw sketches of the town's network. Later, the sketches were compiled using the modified PRA (Participatory Rural Appraisal) method of transect walk to formulate a layman's understanding of the town's street network and the location of old historic structures along the roadside (Figs. 35.7, 35.8 and 35.9). PRA is a methodology adopted where the rural community is involved in identifying the issues, challenges and opportunities for their own progress by creating a bias-free friendly environment (Government of West Bengal 2016) and in this case similar technique has been applied in urban settings involving active participation of the local residents.

The town's residents are well versed in the city's historic structures. Key informant interviews were conducted with individuals, open-ended questions were addressed, and discussions were held on how to implement sustainable methods of restoring the historic structures that dot the landscape of Chandernagore. The transect walks can be viewed as the first attempt at community participation in heritage mapping and identification, with programs to raise awareness among the local population about

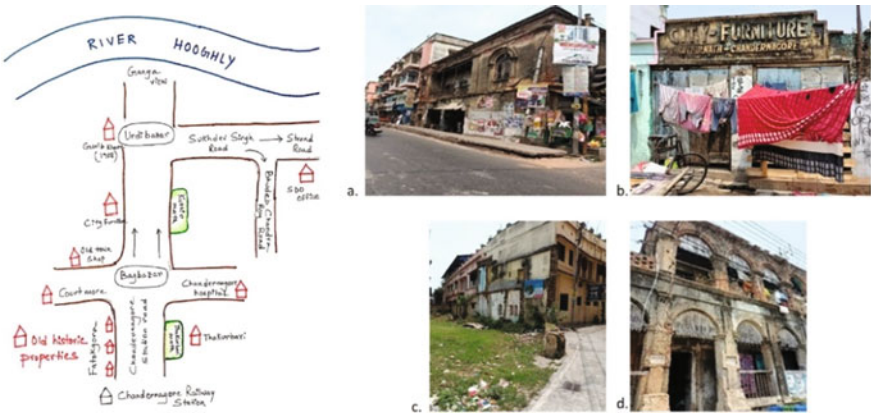


Fig. 35.7 Transect walk I—along the Chandernagore station road—Bagbazar road and Urdi bazar, in Chandernagore, West Bengal, **a** an old shop in Bagbazar area, **b** Old City Furniture shop, **c** Kuthir Math, **d** Gorib Khana (an old historic home). *Source* Field Survey, 2022

Fig. 35.8 Transect walk II—Along the Grand Trunk Road in Chandernagore, from Church Road towards Bhadeswar, in Chandernagore, West Bengal, **a** Liberty gate, **b** Deb Uddan, **c** Kundu house, **d** Kartick Villa, **e** An old town shop. *Source* Field Survey, 2022

Fig. 35.9 Transect walk III—Along the Barasat Road to Vidyalankar and Lokshmiganj Bazar in Chandernagore, West Bengal, **a** Gala Kuthir, **b** Nritya Gopal Smriti Mandir, **c** Lal Dighi, **d** Krishna Bhabani Nari Siksha Mandir, **e** French Cemetery. *Source* Field Survey, 2022

the importance of built heritage. The residents and the locals interviewed suggested rehabilitation of the structures. The walk along the lanes and by-lanes shows that the local people are aware of the city's heritage aspect, which can be used as a positive force in maintaining or restoring the heritage in the future.

Rethinking 'Heritage' Through Action Plan and Outreach Activities

Heritage always calls for inclusion, but the inclusionary aspect of heritage is often underpinned when it comes to development. In the contemporary era, the holistic heritage approach has frequently degraded into layers of ignorance and low priority subjects. Rapid urbanisation in emerging nations has resulted in a complicated process of 'peri-urbanisation' and 'urban sprawl' on the outskirts of big metropolises.

United Nations New Urban Agenda 2016 (UNESCO 2016) emphasised that heritage conservation needs to be a part of inclusive urban economies and has an important role in Holistic Urban Development (United Nations 2017) which can be achieved through all-inclusive approaches (Lorusso et al. 2016). Riganti (2017) pointed out that absence of proper heritage conservation framework has led to unabated urbanising trend at the cost of heritage structures and suggested 'smart heritage' approach as a viable way out. Udeaja et al. (2020) presented a case of Surat city, India, where rapid urbanisation, increasing housing demand led to destruction of heritage at a disturbing rate and recommended avenues to maximise the potential of heritage through sustainable urban-heritage conservation into local urban development projects.

A city in West Bengal named Chandernagore, located in the Hooghly region of Bengal, has seen urban expansion since the time of the French occupation. The city still has important historical structures, but due to urban expansion, the city's rich heritage structures are being eclipsed by the erection of multi-storey buildings. Heritage destruction in Kolkata, its adjacent city, has become a real concern, attracting everyone from ordinary citizens to celebrities to go into the streets to denounce the demolition of old historical monuments around the city (Majumdar 2019). Kolkata, the centre of British authority during the colonial era and home to important British architectural buildings, is the focus of media firms and news networks. Interestingly, media attention and discussions of big conservation projects are mainly limited to big cities like Kolkata. At 40 km from Kolkata, Chandernagore is also caught in the same struggle; however, there has been less emphasis and attention paid to upscale the historic conservation project to raise our own ancient French town. Heritage is frequently viewed from the monument-centric perspective of officially recognised and legally protected buildings and structures that may not be linked with the personal histories, experiences, practices and identities of the people who inhabit and bring a place to life. The town has been holding on to remnants of French traces in public spaces, architecture and culture, despite being upstream from its more well-known cousin, Kolkata. Rapid urbanisation has put the French household architecture, cultural practices and legacy of this trading post at risk, necessitating quick protection. It is crucial to resurrect the town's opportunity by implementing an appropriate historical conservation and management strategy.

The inclusive heritage plan will instil a deep awareness of the river's significance as a conduit for cultural heritage linkages in the minds of all of its activists and scholars. The plan will present a new perspective to galvanise and rethink the understanding that a peripheral city's cultural heritage is equally important in the urban setting within the conventional notions of core and periphery (Fig. 35.10). The field trips also provided a counter-narrative to what is common in the city's core zones, barring the riverside promenade. Wards (31, 32 and 33) in the Chandernagore are well managed with grid patterns, and heritage structures have also received much attention in the wards. The mingling of old and new in open spaces shows us why there is a need to constantly rethink and re-imagine heritage as both a dynamic and fluid process that shapes the town's identity and historical values within its limits (Table 35.4).

The conservation of the heritage buildings is needed for the greater interest of the society which has not only historical facet but also economic, cultural and environmental angles which are also intertwined and procedural guidelines that are well etched in the guidelines of Central Public Works Department 2013. Heritage is frequently portrayed in development discourses as a financial liability for developers and lobbies. A shift from an 'expert-driven approach' to a 'value-based approach' should be made, where values associated with a building should be recognised. The action plan developed here will offer interesting insights to planners and conservationists to rethink and recognise the plurality of heritage values through comprehensive up-scaling of heritage initiatives across the urban fabric (Menchawy et al. 2011).

Fig. 35.10 Charting an inclusive urban-heritage planning model for Chandernagore, West Bengal. Computed by the authors, 2022

Conclusion

The city of Chandernagore is in transitional mode where for urban governance and development bottom-up approach is now being pursued, ensuring multiple stakeholder participation. The micro-urban plans aim to maintain the balance between colonial identity and futuristic modernisation through mixed land use promotion ensuring urban vitality. The resultant heritage tourism and associated businesses can help in developing urban space, unique city centre and prosperous living. Heritage urbanism considers the revitalisation and enhancement of cultural heritage in spatial, urban and landscape contexts, and it explores models for its inclusion in contemporary life (Obad Šćitaroci and Bojanić Obad Šćitaroci 2019). As architecture has a direct bearing on urban form, the authorities have to keep a check on illegal construction and deliberate defacing of heritage units in the name of urban transformation and modernisation. To keep the charm of 'Little Europe' intact, Chandernagore has to develop as a heritage-based smart city providing unique living experience within the KMA.

The ethnographic investigations and heritage mapping crafted in this chapter will deeply ingrain in the minds of academics and professionals a fresh new understanding of how we might 'rethink' heritage. The city's heritage richly manifests culture and architecture. The 'heritage' of the town today has predominantly entered the urban

Table 35.4 Decoding inclusive urban-heritage action planning model for Chandernagore, West Bengal

Building partnerships	Community engagements	Creating a holistic urban-heritage legislation	Establishing a heritage committee	Engaging technical expertise
Identifying potential and strategic partners for management, implementation and knowledge sharing Nurturing private–public partnership Developing coordination of various activities among different actors involved in heritage conservation Focusing on long-term planning and goals rather than short-term plans Initiating collaborations to mobilise funds from targeted state, national and international funding agencies towards more elaborate, comprehensive and sustainable deliverables Designing partnership development program (like online courses and consortium projects) to ensure more participation	Creating a community engagement program by involving the town's communities Organise heritage walks, tours and events to reach citizens and visitors Conducting surveys and interviews with varied age groups to understand their perceptions and aspirations about heritage Strengthening community's knowledge on tangible and intangible assets of the town Developing a collective strategy to comprehend the unique values of various communities involved in heritage preservation Initiating a civic engagement platform for knowledge sharing and idea generation	Integrating local heritage policies in line with national planning interfaces Recognising and valuing tangible and intangible cultural heritage strengthens social cohesion and fosters a sense of place and belonging Enacting laws for heritage units in Chandernagore town so buildings can be restored from further deterioration Promoting a shift from a monumentalism approach to one that addresses heritage and its urban fabric and associated intangible heritage	Establishing a local heritage cell will help to look at the heritage aspects and development more closely Formulating a heritage cell that will thoroughly assess the city's natural and cultural heritage Keeping detailed records of the historical documents Identifying the stakeholders and reaching out to them Form an inclusive heritage group (NGOs, the administrative department, neighbourhood groups) who will do the listing, grading and valuation	Initiating collective mapping and documentation of old heritage buildings and areas Involving technical persons to demonstrate 3D visualisation and share success stories Promoting digitalisation fosters better collaborations and allows people to experience the space digitally Constructing up-to-date and informative websites can act as repositories of information Funding tech-driven restoration activities to boost tourism and that would pave the way for socio-economic development

Source Computed by the authors, 2022

planning discussions. Unfortunately, discussions on heritage are mainly limited to the big cities like Kolkata, while the regional dynamics around the land in other small towns remain largely unexplored. Heritage today needs to be incorporated into the larger domain of policy circles. The people own the city and should know why they need to conserve it. A well-developed strategy will benefit both the city and its residents. The recommendations formulated here provide the city with a fresh new perspective; Chandernagore has a rich history that is distinct from its neighbouring cities. This chapter mapped the city's challenges from heritage conservation perspectives and developed and delivered a sustainable, indestructible, immutable and persistent strategic plan. This plan gave the heritage a chance to function in the community's life and finally provided a chance to integrate and assimilate the protection of the heritage conservation into comprehensive planning programs, through which its history can be retained in contemporary times, facilitating overall urban regeneration of this region.

References

Annoussamy D (2004) L'intermedefrancaisenInde (English).InstitutFrancais de Pondichery, L'Harmattan, Pondicherry. https://books.openedition.org/ifp/2975?lang=en

ATA (2012) Identification of shared cultural heritage: French Heritage in India, Chandernagore. A Project Report, New Delhi

Bandopadhyay B (2003) Chandannagar er SongkhiptoItihas. Chandannagar Corporation, Chandannagar.

Basu A, Kar NS, Kundu M (2020) Urban heritage tourism alongside the bank of Hugli: carrying forward the legacy of "Little Europe in Bengal," India. Tourism in Asian Cities, pp 86–112. Routledge

Bose L, Mukherjee J (2022) Ruined or resurrected: contemporary realities shaping heritage buildings in Chandannagar. J Ind Anthropol Soc 57(2):118–137

Central Public Works Department (2013) Conservation of heritage buildings—a guide. Directorate General, New Delhi

Crawford DG (1902) A brief history of the Hughli district. Bengal Secretariat Press, Calcutta

Das S, Chattopadhyay B (2014) Europe and the Hughli: the European settlements on the West Bank of the River. KP Bagchi and Company

Das R, Nag S, Mitra K (2020) Urban transformations of residential settlements in Colonial Towns: case study of Chandernagore and Serampore. In: Perception, design and ecology of the built environment, pp 23–50. Springer, Cham

Di Giovine MA (2008) The heritage-scape: UNESCO, world heritage, and tourism. Lexington Books

El Menchawy A, Aly SS, Hakim MA (2011) The impact of urban sprawl on the heritage areas through the urban fabric of cities. WIT Trans Ecol Environ 150:299–314

Garden CME (2006) The Heritagescape: looking at landscapes of the past. Int J Herit Stud 12(8):394–411

Garden MC (2004) The heritagescape: exploring the phenomenon of the heritage site (Doctoral dissertation, University of Cambridge)

Ghosh A, Sarkar S (2021) Assessing land use change and potential environmental quality in Chandernagore municipal corporation, India. Environ Dev Sustain 10255–10288

Ghosh A, Mistri B (2015) Rectification of base map of Chandernagore, municipal corporation, West Bengal. Ind J Spat Sci 6(2):40–46

Ghosh S, Siddique G (2018) A dependent city in independent India in the Hughli District: its evolution, expansion and related issues. Int Interdisc Res J 8(4):387–398

Ghosh L (1998) Chandannager-er Kotha (In Bengali). Giridoot, Chandannagar

Government of West Bengal (2016) Participatory rural appraisal. Development circle, Directorate of Forests, Kolkata

Hill SC (1903) Three Frenchman in Bengal or the commercial ruin of the French settlements of 1757. Longmans Green and Company

ICOMOS Study Tour (2017) Europe along the Hooghly. Srerampore (Danish), Chandannagar (French), Chinsurah (Dutch) and Bandel (Portuguese). http://sbh.icomos.org/images/2017_India/Studytour-along-the-Hooghly-Info.pdf, Accessed on 13 Mar 2022

Ivermee R (2020) Hooghly: the global history of a river. Oxford University Press

Kar NS, Basu A, Kundu M, Giri A (2020) Urban heritage tourism in Chandernagore, India: revival of shared Indo-French Legacy. GeoJournal, 1–17

Lorusso S, Cogo GM, Natali A (2016) The protection and valorization of cultural and environmental heritage in the development process of the territory. Conserv Sci Cult Heritage 16:59–88

Majumdar S (2019) Crisis for open Space and Loss of Urban Heritage around Kolkata City. Res J Humanit Soc Sci 10(4):969–972

Menon A (2014) Heritage conservation in India: challenges and new paradigms. In: Proceedings of the SAHC2014—9th international conference on structural analysis of historical constructions, Mexico City, Mexico, pp 14–17

Obad Šćitaroci M, Bojanić Obad Šćitaroci B (2019) Heritage Urbanism. Sustainability 11(9):2669

Rai A (2007) The legacy of French rule in India (1674–1954): an investigation of a process of creolization. City University of New York

Rantanen T (2006) A man behind scapes: an interview with Arjun Appadurai. Global Med Commun 2(1):7–19

Riganti P (2017) Rapid urbanization and heritage conservation in Indian cities BDC. Bollettino Del Centro Calza Bini 17(1):83–98

Seth H (1961) Shanshipta Chandannagar Parichay (In Bengali). Chandannagar Pustakagar, Chandannagar

Seth H (1963) Chandannagar er Porichoy. Nritya Gopal Smriti Mandir Trust, Ramkrishna Printers, Chandannagar, 2010 (reprint)

Siddique G, Ghosh S, Roy A (2020) Assessment of urban expansion and associated spatial transformation of Chandannagar city, West Bengal. Space Cult Ind 7(4):109–121

Taylor J (2015) Embodiment unbound: moving beyond divisions in the understanding and practice of heritage conservation. Stud Conserv 60(1):65–77

Udeaja C, Trillo C, Awuah KG, Makore BC, Patel DA, Mansuri LE, Jha KN (2020) Urban heritage conservation and rapid urbanization: insights from Surat India. Sustainability 12(6):1–26

Ukil A (1996) Morphology of Chandannagar an urban analysis. Unpublished PhD thesis, Department of Geography, University of Calcutta. http://shodhganga.inflibnet.ac.in:8080/jspui/handle/10603/165270

UNESCO (2016) Global report on culture for sustainable Urban development; United Nations Educational, Scientific and Cultural Organization (UNESCO): Paris, France

United Nations (2017) The new urban agenda; United Nations: New York, NY, USA

Vecco M (2010) A definition of cultural heritage: from the tangible to the intangible. J Cult Herit 11(3):321–324

Yung EHK, Zhang Q, Chan EH (2017) Underlying social factors for evaluating heritage conservation in urban renewal districts. Habitat Int 66:135–148

Chapter 36
Review on Application of Call Details Records (CDRs) Data to Understand Urban Mobility Scenarios for Future Smart Cities

Namrata Ghosh, Udit Sarkar, and Prakash Nagesh

Abstract Rapid urbanisation, pollution and inadequate public transit have made mobility more complex, plaguing people worldwide. Urban and Transport planners face a considerable challenge with the vision of future smart cities as it focuses on creating a more cohesive transportation ecosystem for congested cities. The new advancements in mobility with digital innovations and updated real-time data sources supported by data and models will help design an efficient transport system through a thorough understanding of human mobility. However, conducting conventional travel surveys is expensive, with limited sample sizes. Detailed information on travel patterns and the actual demand for travel is hard to get today. Cellular network data collected using the existing infrastructure of mobile operators is a promising new data source and an optimal source to analyse the individual's mobility pattern. Researchers have utilised passively collected data, such as vehicle global positioning system (GPS), mobile network data including call details record (CDR) and Google location history, to define individual travel behaviour patterns. The chapter produces condensed reviews of previous case examples that have adopted similar analytic approaches that involve mobile data aggregation to glean travel information. This study may help researchers and transport authorities understand the potential of mobile phone data as an alternate and more frequently updated data source for future smart cities with several key inferences and the challenges associated with the data. This chapter recommends the framework for data processing and their associated algorithms to understand the mobility pattern using mobile phone data.

Keywords Mobile phone data · GPS data · Urban mobility · Future smart cities

N. Ghosh (✉)
Public System Group, Indian Institute of Management (IIM), Ahmedabad, Gujarat 380015, India
e-mail: namrataghosh033@gmail.com

U. Sarkar
Data and Management Unit, Ministry of Housing and Urban Affairs (MoHUA), Government of India, New Delhi, Delhi 110011, India
e-mail: usarkar@niua.org

P. Nagesh
Centre for Transportation and Logistics, Indian Institute of Management (IIM), Ahmedabad, Gujarat 380015, India

U. Chatterjee et al. (eds.), *Urban Commons, Future Smart Cities and Sustainability*, Springer Geography, https://doi.org/10.1007/978-3-031-24767-5_36

Introduction

With the advent of 'big data era', many huge avenues for understanding human mobility using significant digital footprints, such as geo-tagged social media information, have emerged (Batty 2010) and have been influenced by urban morphology. Urbanism is a way of thinking about how people communicate with the built environment's technologies. The transportation modes (walking, bus, train, flight, etc.), different population groups (age, racial, occupation, etc.), different geographical environments (road network, region, geology, etc.) and different spatial scales are generally considered to be the causes of disparities in the observed patterns of human mobility (intra-urban, inter-urban, etc.). It is well known that mobility resources play several roles in transportation networks and people's travel patterns in urban areas. Data associated with various modes of transportation typically represents human movements for various purposes and at different spatial scales. People from various socio-economic backgrounds use public transit and urban spaces from distinctive perspectives. Geographical factors, population group, workforce like land use distribution and accessibility to resources significantly affect human mobility patterns. For human mobility modelling, it is crucial to understand the constraints of the identified components on observed human mobility patterns. The use of mobile phone data has many advantages in urban planning, such as the activities from people's movements and the intensity of communication at different times of the day.

Understanding human mobility patterns has received a response due to the fast development of location acquisition technologies, complex network sciences and human dynamics (Kang et al. 2013). The hidden patterns of human activity in space and time are important for traffic forecasting (Jiang et al. 2009), disease spread (Wesolowski et al. 2012), tourism management (Ahas et al. 2007), smart city framework (Ratti et al. 2006), urban computing (Zheng et al. 2011) and prediction of future human mobility based on social network structure (Cho et al. 2011). Some studies also track individual spatio-temporal activities for transportation intelligence (Gao et al. 2012; Li et al. 2011; Liao et al. 2010). We revisited research by Hägerstrand (1970) on time geography, which is well known in human mobility studies where researchers use travel diaries to analyse human mobility patterns in space and time due to a lack of updated data collection ability. Detailed information on travel patterns and the actual demand for travel is hard to get today, but due to the introduction of the Internet of Things (IoT) and Information and Communication Technology (ICT) in the cities, real-time feed on individual spatio-temporal movements can be easily extracted. In 2008, González et al. (2008) used mobile phone data to analyse mobility patterns and found that human mobility patterns emerged from the complexity of population heterogeneity and individual Levy Techniques. Due to their inconsistent spatio-temporal data qualities, various techniques often create uncertainty in the concept of human movements.

Why should the urban planning sector be concerned about mobile phone data? Compared to travel survey data, CDR data provides researchers with new opportunities to explore individual mobility from an alternate view, with low cost, a larger sample, greater update frequency and broader spatio-temporal coverage in the cities. Service providers frequently collect mobile phone locations for network management-specific purposes, so databases are technically free of cost to researchers. The databases enable the research of the individual mobility of millions of people across the major city over a prolonged period of time compared to a few thousand household movements within 1–2 days, usually collected through travel surveys. They are continuously updated in real time, which could lead to more efficient and trackable urban performance indicators and promote more prompt policy responses to growing urban problems.

The rapid mobile communication infrastructure installation, accompanied by personal smartphones, greatly influenced city life and technological advancements made people change their social and working habits. As a result, urban dynamics have become much more complex, and data based on the location of smartphones could potentially become one of the most promising new sources for urban analysis. Scientific literature largely lacks areas such as mapping mobile phone operations in cities or simulating urban dynamics based on smartphone movement. Research efforts in the field are limited as obtaining raw data has hindered academic study.

This study takes the first step to understanding the use of CDRs in human mobility characterisation in the Indian context, using a mobile phone location dataset like CDRs footprints. We hypothesise the CDR records to evaluate the effectiveness of the use CDR dataset in human mobility analysis from an individual perspective. For our study, we develop a methodology to establish OD matrices using mobile phone trajectory of individual's continuous and longitudinal movements, though deviating from real human trajectory is captured using call record data (CDR). This chapter facilitates a better understanding of the use of CDR datasets in India and prompts the transport researchers and authorities to utilise real-time data for analysing human mobility patterns as reported in the literature and case examples that have adopted similar analytic approaches that involve mobile data aggregation to glean travel information and explore human movements.

The remainder of this chapter is organised as follows: The next section discusses the existing research related to this study. Section "Case Studies" presents case studies of countries that have used CDR data in their transport studies. Sections "How Location Information of CDR Data Can be Obtained" and "Privacy Issues of Telephonic Regulatory Authority of India (TRAI)" show how the location information is obtained from the CDR data and the privacy concerns in accessing CDR data in India. We then propose CDR data processing framework and interpretation of the CDR data in sections "Data Processing Framework" and "Data Interpretation" based on individual user CDR data to examine the effectiveness of CDR data using origin–destination (OD) matrix analysis to understand the travel pattern. We conclude and discuss this research in section "Conclusion".

Related Work on Previous Applications of Mobile Phone Data to Mobility Studies

This section discusses the relevant research on the applications of CDR datasets in transport studies. As technological advances have evolved, emerging data sources from passive data collection techniques have shown promise in assisting transportation practitioners in better understanding people's movements through space and time. Limited response rates, a big burden on survey participants and high implementation costs plague traditional travel survey results (Wolf et al. 2003). Over the last two decades, mobile phone penetration rates have amplified in both developed and developing countries, and we have seen a surge in the significant research effort. They aim to implement pervasive technologies such as mobile network data, GPS devices and WiFi hotspots in collecting large amounts of real-time data about individuals and cities to investigate various aspects of mobility. Traditional household travel surveys may be supplemented or enhanced with passively collected data, such as GPS, mobile network and cell phone GPS data, to solve relevant problems. Mobile network data, primarily call detail records, were incorporated in other efforts to improve travel surveys.

Due to the unprecedented scale of digital footprints it offers, mobile phone location data obtained by mobile network operators (MNOs) has also emerged as an appealing data source. Call detail records (CDRs) generated by mobile communication activities (i.e. make/receive a phone call, send/receive a text message) are the type of mobile phone location data used in most existing studies. CDRs keep records of the relevant details (e.g. caller/callee, time, duration) of each occurrence and a unique identifier of the cell tower that manages the communication for billing purposes. Related to GPS, a cell phone's location is obtained by measuring its distance from nearby towers. The distance between the towers, the number of them and the signal strength all have an impact on how accurate the data is. Simply stated, data is only captured when the phone is in use, such as when making or receiving a call or sending a message. This technique can be used to find a phone within 50–300 m. When a cell phone moves, the signal from the nearest and strongest tower is used.

On the other hand, a phone does not need to move to shift towers. A phone can 'oscillate' or switch between towers due to network policies on performance optimisation or vicinity to a competing mobile network with similar strength. Oscillation can cause records in travel studies to demonstrate false movements; real mobility can also be wrongly interpreted as an oscillation due to the repetitive nature of the motion. The caller ID, the timestamp, the length of the call or other activity, the longitude and the latitude are all common components of a CDR dataset. There may also be access to additional information, like the call recipient's ID. These IDs are always made anonymous for security reasons, and the formatting differs across carriers.

Consequently, mobile phone data has become a very promising data source for transportation researchers and has strengthened our knowledge of human mobility in recent years. Since individuals are entities in an urban setting, the spatio-temporal aspects of an urban system can be perceived as a generalisation of individual behaviour; thus, CDR data can be used to analyse aggregated mobility patterns of mobile users in cities. Mobile phone location positioning can be done in several ways, for instance, the combination of GPS, signal strength (SS), finger point, ray trace, time difference of arrival (TDOA) and angle of arrival (AOA). Using these data sources would enable researchers to understand better the laws governing human movements and increase the effectiveness and reliability of urban policies.

The future smart cities can be considered complicated mechanisms composed of various processes and components. The rapid growth of IoTs has resulted in inevitable changes in the spatio-temporal aspects of urban mobility, in addition to providing a rich data source for modelling urban systems. Researchers focused on two elements when examining the development of urban and regional planning based on CDR data.

- The spatial structure where the emphasis is given to how mobility patterns in cities are affected by the compactness and size of the cities (Kang et al. 2012).
- Spatial clustering in which hotspot clustering and activity distribution pattern has been addressed (MIT Senseable Lab 2006).

Since CDRs became popular in the research community in recent years, many valuable results about human behaviour and interactions with the urban environment have been observed (González et al. 2008; Song et al. 2010a, b). However, most past studies did not address the representativeness of CDR data in the population-wide context. A large body of literature shows the potential of acquiring geographical location from cell phone data based on mapping the phone usage for urban analysis (Ratti et al. 2006). Calabrese et al. (2011) study describes a new real-time evaluation of the urban dynamics system in Rome based on data from the location of buses, taxis, traffic conditions and pedestrians to understand urban mobility by anonymous monitoring of cellular network data. Bolla and Davoli (2000) suggested a framework for predicting traffic using an algorithm that determines traffic parameters based on location data from cellular phones. Various studies were carried out by Lovell (2001) and Wideberg et al. (2006) on cellular data of mobile devices in terms of transport applications such as traffic data and journey times or speed. To determine the origin–destination flows, different cell phone signalling datasets like billing data consisting of cell phone tower information have been considered and modelled to evaluate the validity of estimating trips (White and Wells 2002). For example, Sohn and Kim (2008) used cell phone tower handover data obtained every time a phone switches a tower it is connected to during a call. While these findings show great potential for using cellular probe trajectory information to understand mobility patterns, all methods have a number of disadvantages that must be resolved before they can be adopted.

There are some other researches on the usage of mobile phone data/CDR data for human travel pattern visualisation (Asakura and Hato 2004; Reades et al. 2009; Phithakkitnukoon et al. 2010; Phithakkitnukoon and Ratti 2011), mobility pattern extraction (Candia et al. 2008; González et al. 2008; Sevtsuk and Ratti 2010; Song et al. 2010a, b; Wang et al. 2012), route choice modelling (Schlaich et al. 2010) and traffic model calibration (Gundlegård and Karlsson 2011; Demissie et al.

2013). The potential for assessing OD matrices using CDR data which are stored by service providers for billing purposes and thus more easily accessible has also been explored by various researchers like (Mellegård et al. 2011), who developed an algorithm to extract CDR data to traffic nodes and Calabrese et al. (2011) focus on the proposing methodology to reduce noise in CDR data. These studies do not discuss the relationship between mobile phones and traffic OD in detail.

Road traffic congestion continues to manifest and propagate in cities around the world. The research by Nair et al. (2019) looks into drivers' route choice behaviour for route selection, with the help of Google Maps API, by gathering traffic speed data from 29 cities worldwide over 40 days. The study compared traffic conditions across global cities on a common datum using crowdsourced data, which has now become readily available for research purposes. Some studies are based on Global Positioning System (GPS) data primarily from navigation devices (Bierlaire and Frejinger 2008; Broach et al. 2012; Hess et al. 2015). In certain areas of the world, navigation system devices are still not generally used.

Certainly, mobile phone datasets can capture partial trajectories of frequent phone users; the sample is huge, thus opening the way to a new paradigm in urban planning. According to researchers, urban structure significantly affects urban-scale mobility patterns, showing that different parts within a city are correlated with different individuals' movement patterns. As a result, the previous study has concentrated on extracting aggregate trends from cell phone data from different urban areas, such as hubs, nodes and places of interest (Phithakkitnukoon et al. 2010). Thus, we discuss some of the case studies where CDR data has been used to understand mobility patterns in different cities.

Case Studies

Dhaka Joint Trip Generation Model Using CDR

The CDR data has been utilised to identify individual mobility pattern using multiple techniques (Bwambale et al. 2020). His chapter explains CDR data's use to predict the trip generation model. The study uses CDR data to verify the reported individual trips in household survey data in Dhaka city. A total of 16,750 household data and 600 million CDR records have been used in the study. The CDR data is analysed to identify users' home locations by identifying a maximum frequency cell tower for each unique ID. Then, home-based trip is extracted for all the users by arranging each user record in order of its timestamp. Using QGIS software, the total trip is calculated for each tower zone.

The proposed framework has significantly tested accurately for trip generation modelling, and it has the potential to model other transport choices, i.e. trip distribution, route choice, etc. This study is a full-proof concept for using mobile phone data fused with the traditional data source to improve the model's temporal and spatial transferability.

Boston Individual Mobility Analysis

The study by Calabrese et al. (2013) compares mobile phone data with odometer reading data to characterise individual mobility. The study helps identify the intra-urban variation of mobility and the non-vehicular component of overall mobility. An algorithm is developed to calculate the users' total trips and the home location at a 500 m-by-500 m grid level. The trip's length is calculated by measuring the distance between the user's consecutive tower location, and the user's tower location estimates the home location at night. The tower location's repetitiveness helps evaluate the home location's accuracy. While comparing the data with census, data showed that 40% of the users had estimated home location with an accuracy greater than 0.5. The result shows that total trip length has been impacted significantly by the spatial distribution of activities like job accessibility. It has been noted that the increasing intersection density negatively impacts total trip length.

When these figures are coupled with vehicle safety inspection results, the study shows that mobile phone traces are a fair proxy for individual mobility and can provide valuable insights into intra-urban mobility trends and the non-vehicular aspect of overall mobility.

Singapore Taxicab and Mobile Phone Data Analysis

In an insightful study by Kang et al. (2013), taxicab trips and mobile phone data are used to understand individual mobility patterns. The datasets consist of 15,000+ GPS logs of taxicabs and 2,000,000+ telecom users' CDR data. The trip length of taxicabs is calculated by measuring the distance between the passenger on board (POB) and the taxicab payment status. To calculate the trip using CDR data, change in two consecutive mobile activity locations is measured. The weekly spatial distribution of taxicab trips and mobile phone movement shows that both trips are highly homogeneous on Sundays. The results also show that it is possible to identify the land use of a particular location by analysing the temporal pattern of incoming and outgoing taxicab trips. The study clarifies the variations in observed human mobility patterns based on taxicab and cell phone data. It also suggests a combined approach to taxicab and cell phone use obtain more in-depth insights into population dynamics, transportation and urban configuration.

How Location Information of CDR Data Can Be Obtained

An urban area is divided into hexagonal cells, or 'cells', with transceiver antennas or 'cell towers' at their centres. When a user travels from cell to cell, the network transfers the call to the next cell tower. Cellular technology enables radio channels to be replicated in non-adjacent cells, allowing a device to accommodate a much larger number of users. Each cell within a cellular network is geographically defined by the range of RF signals perpetuated to multi-dimensional space. When a mobile phone user moves and enters a service cell, the network base stations are designed to recognise that the user is located in the vicinity of the station's area.

In contrast to the latter, utilising data from cell phone networks has many benefits (Townsend 2002). First, travel activity can be explicitly mapped to where it occurs, while on the Internet, activity is linked to the nominal, often fictitious location where a domain is defined. Second, data is not geographically static and, therefore, can account for individual movements as well as the level of communication activity at different times of the day. Third, mobile phones have a very high penetration in most developed countries, making them a perfect technology for acquiring large amounts of statistically relevant data more than the Internet or WiFi; CDR data may include details like the number of calls a person has made to which number and its time and duration of calls to which tower the individual received network while making the particular call. Then, the tower is identified by its unique cell ID number, but it is not always precise as the location is under a sphere of 500 m. CDRs are different from phone tapping in that they contain information, for example, time, date and duration, instead of recording what the person talked about on a phone call. Call data is stored by telecom companies for a period of 6 months, in accordance with government guidelines.

Privacy Issues of Telephonic Regulatory Authority of India (TRAI)

What about privacy? This is the first concern to anyone using location-based devices or apps that may be individual travel movements can be tracked, thus breaching the individual's privacy. Therefore, it is crucial to emphasise that the CDR data mentioned in the chapter does not violate cell phone users' privacy. Sample personal data was received from a single GitHub user (Agarwal 2016) and was treated and analysed in an aggregated and anonymous form, in accordance with the consultation chapter on privacy, security and ownership of the data published by the Telephonic Regulatory Authority of India (TRAI) on July 2018. Thus, it is not possible in any way to link the location data with real individuals or have any access to any personal information like age, gender and phone number.

The chapter aims to create a code of conduct that addresses any privacy concerns that may arise during the review, which is far from encouraging individuals to be tracked and to see the potential of CDR data that could provide researchers with useful travel information to enhance the quality of life in urban communities. Several research findings have shown that sharing such data carries benefits and risks.

The mapping of cell phone data can reveal mobility patterns and interactions in urban centres that are likely to have profound value to urban planning and design. Till date, however, no use of CDR data has been used in India. This may be due to the difficulties in establishing a partnership between academics and network operators and mainly due to government regulations. However, we can see that the mapping of CDR data has been a fertile field of research in many cities across the globe.

Data Processing Framework

The sample of the CDR dataset of a single user is extracted from GitHub. These CDR data consist of anonymous SMS, call log details and other telecommunication transactions of telecom users. The data processing framework for our study is divided into two parts, first, to identify the Base Transceiver Station (BTS) location and, second, to generate the OD matrix from the CDR data, which has been described in the following section. Figure 36.1 represents the summary of the data processing framework. Each attribute in CDR consists of a unique ID (which in this case is the IME number), timestamp, latitude and longitude of the (BTS), which has been used by the telecom user (see Table 36.1).

Tower data conversion

The overall idea is to map the geocoordinates of the BTS and subsequently identify the user's travel pattern. The BTS address is completely unstructured and expressed in a string format. To visualise BTS's location, we first converted them into latitude and longitude values using Google Geocoding API. The BTS address in CDR data enables the capture of the transient origin and destination matrix (Wang et al. 2011), which uses mobile phone data to efficiently and economically capture the travel pattern.

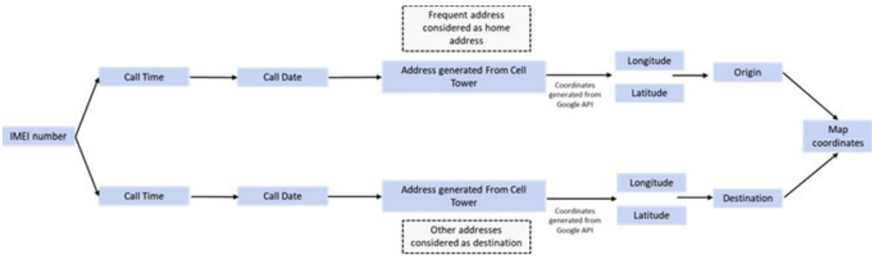


Fig. 36.1 Data processing framework. *Source* Generated by author

Table 36.1 Excerpt of the CDR data

CALL_DIREC	ESN_or_IME	MIN_or_IMS	START_DATE	CALL_TIME	BTS_ADDRESS
IN_CALL	3.54E+14	4.05E+14	01-Jul-12	00:25:04	Old No.36 New
IN_SMS	3.54E+15	4.05E+15	02-Jul-12	01:0S:20	No.28,EVR Rd,
IN_SMS	3.54E+16	4.05E+16	03-Jul-12	05:11:03	Old No.36 New
OUT_SMS	3.54E+17	4.05E+17	04-Jul-12	10:18S7	RAJE5HBATI
OUT_CALL	3.54E+18	4.05E+18	05-Jul-12	10:58:51	No.3/1,Basin
OUT CAIL	3.54E+19	4.05E+19	06-Jul-12	11:28:51	RAJE5HBATI

Source Compiled by author

Tower data to OD matrix

The plotted BTS address has been considered as the user's active location. It is assumed that the serviceable area of a BTS is a traffic analysis zone. To map the OD matrix, initial BTS is considered the origin, and subsequent BTS is considered the destination. For the next set of OD matrix, Destination BTS is changed to Origin BTS, the subsequent BTS is considered the destination, and the process continues. OD cost matrix tool in GIS has been used to calculate the travel pattern.

One limitation of the CDR data is that the geo-tracing of the information depends solely on the unique ID's BTS location. Data can only be traced if the phone has received a call, SMS, or Internet on a certain BTS location. We have used individual CDR data for the study to analyse the travel pattern as it is challenging to extract public CDR in India. The data is extracted from an online source, i.e. GitHub, uploaded by Agarwal (2016). The data comprises 775 call/SMS records, dated between 1 June 2012 and 19 June 2012, of a single user. The CDR data is generated in the following three scenarios,

1. when a user receives or places a call;
2. when a user receives or sends a SMS;
3. when a user connects to the Internet.

Figure 36.2 illustrates the temporal variation recorded over one week. In general, the user generates a few activities on Friday and Saturday. As a result, the number of active pinging from the tower these days shows a decline. The peak is on Tuesday and Wednesday, corresponding to the significant trips generated by the user, respectively.

Data Interpretation

The CDR footprint generated by the single user data is used to identify the user's home location, which is the most frequently used BTS throughout the observation period. From CDR data Fig. 36.3, BTS address, Choolai High Road, Chennai, is the user's home location, and Murugappa Street, Chennai, was the user's regular occupational destination. Other frequent destination travelled by the user includes

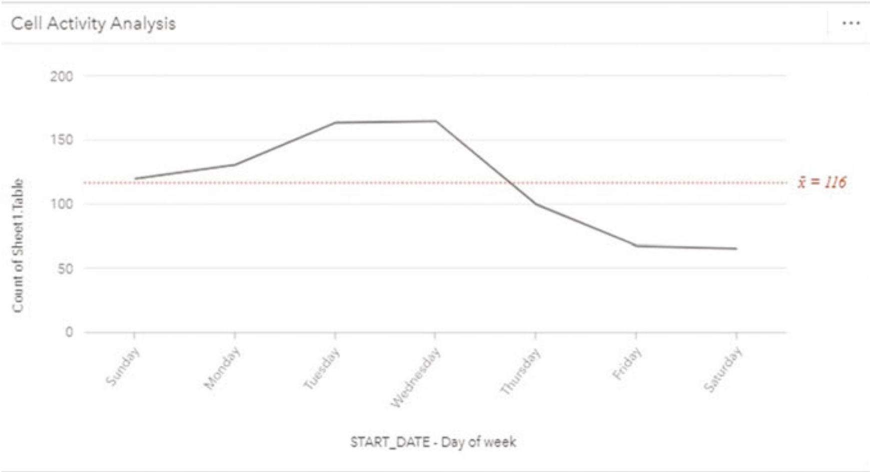


Fig. 36.2 Temporal variation of CDR data over one week. *Source* Generated by author

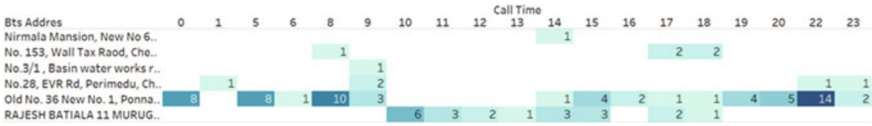


Fig. 36.3 Distribution of user's BTS location. *Source* Generated by author

No. 28 EVR Rd and No. 153 Wall Tax Rd (see Fig. 36.3). The assumptions were based on the number of evidence deduced from the user's call timings. Here, the user's morning and evening calls are deduced as home location, and subsequently, post 10 a.m. till 5 p.m., calls are assumed to be a call from the user's occupation location.

The map shown in Fig. 36.4 attempts to analyse by assessing the mobile behaviour of a single user travelling between different states of India. The OD matrix calculated to analyse the user's travel pattern indicates that the user originated his journey on 1st June 2012 from Chennai and ended in Agra on 19th June 2012. Out of 775 total trips, the user has travelled to 58 unique destinations, including the origin location. In this study, the mobility pattern is analysed based solely on the movement of the person carrying a phone and making calls over 15 days. This mental map determines how an individual moves around cities in India and the travel choices made in the process. Likewise, it builds on the prevalence of cell phones to capture extensive urban dynamics and how it reflects urban interaction patterns.

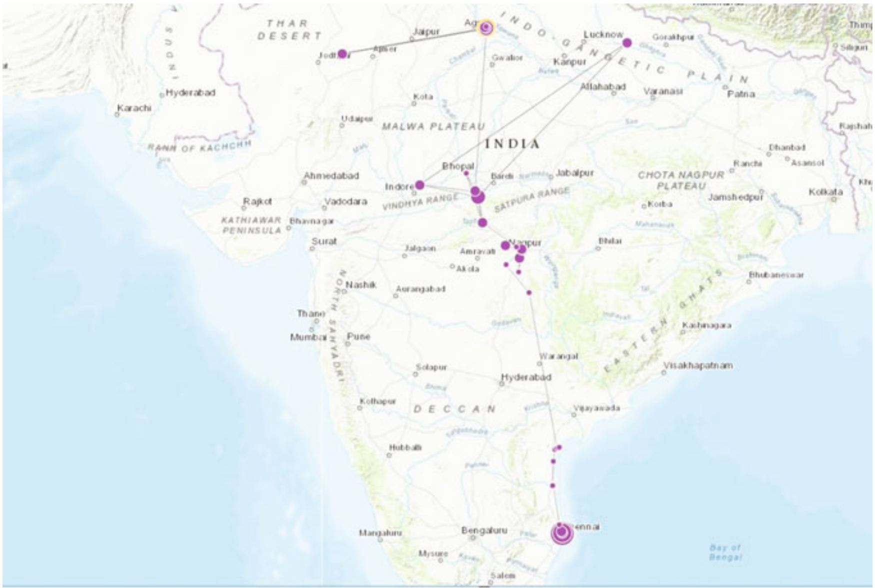


Fig. 36.4 Travel pattern of the user. *Source* GitHub, Sharad Agarwal

Conclusion

This chapter is based on the notion that, despite the boom in the mobile communications market, cellular data is not used in urban analytics in the Indian context. CDRs have been recognised as valuable raw data for human mobility studies. Thus, the aim of the chapter is twofold. This study takes the first step to establish some concepts, demonstrates applications of CDR data in mobility research, summarises state of the art in mapping CDR data and describes some implications for privacy concerns in India. Second, after identifying a lack of research in the application of CDR data in urban studies in India, we present the first findings of an individual user mobility pattern across different cities in India. The important outcome of the research is the data processing framework proposed to understand the travel pattern using CDR data which is interpreted by the author. The methodology is generated based on the individual user mobility analysis. Our objective of this study is to assess the potential of CDR data in mobility research as it has a wide coverage of the population across geographies and can be extracted in real time with relatively low cost. Future research could develop methods to use the CDR data with traffic count data to validate the data, which could be the further scope of the study. Since mobile phone companies already record CDR for billing purposes, the approach is more economical than traditional ones, which rely on expensive household surveys and/or extensive traffic counts. It is also convenient for periodic updates of the OD matrix and extendable for dynamic OD estimation. This method is particularly effective for generating a complex OD matrix where the land use pattern is heterogeneous and asymmetry in the travelling pattern prevails throughout the day. However, there is still a limitation of traditional data sources.

In general, the movements of mobile phones serve as a proxy for all types of human mobility. A brief discussion of potential works based on mobile phone usage is included in this chapter. In recent years, the extensive range of handheld devices and the cell phone infrastructure can provide unlimited real-time information on any geographic area at a very low cost. The lack of understanding of the potential of cell phone data to study urban dynamics is one of the main issues faced by urban and transport researchers. The data processing framework and the interpretation of the CDR dataset analysed in this chapter deals only with an individual user's mobile phone movement. Therefore, access of the CDRs database of all subscribers in any selected study area would have given a deeper understanding of the travel behaviour and the route choice of individuals. Such validation attempts still need to be made in India.

In addition, research has so far been limited to available datasets collected by service providers and the privacy issues in India. The most successful next step will come from ad hoc experiments developed in partnership with India's cell phone operators and government agencies. Such findings seem to open up a new and promising line of urban and transport researchers in India and help calibrate and validate land use and transportation models. In the urban setting, making sense of the infinite flow of data from mobile phone networks is still unknown territory. By analysing data from base stations, urban planners can obtain the ability to monitor quickly evolving urban dynamics that are hard to get with traditional surveys. Furthermore, using data from mobile phones can also deepen our understanding of integrating transportation and land use inference. One promising approach is to use datasets on human movement patterns linked to different modes of transportation to reveal the hierarchical community structure of the city at different scales. In this big data era, understanding the efficacy of CDRs in addressing various research questions can be important to many applicable areas ranging from urban design to transportation planning to air pollution and smart cities.

Acknowledgements The research in this chapter used mobile phone data made available by a GitHub user, Sharad Agarwal.

References

Agarwal S (2016) Comprehensive CDR analyzer—CCAT : call data record analyser for forensic investigation. Available at: https://github.com/sharad1126/ccat (Accessed: 1 Mar 2021)

Ahas R et al (2007) Seasonal tourism spaces in Estonia: case study with mobile positioning data. Tour Manage 28(3):898–910. https://doi.org/10.1016/j.tourman.2006.05.010

Asakura Y, Hato E (2004) Tracking survey for individual travel behaviour using mobile communication instruments. Transp Res Part C: Emerg Technol 12:273–291. https://doi.org/10.1016/j.trc.2004.07.010

Batty M (2010) The pulse of the city. Environ Plann B Plann Des 37:575–577. https://doi.org/10.1068/b3704ed.

Bierlaire M, Frejinger E (2008) Route choice modeling with network-free data. Transp Res Part C: Emerg Technol 16(2):187–198. https://doi.org/10.1016/j.trc.2007.07.007

Bolla R, Davoli F (2000) Road traffic estimation from location tracking data in the mobile cellular network. In: 2000 IEEE wireless communications and networking conference, pp 1107–1112. https://doi.org/10.1109/wcnc.2000.904783

Broach J, Dill J, Gliebe J (2012) Where do cyclists ride? A route choice model developed with revealed preference GPS data. Transp Res Part a: Pol Pract 46(10):1730–1740. https://doi.org/10.1016/j.tra.2012.07.005

Bwambale A et al (2020) Getting the best of both worlds: a framework for combining disaggregate travel survey data and aggregate mobile phone data for trip generation modelling. Transportation 1–28. https://doi.org/10.1007/s11116-020-10129-5

Calabrese F et al (2011) Estimating origin-destination flows using mobile phone location data. IEEE Pervasive Comput 10(4):36–44. https://doi.org/10.1109/MPRV.2011.41

Calabrese F et al (2013) Understanding individual mobility patterns from urban sensing data: a mobile phone trace example. Transp Res Part C: Emerg Technol 26:301–313. https://doi.org/10.1016/j.trc.2012.09.009

Candia J et al (2008) Uncovering individual and collective human dynamics from mobile phone records. J Phys a: Math Theor 41:1–11. https://doi.org/10.1088/1751-8113/41/22/224015

Cho E, Myers SA, Leskovec J (2011) Friendship and mobility: user movement in location-based social networks. In: Proceedings of the ACM SIGKDD international conference on knowledge discovery and data mining, pp 1082–1090. https://doi.org/10.1145/2020408.2020579

Demissie MG, de Almeida Correia GH, Bento C (2013) Intelligent road traffic status detection system through cellular networks handover information: an exploratory study. Transp Res Part C: Emerg Technol 32:76–88. https://doi.org/10.1016/j.trc.2013.03.010

Gao Y et al (2012) 'Visualization of Taxi Drivers' Income and Mobility Intelligence'. In: Advances in visual computing, Springer, pp 275–284. https://doi.org/10.1007/978-3-642-33191-6_7

González MC, Hidalgo CA, Barabási AL (2008) Understanding individual human mobility patterns. Nature 453(7196):779–782. https://doi.org/10.1038/nature06958

Gundlegård D, Karlsson JM (2011) Road traffic estimation using cellular network signaling in intelligent transportation systems. Wireless Technol Intell Transp Syst

Hägerstrand T (1970) 'Reflections on "what about people in regional science?"'. Papers of the Regional Science Association, pp 7–24. https://doi.org/10.1007/BF01954291

Hess S et al (2015) Developing advanced route choice models for heavy goods vehicles using GPS data. Transp Res Part E: Logistics Transp Rev 77:29–44. https://doi.org/10.1016/j.tre.2015.01.010

Jiang B, Yin J, Zhao S (2009) Characterizing the human mobility pattern in a large street network. Phys Rev E 80(2):1–11. https://doi.org/10.1103/PhysRevE.80.021136

Kang C et al (2012) Intra-urban human mobility patterns: an urban morphology perspective. Phys A 391(4):1702–1717. https://doi.org/10.1016/j.physa.2011.11.005

Kang C et al (2013) Exploring human movements in Singapore: a comparative analysis based on mobile phone and taxicab usages. In: Proceedings of the ACM SIGKDD international conference on knowledge discovery and data mining. https://doi.org/10.1145/2505821.2505826

Li B et al (2011) 'Hunting or waiting? Discovering passenger-finding strategies from a large-scale real-world taxi dataset. In: IEEE International conference on pervasive computing and communications workshops, PERCOM Workshops 2011, pp 63–68. https://doi.org/10.1109/PERCOMW.2011.5766967

Liao Z, Yu Y, Chen B (2010) 'Anomaly detection in GPS data based on visual analytics'. In: VAST 10—IEEE conference on visual analytics science and technology 2010, Proceedings, pp 51–58. https://doi.org/10.1109/VAST.2010.5652467

Lovell DJ (2001) Accuracy of speed measurements from cellular phone vehicle location systems. ITS J 6(4):303–325. https://doi.org/10.1080/10248070108903698

Mellegård E, Moritz S, Zahoor M (2011) Origin/destination-estimation using cellular network data. Proceedings—IEEE international conference on data mining, ICDM, pp 891–896. https://doi.org/10.1109/ICDMW.2011.132

MIT Senseable Lab (2006) Mobile landscape graz in real time. Available at: http://senseable.mit.edu/graz/ (Accessed: 28 Feb 2021)

Nair DJ et al (2019) Characterizing multicity urban traffic conditions using crowdsourced data. PLoS ONE 14(3):1–16. https://doi.org/10.1371/journal.pone.0212845

Phithakkitnukoon S, Ratti C (2011) Inferring asymmetry of inhabitant flow using call detail records. J Adv in Inf Tech 2(4):239–249. https://doi.org/10.4304/jait.2.4.239-249

Phithakkitnukoon S et al (2010) Activity-aware map: identifying human daily activity pattern using mobile phone data. Hum Behav Underst 6219(3):14–25. https://doi.org/10.1007/978-3-642-14715-9_3

Ratti C et al (2006) Mobile landscapes: using location data from cell phones for urban analysis. Environ Plann B Plann Des 33(5):727–748. https://doi.org/10.1068/b32047

Reades J, Calabrese F, Ratti C (2009) Eigenplaces: analysing cities using the space—time structure of the mobile phone network. Environ Plann B Plann Des 36(5):824–836. https://doi.org/10.1068/b34133t

Schlaich J, Otterstatter T, Friedrich M (2010) Generating trajectories from mobile phone data. TRB 89th annual meeting compendium of papers, vol 339, pp 1–18. Available at: http://www.isv.uni-stuttgart.de/vuv/publication/downloads/201001_JS_TO_Fr_TRB-Generating_Trajectories_from_Mobile_Phone_Data.pdf

Sevtsuk A, Ratti C (2010) Does Urban mobility have a daily routine? Learning from the aggregate data of mobile networks. J Urban Technol 17(1):41–60. https://doi.org/10.1080/10630731003597322

Sohn K, Kim D (2008) Dynamic origin-destination flow estimation using cellular communication system. IEEE Trans Veh Technol 57(5):2703–2713. https://doi.org/10.1109/TVT.2007.912336

Song C, Koren T et al (2010a) Modelling the scaling properties of human mobility. Nat Phys 6:818–823. https://doi.org/10.1038/nphys1760

Song C, Qu Z et al (2010b) Limits of predictability in human mobility

Townsend AM (2002) Mobile communications in the 21st century city. In: Diaper D, Sanger C (eds) The wireless world: social and interactional aspects of the mobile age. Springer, pp 62–77

Wang P et al (2012) Understanding road usage patterns in urban areas. Sci Rep 2:1–6. https://doi.org/10.1038/srep01001

Wang J et al (2011) Dynamic OD expansion method based on mobile phone location. In: Proceedings—4th international conference on intelligent computation technology and automation, ICICTA 2011, pp 788–791. https://doi.org/10.1109/ICICTA.2011.204

Wesolowski A et al (2012) Quantifying the impact of human mobility on malaria. Science 338(6104):267–270. https://doi.org/10.1126/science.1223467

White J, Wells I (2002) Extracting origin destination information from mobile phone data. Road Tran Sporl Inf Cont pp 30–34. https://doi.org/10.1049/cp:20020200

Wideberg JP, Caceres N, Benitez FG (2006) Deriving traffic data from a cellular network. In: 13th world congress on intelligent transport systems and services, pp 1–8

Wolf J, Oliveira M, Thompson M (2003) Impact of Underreporting on mileage and travel time estimates: results from global positioning system-enhanced household travel survey. Transp Res Rec 1854:189–198. https://doi.org/10.3141/1854-21

Zheng Y et al (2011) Urban computing with taxicabs. In: UbiComp'11—Proceedings of the 2011 ACM conference on ubiquitous computing. New York, NY, pp 89–98. https://doi.org/10.1145/2030112.2030126

Chapter 37
Streamlining Freight Transport Through Planning Interventions in Vijayawada City

Vullapu Sai Sesidhar, Jagrati Jain, and Ayon Kumar Tarafdar

Abstract Freight transport has many challenges in urban mobility. Goods vehicles are designed with an objective to maximise the capacity of the vehicle; as a result, the dimensions of goods vehicles are more and speed of vehicles is less. As the vehicles are big in size, they occupy more PCUs on the road resulting in reduction of road capacities and they also block the visibility of comparatively smaller passenger vehicles. As the goods vehicles are not designed for higher speeds, slow-moving goods vehicles retard the movement of passenger vehicles on roads leading to congestion and queuing of other vehicles behind the slow-moving vehicle. The congestion and reduced speeds increase the travel time of all vehicles, and this results in economic and financial losses for all public, private and goods vehicles. In this backdrop, the study aims to analyse the issues related to transport of goods vehicles in urban areas and to identify alternatives which can improve the efficiency of freight transport in urban areas. The city of Vijayawada is a trading and commercial hub of Andhra Pradesh with a well-connected railway network and a road network with two national highways passing through the city and connected through the air by an international airport located at Gannavaram 20 km from the city. All the agriculture products from surrounding areas of the fertile delta formed by the Krishna River are traded and exported to other parts of the country from Vijayawada. Apart from this, the city also acts as a junction for North–South and East coast corridors connecting major cities like Hyderabad, Visakhapatnam, Chennai, Bangalore and Machilipatnam which brings a significant amount of freight traffic to the city on a daily basis. The huge freight volume flowing through the city every day causes hindrance to city traffic causing delays, congestion, pollution and safety threats to road users of the city but the movement of goods vehicles is an important aspect to keep the trade activity uninterrupted. The city lags in infrastructure for handling freight such as parking areas, loading/unloading, bypassing, and weighing. In this context, the study aims to improve the traffic scenario of Vijayawada by developing an

V. Sai Sesidhar (✉) · A. K. Tarafdar
Department of Planning, School of Planning and Architecture, Vijayawada, Andhra Pradesh, India
e-mail: sesi.vegeta@spav.edu.in; sesi.vegeta@gmail.com

J. Jain
RV College of Architecture, Bengaluru, India

U. Chatterjee et al. (eds.), *Urban Commons, Future Smart Cities and Sustainability*, Springer Geography, https://doi.org/10.1007/978-3-031-24767-5_37

efficient freight distribution plan in the city that strategies upon the network improvement for freight and suggests appropriate land use development and decentralises the freight functions of the city.

Keywords Urban freight · Truck terminal · Goods infrastructure · Freight corridor · Freight terminal oriented development

Introduction

Background of the Study

Freight is an important part of urban economy which helps in providing the citizens and businesses with the daily essential products. All the urban services from shops, restaurants, markets, and construction materials are delivered by urban freight. It is essential to ensure that urban freight delivers these goods reliably at a minimal cost for functioning of urban economy. However, these freight movements generate vehicle trips that cause congestion, air pollution, road accidents and other negative impacts to urban transport system. (Ministry of Housing and Urban Affairs 2016).

Indian Freight transport sector is expected to grow with a compounded annual growth rate of 13% which is driven by the growth of marketing, retail, fast-moving consumer goods, etc., which are largely dependent on freight transport. In India, 63% of total freight movement is carried out through road with 2.2 million multi-axle trucks and 0.6 million mini trucks carrying 3000 million metric tonnes of annual load (Madhu Errampalli 2019).

In the Indian context, most of the class I cities do not have adequate infrastructure like truck terminals, bypass, ring road, integrated freight complex, etc., for efficient handling of freight which is passing through and coming to the city. Certain urban areas restrict the freight from entering into city during peak hours due to hindrances caused by freight and heavy vehicles to the urban traffic. This results in obstruction of freight movement at a corridor and highway level due to the presence of cities in between and the restrictions existing. In some other cities where the restrictions are not existing, the freight traffic causes congestion, delays and pollution in the urban areas leading to economic losses.

Freight traffic which is destined and within the city is essential for the city's economic dynamics and cannot be ignored. The relation between urban traffic levels and urban liveability of Indian cities has gained importance, but most of the focus in literature is found to be in passenger traffic. Lack of unified institution or department for freight management in city and state and central government policies makes the sector more complex. In general, freight vehicles such as Light Commercial Vehicles and Heavy commercial vehicles emit a greater proportion of SOx, NOx and COx pollutants than passenger vehicles.

Need for the Study

There are four different types of freight in urban supply chain which are Heavy/Bulk freight, Medium value medium density freight, Business-to-Business (B2B) freight for urban consumption and Business to consumer (B2C) freight for urban residents; from these, the Heavy/Bulk freight and Medium value medium density freight are mostly part of regional supply chain where as B2B and B2C are part of urban supply chain. The Heavy and medium density freight vehicles are mostly restricted to the access of city roads and are diverted to the bypass or ring roads but the B2B and B2C vehicles will be plying on the urban roads. To make these B2B and B2C freight, more efficient crowdsourced shipping and delivery are being practised by courier partners in some countries. As the goods vehicles are not designed for higher speeds, they tend to retard the movement of passenger vehicles on roads leading to congestion and reduced travel speed for all urban vehicles. This results in economic and financial losses and brings down the efficiency of the urban roads. Also, in general, freight vehicles such as Light Commercial Vehicles and Heavy commercial vehicles emit a greater proportion of SOx, NOx and COx pollutants than passenger vehicles. Relation between urban traffic levels and urban liveability of Indian cities has gained importance, but most of the focus in literature is found to be in passenger traffic and mass transit. While passenger traffic is important, freight is critical and integral to the growth of the city's economy as the retail and wholesale needs of each city are dependent of freight traffic. Hence, it is important to focus on analysis and study into this sector for any urban context as they are integral to growth and economy of a city and yet considered as an externality. Existing literature points towards rerouting or reducing the volume of urban freight, which is applied in many contexts. However, there is little literature on how to strategically use existing urban transport infrastructure to address the issue.

Existing Issues Related to Urban Freight

See Fig. 37.1.

Economic

About 40% of the freight trips made in India are empty or less than half load trips which indicates reduction in the efficiency of freight movement and less vehicle utilisation. Heavy freight vehicles entering urban areas cause congestion as 80% of class I Indian cities experience V/C ratios of more than 1 in the major arterial roads of the city. This results in congestion and reduction in travel time, thus contributing to the economic losses in terms of time and fuel. The projected freight considering

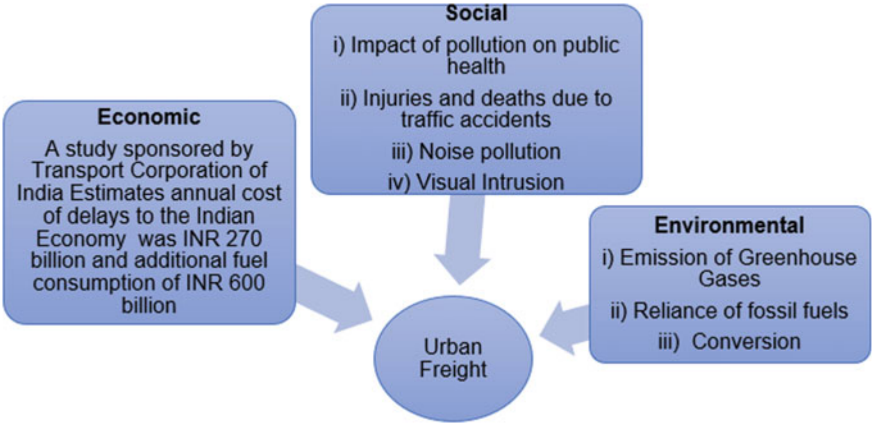


Fig. 37.1 Impacts of freight on urban areas (Transport Corporation of India 2015)

the current growth rates worsens the V/C ratio to more than 2 in most of the cities like Vijayawada.

Total annual economic loss for the Indian economy due to the cost incurred by delays is Rs 270 Billion, and additional loss due to excess fuel consumption is Rs 600 Billion.

Social

As most of the class I cities in India lacks in bypassing and ring roads for movement of freight, the presence of heavy vehicles on urban roads becomes unavoidable which comes with a bundle of social issues such as

- impact of pollution caused by heavy vehicles on public health;
- injuries and deaths due to traffic accidents caused by low visibility and obstruction of vision by heavy vehicles;
- the heavy vehicles generate noises greater than 60 dB which causes adverse health effects on citizens.

Environmental

Freight and heavy vehicles emit toxic pollutants such as Carbon monoxide and oxides of nitrogen and sulphur which worsens the air pollution index of cities and makes the air unbreathable as the heavy vehicles emit proportionately more, i.e. 40% pollutants in the urban traffic which worsens the situation in the cities where the heavy vehicles pass through urban roads.

Research Methodology

Aim

To improve the Urban Freight Scenario of Vijayawada City through streamlining the freight mobility.

Objectives

1. To estimate the Quantum and characteristics of urban freight transport in Vijayawada city.
2. To assess the Impact of freight traffic on urban transport in terms of congestion and delays.
3. To forecast urban freight demand for Vijayawada city.
4. To identify the requirement for Infrastructure related to parking, storage, and servicing of freight traffic with spatial suitability analysis.
5. To develop a city-level freight traffic management plan in terms of routing, restrictions, zoning, and facilities.

Research Hypothesis

Implementing an effective freight distribution model using alternative routing based on freight demand improves urban traffic scenarios in terms of congestion and travel time.

Research Questions

Can an effective freight management model be integrated with urban mobility planning in a trading and business hub like Vijayawada city?

Scope and Limitation

- The scope of the study is to identify the existing issues pertaining to urban freight transport of Vijayawada city and improve the efficiency of urban freight transport for seamless movement of freight in the city.

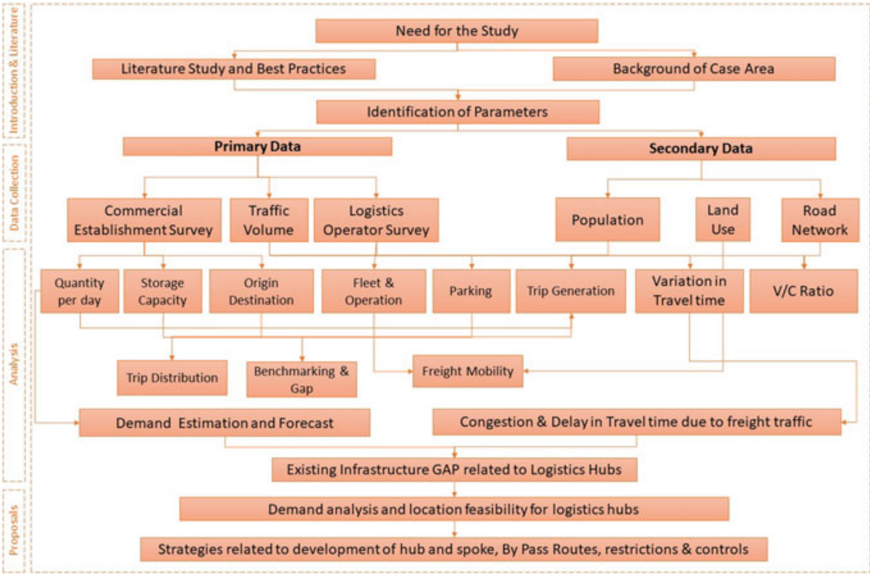


Fig. 37.2 Methodology (*Source* Prepared by Author)

- The research may not cover much in detail of the financial evolution of proposed alternatives (Figs. 37.2 and 37.3).

Literature Review

There are some established concepts and good practices in theory for sustainable urban goods movement. However, their application in II-tier cities like Vijayawada is not found in literature. However, the literature broadly speaks about urban freight policymaking and strengthening of policy framework for the sector but where less attention is being paid to the sector by governments at national, state and municipality levels which is hindering the process. The efficiency issues in the urban goods movement due to vehicles running loaded with lower than the capacity and return trips of empty vehicles which results to increase in V/C ratio of roads, traffic congestion, issues in loading and unloading, increased fuel consumption and parking issues. Coming to the upgradation or provision of urban freight infrastructure, the issue is faced with uncertainty and inadequate availability of urban freight movement data. So, there is a need for integrated urban freight data collection framework which helps decision-makers to understand goods movement patterns and come up with better solutions.

In the urban freight movement, it is observed that in many cases goods vehicles deliver part load trips to the businesses or consumers in the urban areas which increases the effective number of trips to deliver the same amount of goods in the

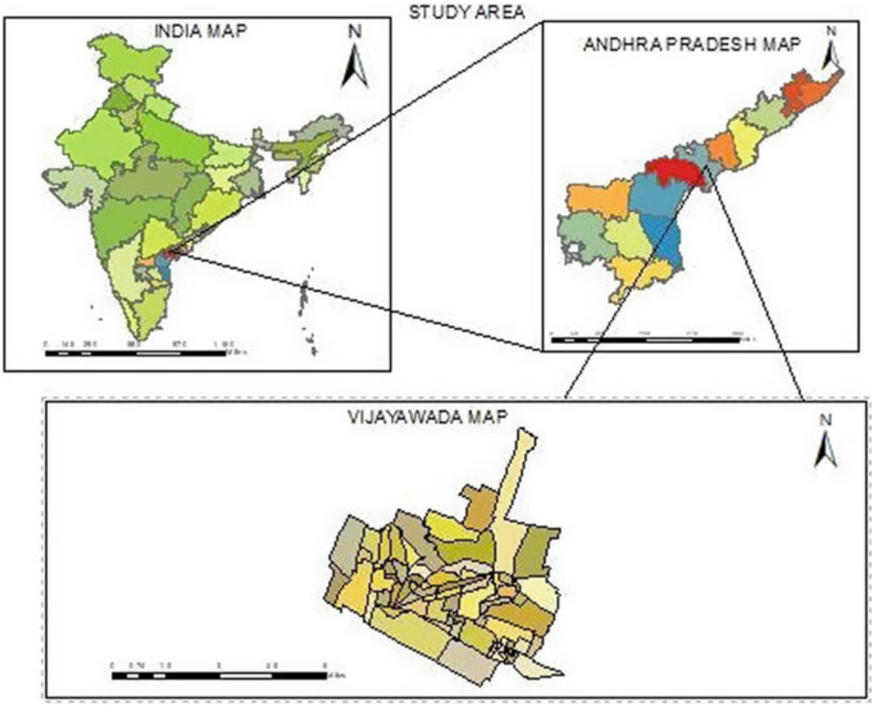


Fig. 37.3 Vijayawada location map (*Source* Sri Harsha 2020)

city. Establishment of consolidation centres where the pooling of trips can be done diminishes the need for goods vehicles to deliver part loads into urban areas and it also helps in increase of load utilisation factor of goods vehicles. An organised urban freight distribution model can largely improve the urban logistics and helps to save in costs of congestion, empty trips, excess fuel, infrastructure, etc., and help for an organised and free movement of goods in the urban areas also reducing the future congestion. The large players of logistics market in the country Amazon, Flipkart and other express courier services use the hub and spoke distribution model for logistics and have been very successful in implementation of the same for door-to-door deliveries throughout the country. Thus, the hub and spoke goods distribution model can be considered as one of the best and successful models. It is important in this context to take up a case like Vijayawada to demonstrate and find the operational modifications needed to apply the said concepts and improve/regulate freight traffic in the city (Federal Ministry for Economic Cooperation and Development 2014).

Research Papers

See Tables 37.1 and 37.2.

Table 37.1 Review of research papers

Article title	Sustainable urban freight transport adopting public transport-based crowd shipping for B2C deliveries	Urban freight distribution: Impact of delivery time on Sustainability
Author and publisher details	Valerio Gatta, Edoardo Marcucci, Marialisa Nigro and Simone Serafini—By European transport research review (https://etrr.springeropen.com/track/pdf/10.1186/s12544-019-0352-x)	Abdelhamid Moutaoukil, Gilles Neubert, Ridha Derrouiche–Online Paper by International Federation of Automatic Control (IFAC) Hosting by Elsevier Ltd. (https://www.sciencedirect.com/science/article/pii/S2405896315006813)
Case area description	Rome, Italy	Saint Etienne, France
Datasets/parameters/indicators used	480 Stated preference (SP) Sample surveys with demographic, social, behavioural, trip, crowd shipping configurations using SP, shipping cost, time schedule flexibility	Number of customers, fixed cost of acquisition/rental of type k vehicle α, demand for customer, distance of the arc, capacity of a vehicle, emission of an empty and loaded vehicle of type k
Analysis method(s)	Potential demand side and supply side modelling using econometric method. Horizon year potential demand estimation	Fleet size and mix vehicle routing problem and sustainability, economic cost of routing problem
Findings and conclusions	Crowd shipping provides a good delivery service in the last mile. Automated parcel lockers (pickup and drop) location is the most relevant feature even more important than remuneration	Distribution centre often appears as a good solution to meet the new objective of the policymakers, redesigning the flow of goods while not increasing the cost, reducing pollution and making the city more attractive
My overall remarks	The parameters such as Shipping fee, shipping time, and time schedule flexibility can be adopted for the case area freight demand estimation	Redesigning the flow of goods vehicles through vehicle routing problem by detailed situation analysis can fetch significant savings in form of congestion and delays

Sources Valerio Gatta (2019), Abdelhamid Moutaoukil (2015)

Table 37.2 Review of research papers

Article title	Costs of congestion: literature-based review of methodologies and analytical approaches. Scottish executive, Edinburgh
Author and publisher details	Grant-Muller and SMLaird, JJ—Scotish Executive (http://eprints.whiterose.ac.uk/76210/)
Case area description	Birmingham, UK
Datasets/parameters/indicators used	Mean and variable (standard deviation) journey times from link to link, throughput (vehicles per time interval), annual delay per road user
Analysis method(s)	To quantify the congestion of traffic flow in terms of delay in travel time using above-mentioned indicators and comparing the same between links
Findings and conclusions	There is strong empirical evidence that growth in vehicle kilometres is a function of income and travel impedance or generalised cost. Transport policy that increases incomes and reduces travel impedance has to use other measures to prevent an increase in vehicle demand or has to reduce the need to travel
My overall remarks	The indicators such as mean journey time and variance in journey time can be adopted in the study to determine the impact of freight on urban traffic

Source Anon (2006)

Learnings from Literature

From the article Sustainable urban freight transport adopting public transport-based crowd shipping for B2C deliveries, the parameters such as shipping fee, shipping time, and time schedule flexibility can be adopted for the case area freight demand estimation.

From the article urban freight distribution: impact of delivery time on sustainability; the redesigning the flow of goods vehicles through situation analysis can fetch significant savings in form of congestion and delays.

From the article costs of congestion: literature-based review of methodologies and analytical approaches; the indicators such as mean journey time and variance in journey time can be adopted to quantification and mapping of congestion due to urban freight. This helps to fulfil the objective of identifying impact of freight on urban traffic.

Table 37.3 Population

Name	Population
Vijayawada (M Corp.)	1,021,806
Enikepadu (OG)	11,039
Nidamanuru (OG)	10,375
Ramavarappadu (CT)	22,222
Prasadampadu (CT)	13,941
Penamaluru (OG)	13,170
Kanuru (CT)	49,006
Poranki (CT)	25,545
Total	1,143,232

Case Area Description

Introduction

Vijayawada is 2nd most populated city in the state of Andhra Pradesh with a population of 11.57 lakh as per census 2011. It is located on the banks of river Krishna. The city is spread in an area of 61.88 km^2 with 3.5 lakh households. The city is one of the major trading and business centres of the state and is known as the business capital of Andhra Pradesh.

Demography

The total population of Amaravati Metropolitan Region Development Authority is 11.43 lakhs which include the municipal corporation of Vijayawada, outgrowths of Enikepadu, Nidamanuru and Penamaluru and census towns of Ramavarappadu, Prasadampadu, Kanuru and Poranki (Census of India 2011) (Table 37.3).

Transportation

Roadways

Vijayawada is a major transport hub of South India. It is connected by 3 National highways passing through the city which are National Highway 65 (Machilipatnam to Mumbai) which is passing from east to west, National Highway 16 (Chennai to Kolkata) which is passing from south to north and National Highway 30 (Vijayawada to Sitarganj) originating at Vijayawada. The city has one major bypass connecting National Highway 65 and National Highway 16 from Gollapudi to Ramavarappadu.

Railways

Vijayawada is well connected to various parts of country through railway network. It is one of the biggest railway junctions in India and is a divisional headquarters under South Central Railway administering a running track of 1646 kms. The following main lines pass through Vijayawada:

- Vijayawada–Guntur–Guntakal–Hubli/Bangalore;
- Vijayawada–Tenali–Gudur–Tirupati/Chennai;
- Vijayawada–Gudivada–Narsapur/Machilipatnam;
- Vijayawada–Rajahmundry–Vizag–Howrah;
- Vijayawada–Warangal–New Delhi/Secunderabad.

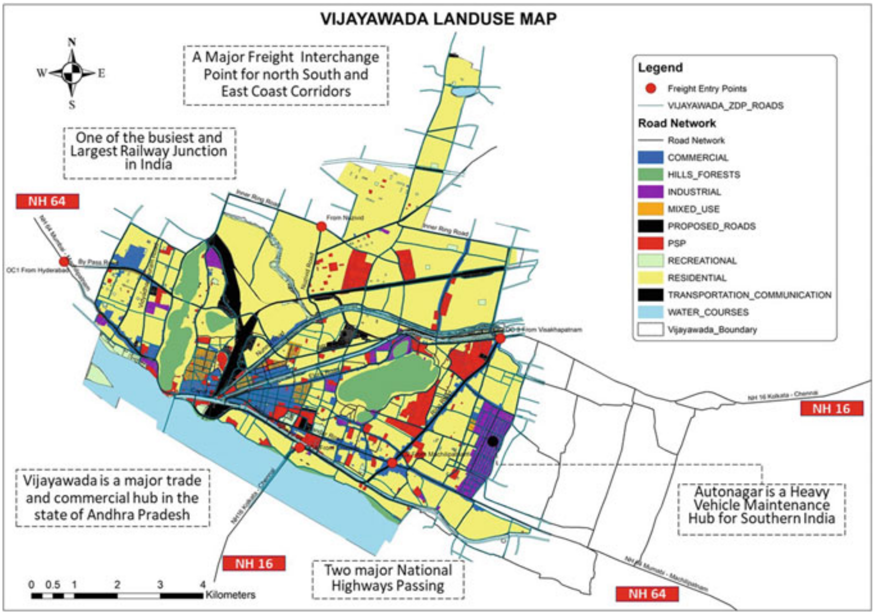
Airways

Vijayawada has an international airport located at Gannavaram which is 18 kms from the city and has flights operating to Delhi, Hyderabad, Bangalore, Jaipur, Singapore, Ahmedabad and many other places.

Logistics

Vijayawada has seen a tremendous growth of population, economic and administrative activities and associated vehicles, due to the bifurcation of the state of Andhra Pradesh in 2015 and the development of the Vijayawada region as the working capital of the State. Vijayawada, being a transport and commercial hub, has everyday consistent amount of freight transport to the city (Map 37.1).

The city acts as a trading hub for the surrounding districts of Krishna, Guntur and West Godavari where the agricultural and other primary sector products are transported here for trade and export. As the surrounding area and districts fall under Krishna and Godavari delta regions, the fertile soils of delta give a good yield of agricultural crops like Paddy, Sugarcane, and Groundnut. Tonnes of Agricultural Products and civil supplies are traded every day at wholesale market complex located at Mahendranagar by farmers and merchants across the country apart from this Rytu bazar at MG roads serves as a wholesale trading hub for vegetables across the state and imports/exports from other states too. The city stands as one of the largest exporters of mango in the country from Asia's biggest mango market located at Nunna. The Jawaharlal Nehru Auto Nagar Industrial Estate popularly known as Auto Nagar is an industrial park dedicated for automobile industry located in the city and is one of the largest automobile hubs of Asia which has been established with a motive



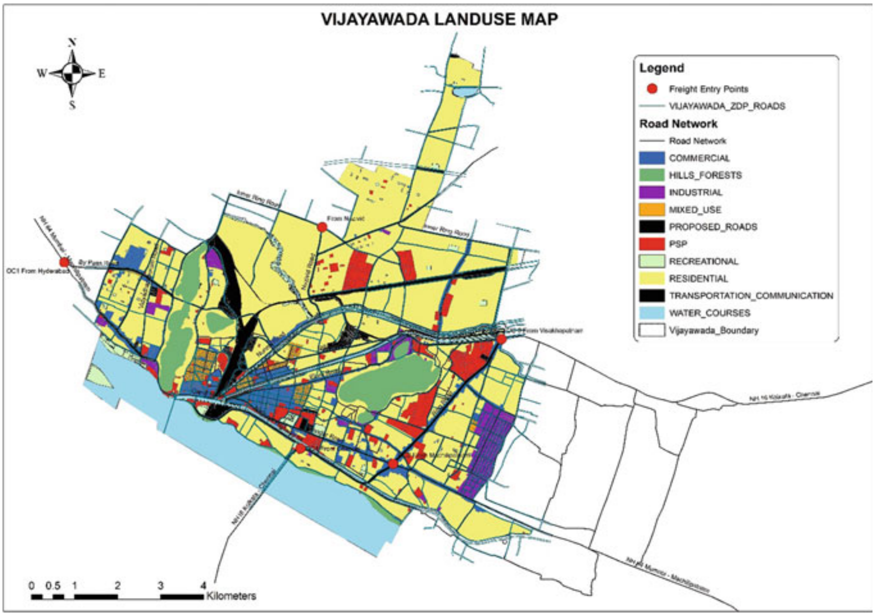
Map 37.1 Vijayawada introduction map

to provide service and repairs for Heavy Motor Vehicles. Numerous electrical and mechanical workshops are functioning in the huge industrial estate that sprawls in an area of 276 acres of land where automobile body building works, clutch and brake servicing, electrical works, radiator works, painting works, etc., are carried out every day for which many Heavy gear and commercial vehicles from across the state and neighbouring states visit the Auto Nagar.

As the city has a well-established rail network and is a major rail head in the country, import and export of goods from and to all over the country is carried out from the city. The city has 3 goods train siding with loading and unloading facilities at Vijayawada Thermal Power station for Coal, Nagarjuna Cement for Cement at Kondapalli and Food Corporation of India at Krishna Canal for agricultural and food products. The city is a part of proposed network of Dedicated freight corridors by Indian Railways where it acts as a junction for North–South (Delhi – Chennai) and East Cost (Kharagpur – Vijayawada) dedicated freight corridors which gives a scope for large increase in the goods traffic of the city.

Land Use

The Vijayawada land use depicts a majority share of residential with 50% of land. The Public Semi-public and commercial land uses are equally distributed throughout the city. Industrial land use is concentrated in south-east part of city where Autonagar the automobile hub is located and Andhra Pradesh Industrial Infrastructure Corporation Limited is located (Vijayawada Municiapall Corporation 2010) (Map 37.2 and Fig. 37.4).



Map 37.2 Vijayawada land use map

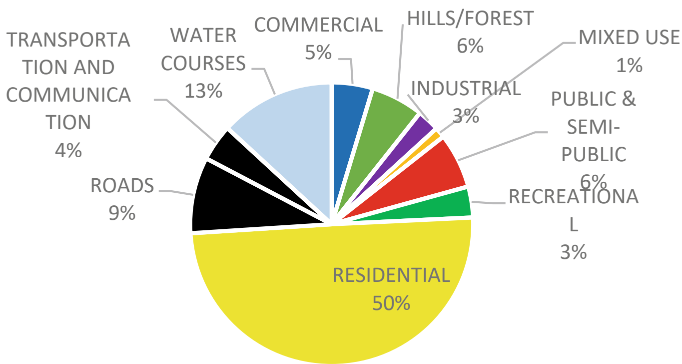


Fig. 37.4 Land use pie chart

Data Collection

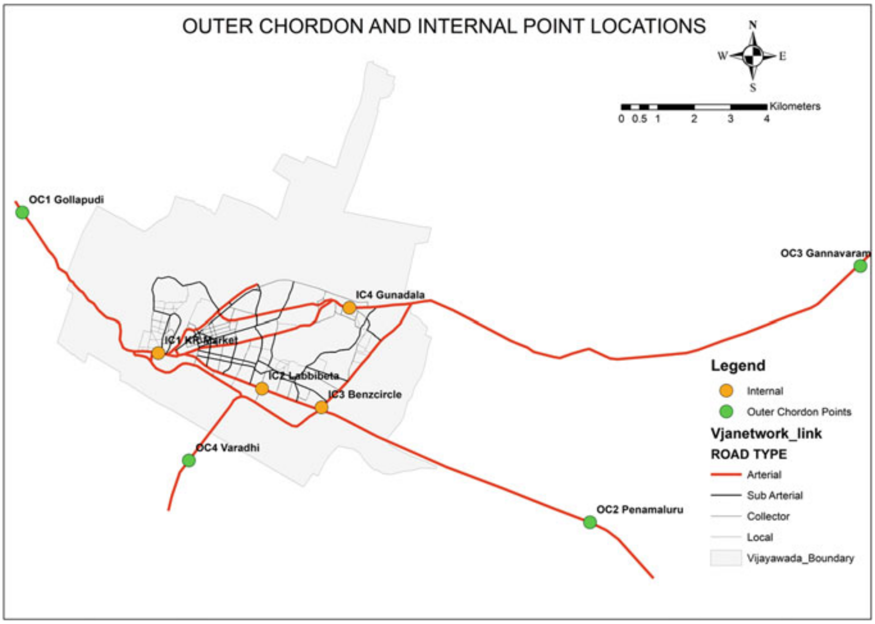
From the outcomes of literature study, the objectives have been mapped to the respective parameters and further with the related indicators. Based on the indicators, the data required for working out objectives has been identified and would be further collected through primary and secondary data collection through surveys like classified traffic volume counts, logistics operator survey and commercial establishment survey. Other secondary data would be collected from master plan, census of India and Municipal corporation of Vijayawada (Map 37.3; Table 37.4).

Three primary surveys have been conducted for the study which are

- Classified traffic volume counts;
- Logistics Operator Survey;
- Commercial establishment survey.

The following table shows sample and location details of the surveys conducted for the study (Tables 37.5 and 37.6).

The logistics operator and commercial establishment survey are carried out to capture the data related to freight infrastructure and mobility pattern.



Map 37.3 Survey location OC map (*Source* Primary Survey 2021a, b)

Table 37.4 Parameter and indicators

Objective	Parameter	Indicators
To estimate the quantum and characteristics of urban freight transport in Vijayawada city	Existing freight infrastructure, freight traffic characteristics	Share of freight traffic, road network length and density, freight volume, V/C ratio, terminals, loading/ unloading facilities, freight generation and attraction zones
To assess the impact of freight traffic on urban transport in terms of congestion and delays	Congestion and delays due to freight traffic (In specific routes/corridors)	Variation in travel time and traffic density of public and private transport as compared between freight routes/corridors and non-freight routes/corridors
To forecast urban freight demand for Vijayawada city	Wholesale and retail sector demand, trip length, travel time	Population, consumption, origin and destination, distance, travel times on various routes in relation to wholesale markets and commercial nodes, demand areas for location of logistics hubs and distribution network
To identify requirement for Infrastructure related to parking, storage and servicing of freight traffic with spatial suitability analysis	Benchmarking related to logistics hub design	
To develop a city-level freight traffic management plan in terms of routing, restrictions, zoning and facilities	Strategies related to development of hub and spoke, bypass routes, restrictions and controls and facilities management	

Sources Anon (2006), Abdelhamid Moutaoukil (2015)

Table 37.5 Primary survey

Survey	Location	Sample collected
TVC	OC1 Hyderabad	1 Day
TVC	OC2 Machilipatnam	1 Day
TVC	OC3 Vizag	1 Day
TVC	OC4 Chennai	1 Day
TVC	IC1 KR Market	1 Day
TVC	IC2 Labbipet	1 Day
TVC	IC3 Benz Circle	1 Day
TVC	IC4 Gunadala	1 Day
Logistics Operator Survey	VRL, SRS, Perishable and Agriculture operators	10
Commercial Establishment	MG Road, KR Market, Wholesale market	40

Table 37.6 Data collected—primary survey

Survey	Data collected	Application
Traffic volume count	Classified hourly volume count	Volume, classification, peak hour, V/C
Logistics operator	Fleet data, parking, loading and unloading	Fleet Utilisation, parking demand and Infrastructure
Commercial establishment	Warehouse, OD, quantity of goods handled, type of commodity	Type of goods, Desired Line Diagram

Analysis and Findings

Outer Cordon Comparative Analysis

From the total traffic volume chart of comparative analysis of all outer cordon points, we can see that outer cordon 1 (OC1) on National Highway 64 towards Hyderabad has a major traffic volume of 50,137 vehicles compared to other outer cordon points (Figs. 37.5 and 37.6).

From the outer cordon comparative analysis, it can be observed that the 2-Wheeler is predominant mode at all the outer cordon points. In the freight, mostly 2-Axle truck and 3-Axle truck stand as predominant mode of transport (Map 37.4).

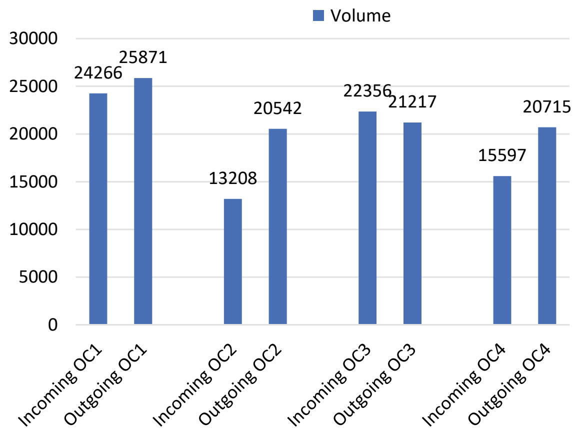


Fig. 37.5 Traffic volume count OC (Primary Survey 2021a, b)

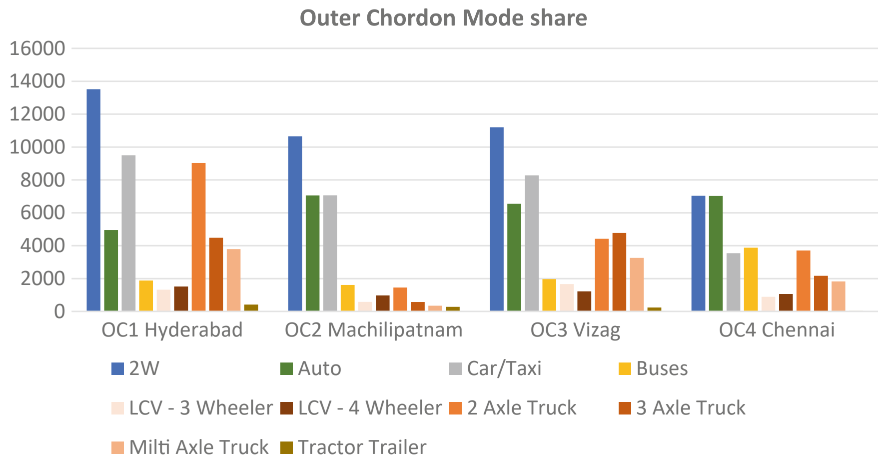
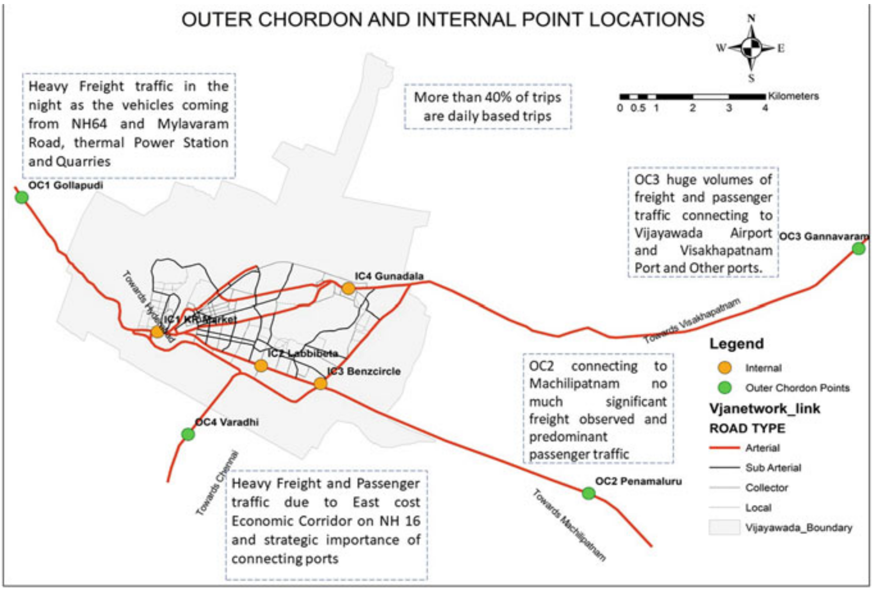


Fig. 37.6 Outer cordon mode share (Primary Survey 2021a, b)



Map 37.4 Outer cordon TVC inference map

Traffic Volume Count Inferences

From the classified traffic volume count survey conducted at 4 outer cordon points by comparing and analysing the data, following inferences have been drawn out for four outer cordon points.

Outer Cordon 1 on National Highway 64 (Machilipatnam–Mumbai) towards Hyderabad at Gollapudi.

Outer Cordon 1 has recorded highest total volume of vehicles with a total of 50,137 vehicles incoming and outgoing per day. This point has the highest share of freight traffic compared to other points as heavy freight traffic is received from Dr. Narla Tata Rao Thermal power station, Nagarjuna cements at Kondapalli and stone quarries near Ibrahimpatnam.

Outer Cordon 2 on National Highway 64 (Machilipatnam–Mumbai) towards Machilipatnam at Penamaluru.

Outer Cordon 2 has recorded a total of 33,750 vehicles incoming and outgoing per day, and this point has lowest share of freight traffic compared to others due to not much significant activities at Penamaluru; however, traffic is comparatively more at Autonagar and Patamata.

Outer Cordon 3 on National Highway 16 (Kolkata–Chennai) towards Visakhapatnam at Gannavaram.

Outer Cordon 3 has recorded a total of 48,227 vehicles incoming and outgoing per day and this point has a moderate share of goods vehicles as it is connecting to Vijayawada airport and Visakhapatnam port.

Outer Cordon 4 on National Highway 16 (Kolkata–Chennai) towards Chennai at Varadhi.

Outer Cordon 4 has recorded a total of 36,312 vehicles incoming and outgoing per day and this point has a moderate share of goods vehicles being on East Cost economic corridor with strategic importance of connecting ports.

Truck Operator Survey

Type of commodities graph generated from the origin–destination survey conducted as a part of truck operator survey shows that food grains, industrial materials and building materials are major commodities as vegetables, paddy and other food grains are brought from nearby villages and are traded and transported from city (Figs. 37.7 and 37.8).

As per the response from truck operator survey for the operational difficulties faced by truck operators, the major issue faced is no parking which has been reciprocated by 33% of the respondents and followed by that the next major issue faced by operator is spatial and temporal restrictions which is reciprocated by 21% of respondents (Map 37.5).

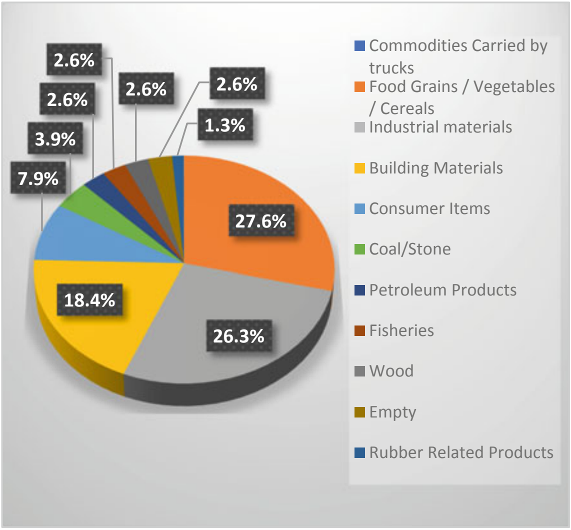
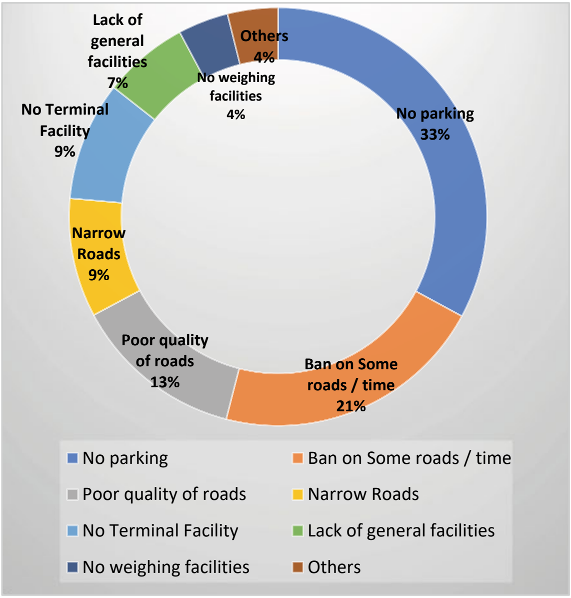
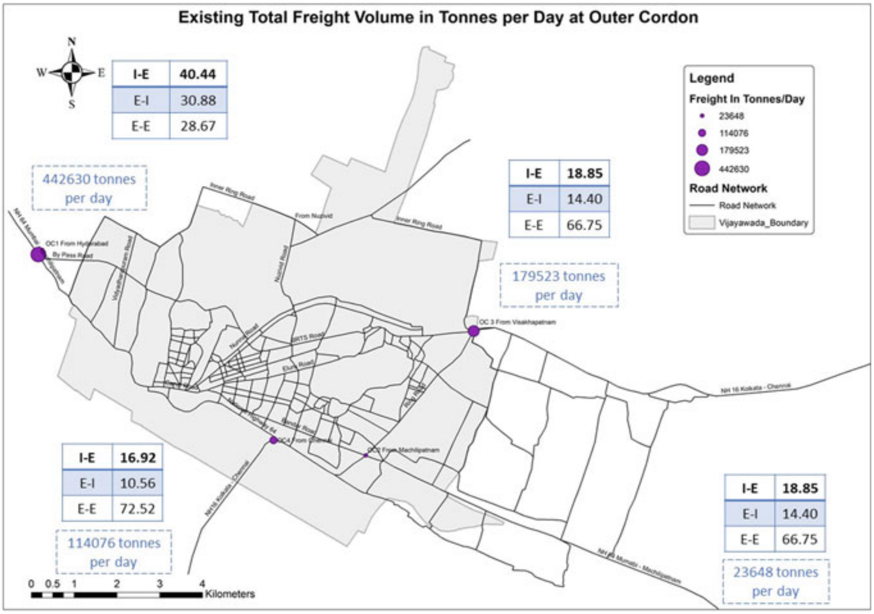


Fig. 37.7 Type of commodities (Primary Survey 2021a, b)



(Primary Survey, 2021)

Fig. 37.8 Operational difficulties (Primary Survey 2021a, b)



Map 37.5 Existing freight volume Map

Impact of Freight on Urban Traffic

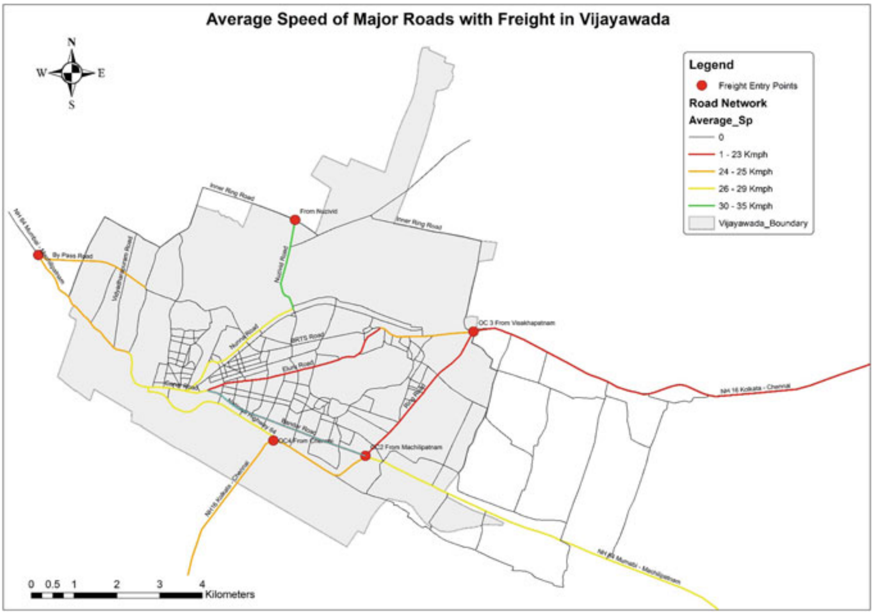
Average Speed with Freight

The average speed of major roads with freight in Vijayawada map shows the average running speed of major arterial roads in the city which is the speed including freight traffic on the roads (Map 37.6).

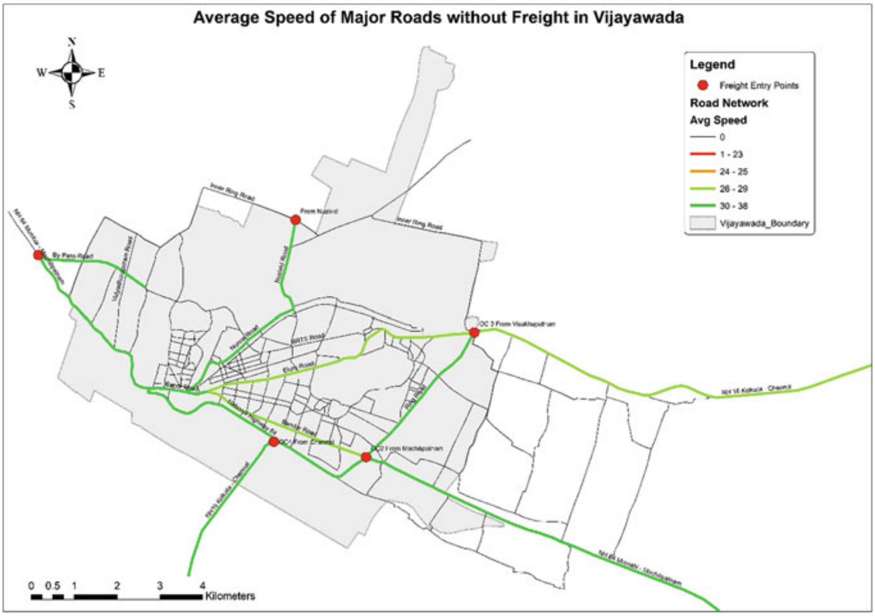
Average Speed Without Freight

The average speed of major arterial roads without freight traffic is calculated by using average speed of major roads with freight and subtracting the freight volume from the total volume which we get from classified volume count and multiplying it with the passenger density we get the new average speed of roads without freight traffic (Map 37.7 and Fig. 37.9; Table 37.7).

From the table showing average speeds of major roads with and without freight traffic in Vijayawada, it is evident that a significant improvement of more than 5 kmph is seen in the average speed of major roads like National Highway 64, Bypass road and Ring road which shows a considerable impact of freight on the average speeds of major roads in Vijayawada (Fig. 37.10).



Map 37.6 Average speed of major roads with freight



Map 37.7 Average speed of major roads without freight

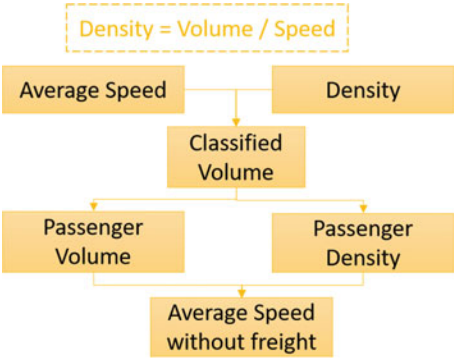


Fig. 37.9 Average speed calculation

Table 37.7 Average speed with and without freight

S. No.	Road name	Freight allowed	Average speed	Average speed without freight
1	Gunadala Road	Yes	23.92	27.65
2	Bandar Road	Yes	22.55	25.33
3	Bypass Road	Yes	**24.53**	***30.20***
4	Canal Road	Yes	29.35	34.25
5	Eluru Road	Yes	22.60	26.21
6	National Highway 64	Yes	**29.35**	***35.53***
7	NH 16 Kolkata - Chennai	Yes	22.31	27.85
8	NH 64 Mumbai - Machilipatnam	Yes	**28.12**	***34.36***
9	NH 64 Mumbai - Machilipatnam	Yes	**25.19**	***38.12***
10	NH16 Kolkata—Chennai	Yes	24.35	29.15
11	Nunna Road	Yes	27.54	33.26
12	Nuzividu Road	Yes	34.63	38.10
13	Ring Road	Yes	**23.61**	***33.60***

The simple regression graph shows an inverse relation among journey speed of the roads and freight traffic volume which implies reduction in journey speed with increase in freight volume.

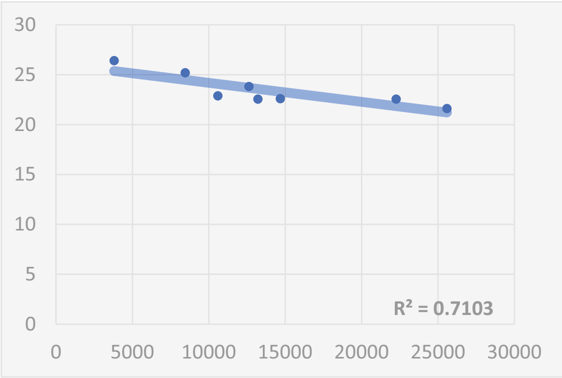


Fig. 37.10 Journey speed versus freight volume

Freight Analysis Zones (FAZ)

Freight analysis zone is a smallest geographical unit of analysing freight traffic in urban areas. An urban area is delineated in freight analysis zones based on various factors. However, in this case land use, administrative boundary and freight routes have been used for the delineation of Freight analysis zones and the study area has been delineated into 32 freight analysis zones of which 28 are internal zones and 5 are external zones used for analysing external traffic (Fig. 37.11 and Map 37.8).

The land use is considered as main aspect for delineation of freight analysis zones as trip production and attraction are function of land use. From the commercial and industrial zones map of Vijayawada, it can be observed that most of the commercial areas are concentrated in the core area of the city and industrial zones are concentrated in the south-eastern part of the city (Map 37.9).

The delineated freight analysis zones map shows study area delineated into 32 freight analysis zones. Form the map, it is evident that major wholesale commercial zones are at the core area where major arterial roads meet in the city. The residential zones are distributed along the core area of the city whereas the public semi-public are concentrated in two different areas of the city.

From the freight analysis zone, the type of freight analysis zone based on predominant land use and function of the zone has been tabulated in the adjacent table. 11, 12, 16 and 13 are the major transport zones which include bus station, railway station

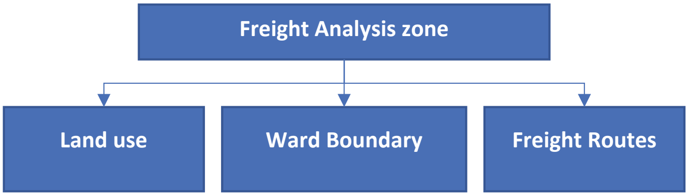
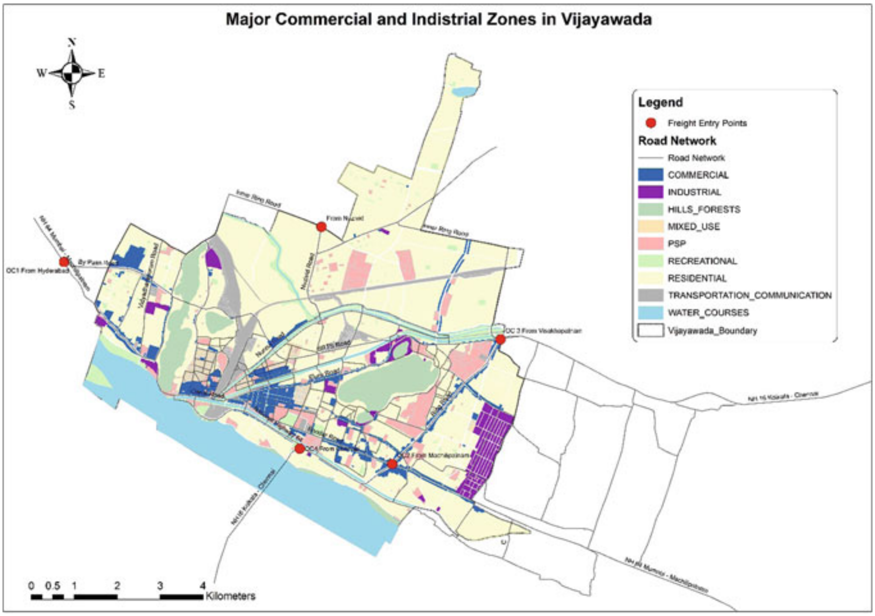
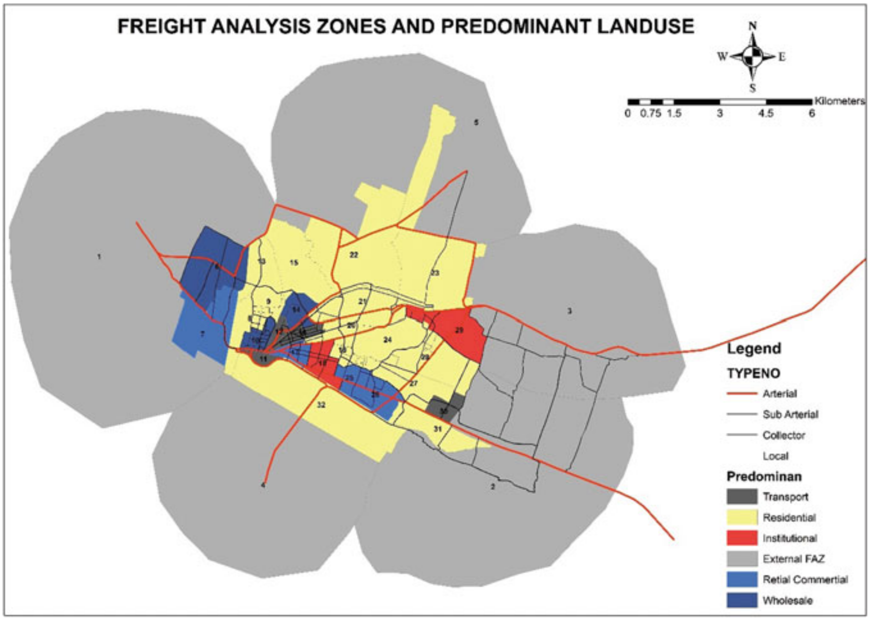


Fig. 37.11 Freight analysis zones (FAZ)



Map 37.8 Major commercial and Industrial zones map



Map 37.9 Freight analysis zones with predominant land use

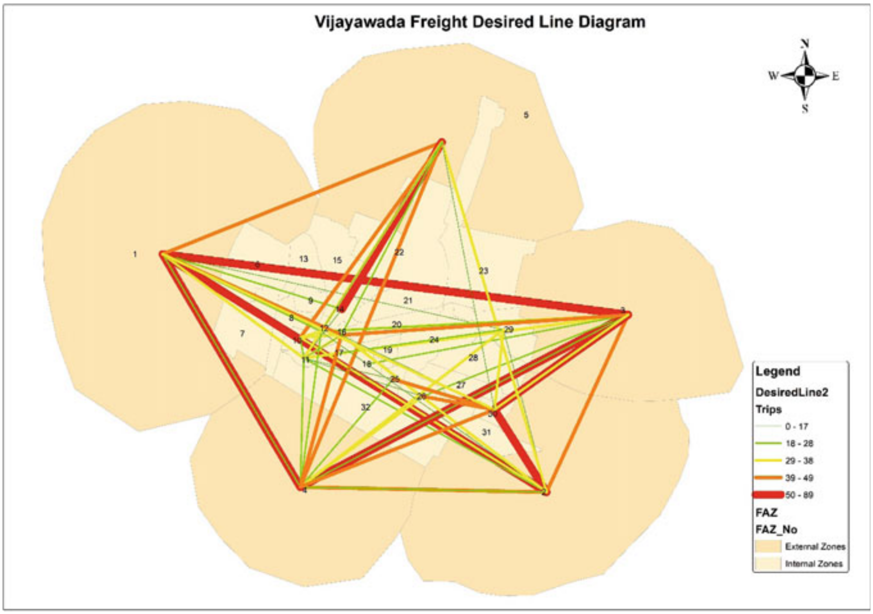
Table 37.8 Freight analysis zone type

FAZ type	FAZ no
Retail	7, 17, 25, 26
Wholesale	6, 10, 14
Transport	11, 12, 16, 30
Institutional	18, 29
Internal FAZ	6–32 (27)
External FAZ	1–5 (5)

and also private passenger and freight transport zones in the city. There are 27 internal and 5 external freight analysis zones (Table 37.8).

Desired Line Diagram

The Desired Line diagram is built on origin destination data collected from the truck operators through truck operator survey. The origin–destination data is tabulated into the Freight analysis zones and is calibrated using the shortest distance matrix in order to obtain the origin–destination trip matrix. The origin–destination trip matrix is linked with freight analysis zones to generate Freight desired line diagram of Vijayawada city (Map 37.10).



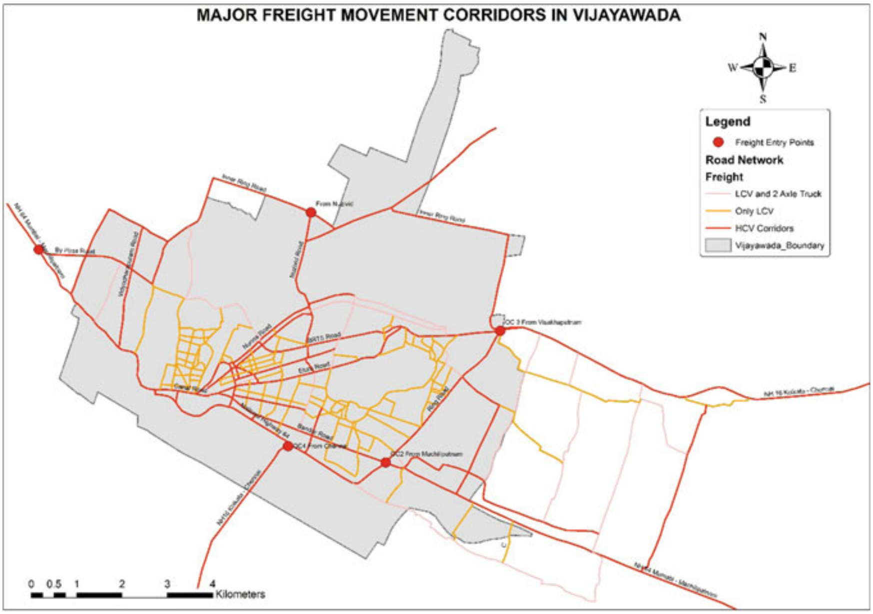
Map 37.10 Freight desired line diagram

From the freight desired line diagram map of Vijayawada, it can be observed that the major attraction Freight Analysis Zones are FAZ 30 where Autonagar is located which is an automobile hub and FAZs 11 and 12 which are bus station and railway station stand as the major attraction points in the city followed by FAZ 10 which is wholesale market.

Major Freight Movement Corridors

The map shows existing roads of freight movement in the city classified according to the type of vehicles allowed on the roads as per the maximum allowable vehicle on a given road. This shows the freight movement pattern in the city (Map 37.11).

From the Existing freight movement corridors, it can be observed that a haphazard freight movement pattern is existing in the city with no proper segregation and hierarchy of freight vehicles assigned to the corresponding roads based on the capacity and requirement. This unorganised freight movement pattern results in congestion, traffic jam, and delay in travel time leading to economic losses in the city.



Map 37.11 Major freight movement corridors

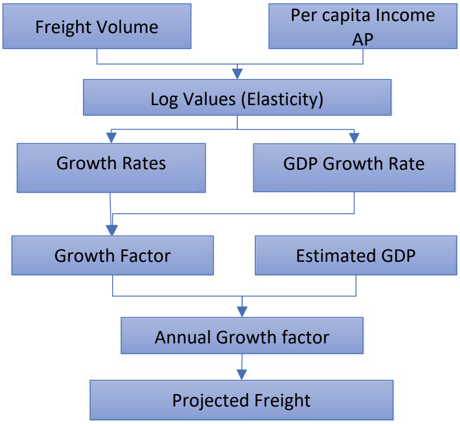


Fig. 37.12 Freight demand forecast

Freight Demand Forecasting

The existing freight demand is forecasted to 2041 using economic time series where the GDP growth rates of Andhra Pradesh and freight volume are used to determine the elasticity values using logarithm. Further, the growth rates are multiplied with GDP growth rate to get growth factors and the same are multiplied with estimated GDP of India for next 20 years and added with 1 to obtain annual growth factor which are multiplied with base year freight volume to get projected freight volume (Figs. 37.12 and 37.13).

The projected freight volume in tonnes shows a huge increase in freight traffic is seen going up to 10,00,000 Metric tonnes per day at Outer Cordon 1 towards Hyderabad and significant increase at other points. It shows an immediate need for management of freight traffic in the city to avoid future congestion (Map 37.12).

Freight Challenges and Recommendations

Inadequate Freight Infrastructure

The existing goods yards in the city lack in basic infrastructure like loading unloading facilities are absent in the city, and all the loading activities are carried out informally in the city. Weighbridges, maintenance, dormitories and food, refreshments, etc., are absent. These goods yards are barely enough to cater the huge freight demand of the city (Table 37.9).

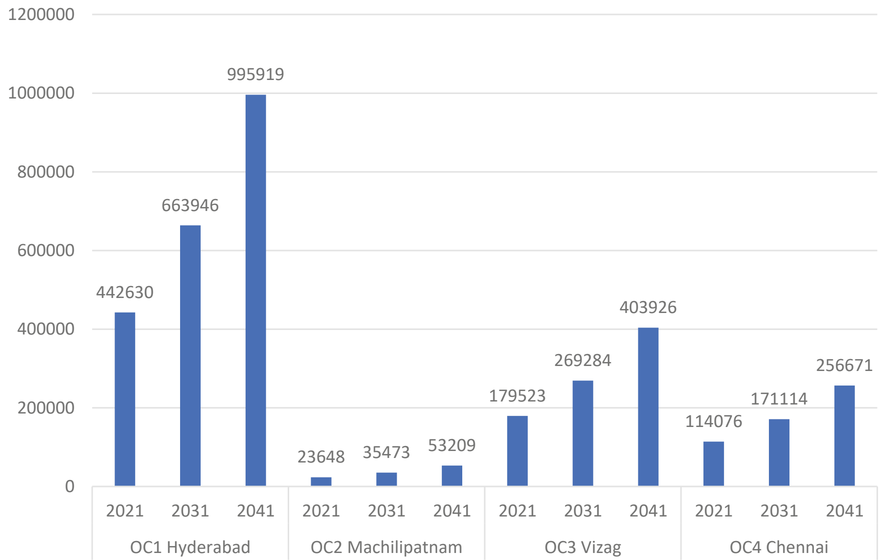
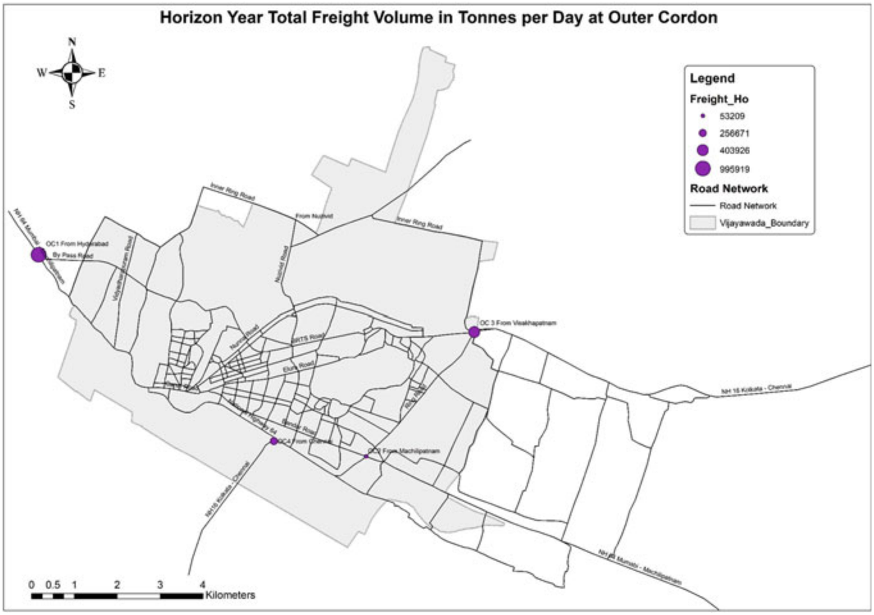


Fig. 37.13 Forecasted freight in tonnes per day



Map 37.12 Horizon year freight volume at outer cordon

Table 37.9 Freight infrastructure

Freight infrastructure	Autonagar goods yard	Bhavaninagar goods yard
Area	2000 m^2	2200 m^2
existing challenges	Lack of basic infrastructure facilities like bays, toilets and improper parking	Lack of basic infrastructure facilities like Parking bays, Loading unloading facilities and poor maintenance

Lack of Parking Facilities

There are no formal parking facilities for freight vehicles in the city. It is observed that the vehicles are crossing city in the allowed time and parking along highways at the outer areas of the city and informal parking near restaurants, Dhabas, maintenance shops and beside highways is observed.

Road Safety and Accidents

The total road accidents in Vijayawada Zone limit are 1620 in the year 2014 as per the Comprehensive Mobility Pan and the accidents involving goods vehicles are 631 which accounts 38.9% of total accidents. This shows that freight vehicles are responsible for a significant number of accidents in urban limits of Vijayawada.

From this, it is evident that a safety threat is posed by freight traffic for the people in urban areas in many ways like road accidents, threat to pedestrians, loss of visibility and increased pollution (Fig. 37.14).

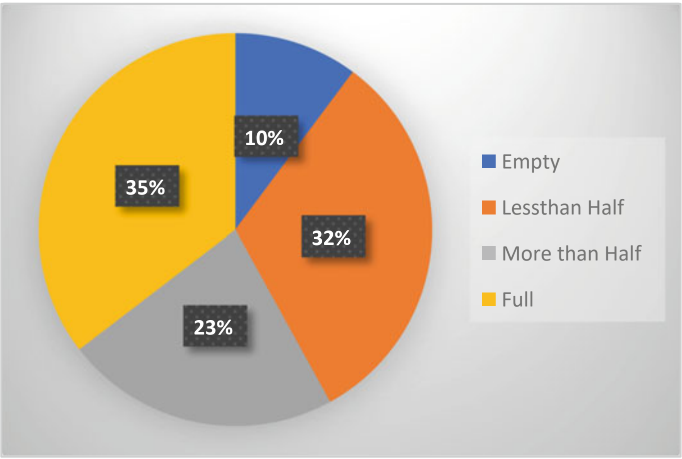


Fig. 37.14 Truck capacity utilization

Truck Capacity Utilisation

From the origin–destination survey, it is observed that empty load and half load trips are about 40% of total trips which shows that the truck capacity utilisation is low resulting in a greater number of trips for transporting less load increasing congestion and pollution.

Recommendations

It is recommended to provide truck terminals in all 4 directions of the city with facilities of parking area, maintenance facilities, refreshment and resting for drivers, weighbridges and transport agent offices and all other facilities of truck terminals as per the prescription of IRC standards.

To address the haphazard movement of freight and increase the accessibility of freight to pass through the city, a HCV freight movement corridors around the city are suggested to enable round-the-clock movement of freight around the city and it has to be achieved as a long-term goal for the freight management in the city.

Proposals

Truck Terminals

As per the findings of study, it is recommended to instal 4 truck terminals in all four directions of the city. The area required for a Truck Terminal as prescribed by Urban and Regional Development Plan Formulation and Implementation (URDPFI) guidelines 1996 is 1 ha for Every 300 tonnes of Inflow (Ministry of Housing and Urban Affairs 1996) (Table 37.10).

Table 37.10 Area required for truck terminals

Area	Inflow of HCV	Area required (ha)
Outer cordon 1	20,000 Tonnes	65
Outer cordon 2	9000 Tonnes	30
Outer cordon 3	15,000 Tonnes	50
Outer cordon 4	13,000 Tonnes	45

Suitability for Location of Truck Terminals

Parameters for Suitability

Spatial suitability analysis has to be carried out to determine the suitable location for establishment of truck terminals in all the directions of city. Suitability is to be carried out to identify the most beneficial locations for efficient movement of freight and profitable operation of the truck terminals.

Following are the parameters considered for suitability and the causative factors for choosing the same.

- Proximity to Road Network—For Good Connectivity
- Proximity to Commercial Area—Ease of business
- Proximity to Industrial Area—Ease of business
- Proximity to Terminals—Intermodal connectivity
- Proximity to Municipal boundary—Land Value (Table 37.11).

From the land suitability, the areas just beyond the municipal boundary stand as most suitable land for establishment of truck terminals (Map 37.13).

Location of Proposed Truck Terminals

Four truck terminals are recommended to be installed in the city in four directions along the national highways at the city outskirts to facilitate parking, resting, loading/unloading, warehousing and maintenance of trucks with all the necessary amenities. Based on the area requirement calculated according to URDPFI recommendations, the respective land for 4 truck terminals has been identified and located based on the land suitability and availability of vacant land (Map 37.14).

After the identification of truck terminal locations, a detail breakup of activities in the truck terminal and requirement of land accordingly is required for operation of the truck terminals. A brief land use breakup for various activities in the truck terminal like Godown, Parking, Circulation, Loading/unloading, offices and commercial areas is calculated as per the land use breakup of truck terminal recommended by urban and regional development plan formulation and implantation guidelines (Table 37.12).

Specifications of Truck Terminals

The area requirement under various activities for all the truck terminals is obtained, and the capacities of truck terminal in terms of various facilities like parking, loading/unloading and warehousing are calculated (Table 37.13).

The table shows capacities of each truck terminal in terms of maximum tonnage handled per day, maximum trucks per day, warehousing capacity, parking bays and loading/unloading bays calculated according to IRC guidelines for design of truck terminals (Fig. 37.15).

The typical layout of parking in truck terminal shows the arrangement of 78 parking bays in a site of 84 m × 74 m (0.62 ha).

Table 37.11 Spatial suitability parameters

Parameter	Classes (m)	Score	Weightage	
Proximity to road network	0–500	5	25	Proximity to road network is an important aspect for the accessibility of truck terminal and the same has been divided in 5 classes and allotted a weightage of 25 %
	500–1000	4		
	1000–1500	3		
	1500–2000	2		
	2000–2500	1		
Proximity to commercial	0–100	5	20	Proximity to commercial and industrial areas is a driving factor as it directly impacts the business of freight vehicles and is related to the sustenance of truck terminals and hence is given a weight of 20% each
	100–250	4		
	250–500	3		
	500–1000	2		
	1000–2500	1		
Proximity to industrial	0–100	5	20	
	100–250	4		
	250–500	3		
	500–1000	2		
	1000–2500	1		
Proximity to terminals	0–100	5	20	Proximity to terminals is important for intermodal transport, import and exports and hence given a weightage of 20%
	100–250	4		
	250–500	3		
	500–1000	2		
	1000–2500	1		
Proximity to municipal boundary	0–500	5	20	Proximity to municipal boundary determines land price and hence given a weightage of 15%
	500–1000	4		
	1000–2500	3		
	2500–4000	2		
	4000–5000	1		

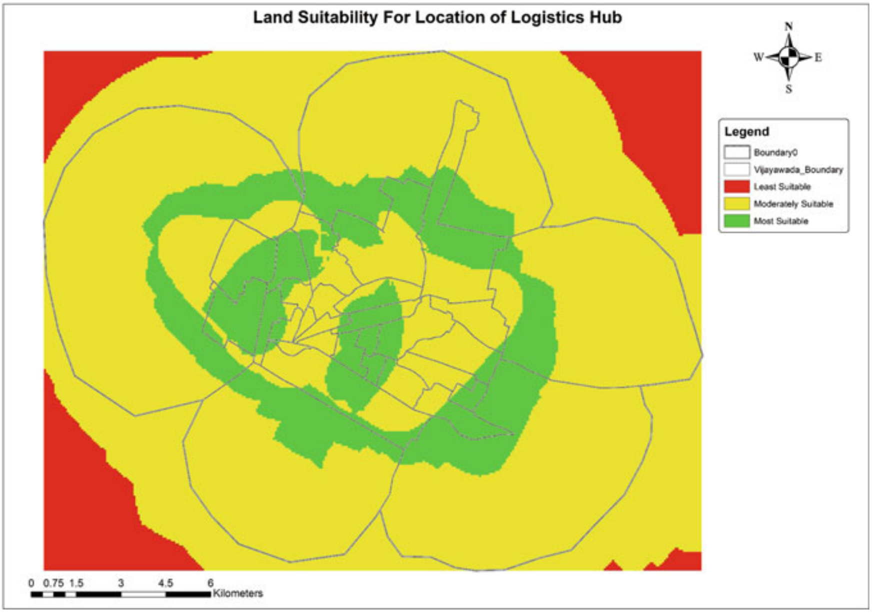
Three types of parking bays are included in the design which are as follows.

1. Light Van—5 × 3 m;
2. Rigid goods vehicle—12 × 3.5 m;
3. Articulated goods vehicle—16 × 3.5 m.

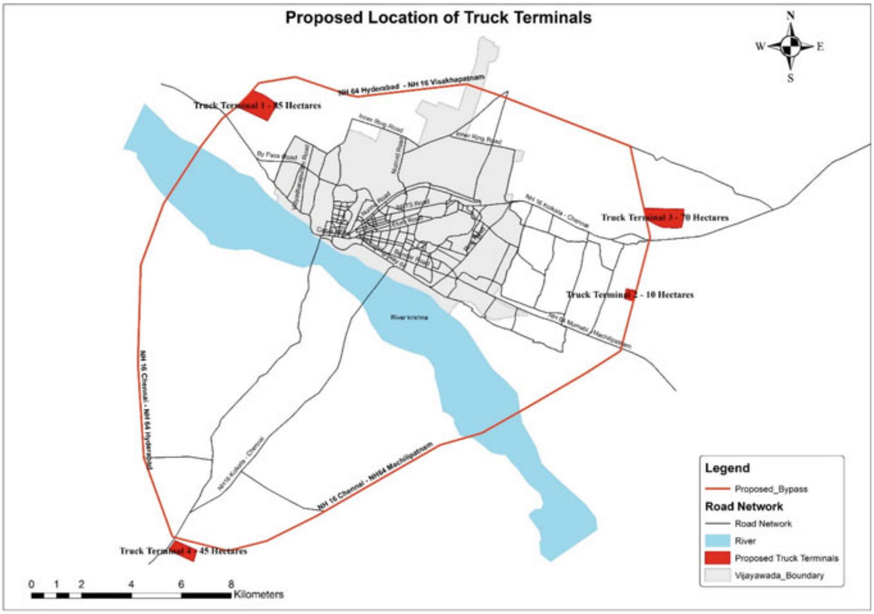
As per the recommendations of IRC 100, parking bays can be accommodated including the circulation area in one Hectare of land.

Benefits of Truck Terminals

Following are the benefits from operation of truck terminals in the city



Map 37.13 Spatial suitability map



Map 37.14 Proposed truck terminals location map

Table 37.12 Land use breakup of truck terminals

Area in Ha	%	85	10	70	45
Broad land use breakup of truck terminal		OC1	OC2	OC3	OC4
Transport operations (office, godown, loading/unloading)	30	25.4	3.0	21.0	13.4
Service (petrol pump, service, weigh bridge)	6	5.1	0.6	4.2	2.7
Public semi-public (post office, police, etc.)	3	2.5	0.3	2.1	1.3
Commercial	3	2.5	0.3	2.1	1.3
Parking	18	15.2	1.8	12.6	8.0
Open spaces	10	8.5	1.0	7.0	4.5
Circulation	28	23.7	2.8	19.6	12.5
Others	2	1.7	0.2	1.4	0.9

Ministry of Housing and urban Affairs (2014)

Table 37.13 Specifications of truck terminals

	Area in Ha	Volume	Tonne/day	100/Ha	150/Ha	5000 MT/Ha
		Total trucks per day	Maximum tonnage	Parking bays	Loading/unloading	Warehousing
OC1	85	1130	26,000	1500	1875	62,500
OC2	10	540	3250	300	225	7500
OC3	70	1200	21,250	1200	1650	45,000
OC4	45	1140	13,500	1000	1200	30,000

Ministry of Housig and Urban Affairs (2016)

- 10 min of travel time saved for every 5 kms travelled in the city which reduces congestion and traffic jams in the city.
- No unnecessary movement of heavy freight vehicles in the city reducing pollution and enhancing safety.
- All the trading of city at one point making business-to-business trading easier and more efficient.
- No further delay in receiving deliveries and dispatching goods as round-the-clock access to freight is achieved.
- All parking, loading, maintenance, resting facilities and operator office at one point reduces burden on truck operators.
- No more operational difficulties regarding route restrictions, parking, time restriction and issues for police.
- A safe, efficient and uninterrupted movement of daily goods vehicles through the city without any hindrance to activities in the city.

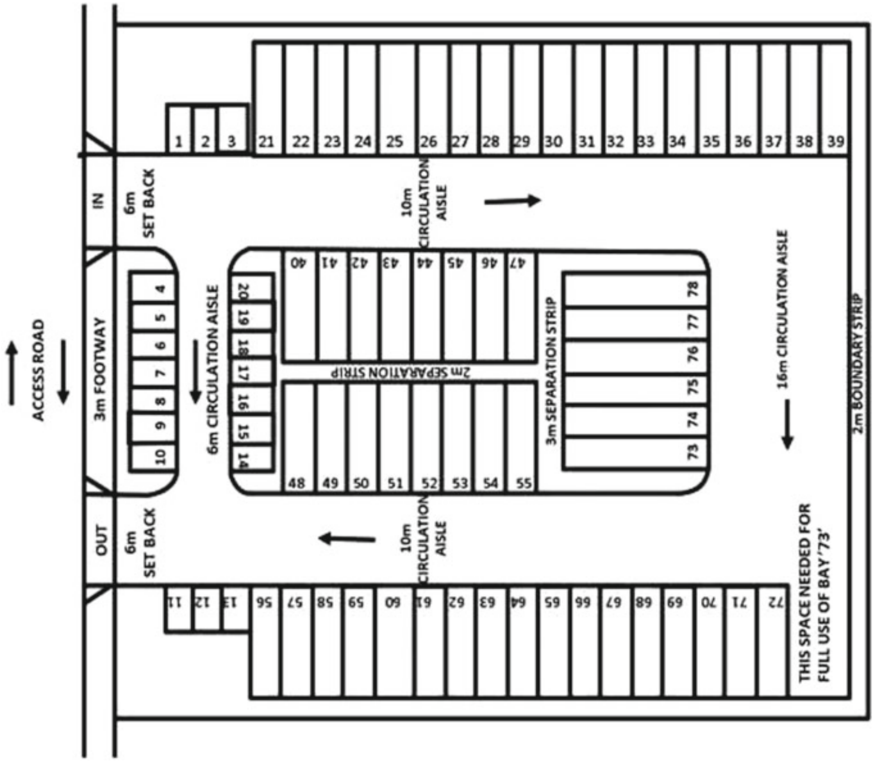


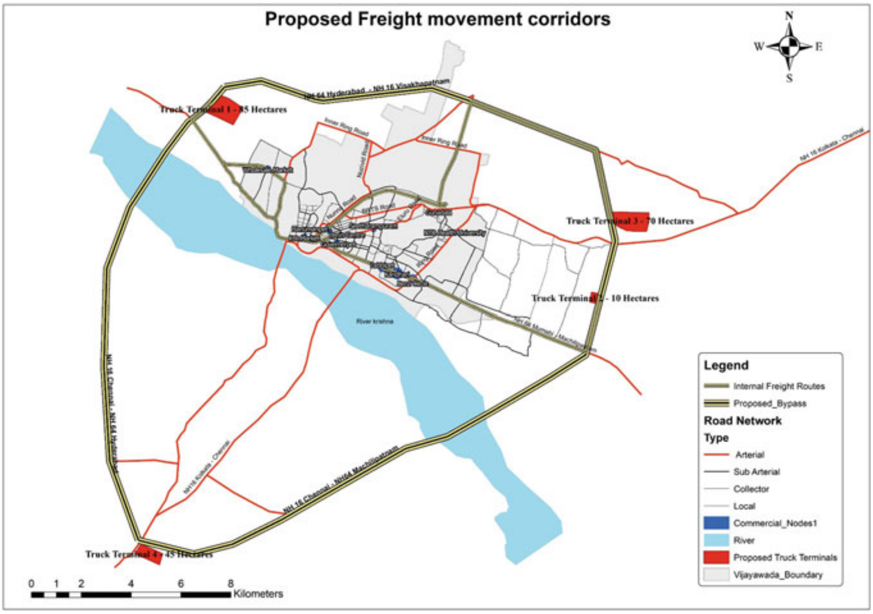
Fig. 37.15 Typical parking layout for truck terminal (Ministry of Housig and Urban Affairs 2016)

Freight Movement Corridors

The main objective of routing strategy is to provide free movement of goods vehicles to and through the city without causing inconvenience to the city traffic. As 40% of freight traffic in the city is bypassing traffic, an efficient freight movement eliminates unnecessary movement of freight vehicles in the city (Map 37.15).

Strategy 1: A bypass route connecting all the truck terminals which does not pass through the city is proposed. This bypass acts as a heavy vehicle movement corridor providing uninterrupted flow of goods through the city round the clock without any hinderance to goods movement.

Strategy 2: Internal freight movement route for connecting major commercial areas to the proposed truck terminals. This route is recommended for movement of Light Commercial Vehicles (LCV) which will act as feeder services for truck terminals. Further, a time window of 8 h from 22:00 to 06:00 is provided for permitting unavoidable heavy vehicles into the internal routes which has to enter the city (Table 37.14).



Map 37.15 Map 15 Proposed Freight Movement Corridors Map

Table 37.14 Description of proposed bypass road

Bypass	Description	Length (km)	Existing/proposed
South-West Arm	Form NH16 Chennai to NH64 Hyderabad	19.95	CMP proposed IRR
South-East Arm	Form NH16 Chennai to NH64 Machilipatnam	20.15	CMP proposed IRR
North-West Arm	NH64 Hyderabad to NH16 Visakhapatnam	19.40	CMP proposed bypass
North-East Arm	NH64 Machilipatnam to NH16 Visakhapatnam	4.65	CMP proposed bypass

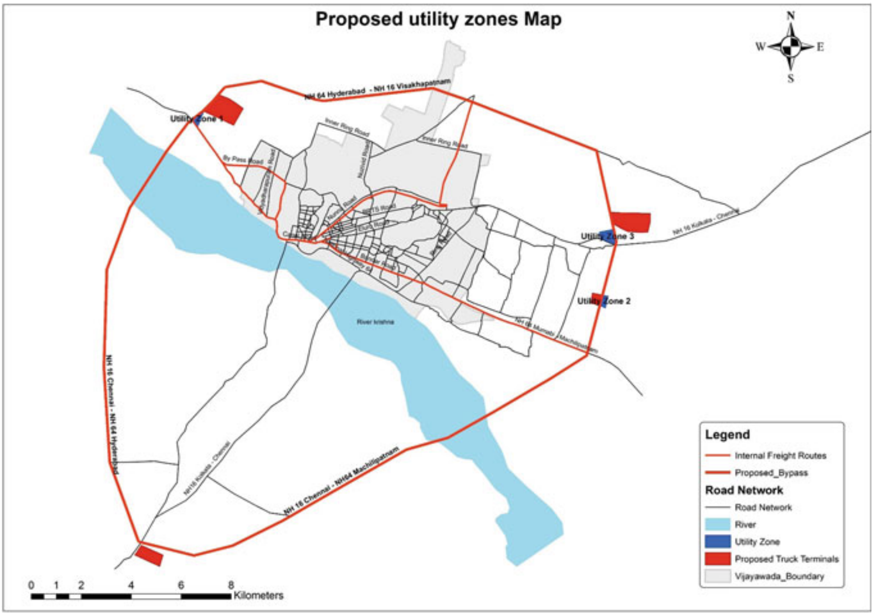
Amaravati Metro Rail Corporation Limited (2017)

The heavy vehicle movement corridor is proposed by considering the proposed bypass and internal ring road given by the Comprehensive Mobility Plan of Vijayawada and utilising the same for movement of freight vehicles. The bypass and internal ring road of Vijayawada are already under construction and expected to be operational soon. Thus, there is no new road construction for freight movement which reduces the construction cost.

Land Use Utility Zones

Similar to the concept of Transit Oriented Development (TOD), three land utility zones are recommended near the proposed truck terminals with an objective to value capturing of the upcoming development. The utility zones are of 10 ha each and identified in the vacant land near truck terminals (Map 37.16).

These zones are characterised with mixed use and dominated by commercial, small-scale industries and public semi-public uses with minimum residential use, and incentive development is recommended (Table 37.15).



Map 37.16 Proposed land use utility zones map

Table 37.15 Proposed land use of utility zones

Land use	Percentage (%)
Commercial	40
Public semi-public	10
Industrial (small scale)	35
Recreational	5
Others	10

Delhi Development Authority (2007)

Advantages of Utility Zones

The concept of utility zones is to look into further benefits that can be achieved using the proposed truck terminals. Following are the benefits fetched by land use utility zones.

1. Decentralising the commercial activity in city which is presently concentrated in the CBD in central areas of KR market, MG Road and Eluru road.
2. The utility centres in all directions providing commercial and recreation facilities reduce the need to travel to CBD from all the corners of city.
3. The utility centres with commercial and industrial activity will support and supplement to logistic operations of truck terminals for commercial areas.
4. The new utility zones act as a counter magnet for growth and development of the city of Vijayawada and help to check further congestion in the city.

Conclusion

In most of the tier-two Indian cities, there is less focus on freight in their respective comprehensive mobility plans. The recent plans do include freight sector in CMP but there is less focus on integrating the freight with future development of cities. As India has an agrarian economy, cities like Vijayawada play a crucial logistics role in the export–import (EXIM) operations for collection of agricultural crops and distribution of industrial goods, integrating freight with future development of such cities is essential to avoid the future congestion and streamline the infrastructure development. This chapter has explored how creation of freight infrastructure can be value captured and integrated with the future development of city based on the freight demand. The case area of Vijayawada is a tier-two city and a strategic commercial and trading hub for the state of Andhra Pradesh with an efficient network connectivity; this brings a large amount of freight to the city every day. From the analysis, it is evident that a consistent amount of freight traffic brought by National Highway 64 and National Highway 16 is entering the city everyday and thousands of tonnes of freight is being handled by the city everyday for the trade and commerce purpose in a haphazard and organic manner. From the analysis of average speed with and without freight traffic on major arterial roads, it is observed that an average improvement of 5 kmph in average speed can be achieved by avoiding the freight traffic on city roads. The regression analysis of freight volume and average speed of roads shows an inverse relation between them stating that the average speed of a road is decreasing with an increase in the freight traffic. The analysis provides a piece of clear evidence that mixing traffic of all kinds and moving it on the same roads results in traffic congestion and delays in the city. The traffic of Vijayawada is projected to 2041 using the econometric method, and huge demand of freight for freight traffic is identified. The city does not have sufficient infrastructure to support the freight traffic, and the roads in the city are already congested to handle heavy freight vehicles. Thus, 4 truck terminals are recommended in 4 directions of the city which are equipped with all the required infrastructure like parking, loading/unloading, maintenance, servicing, refreshments and operator offices and will serve as a one-stop destination for the freight traffic which is associated with either terminating or originating from the city. The research question "Can an effective freight management model be integrated with the urban mobility planning in a trading and business hub like Vijayawada city?" is solved as a freight model has been integrated with the urban mobility of Vijayawada and it stands efficient. Thus, the study hypothesis "Implementing effective freight distribution model using alternative routing based on freight demand improves urban traffic scenario in terms of congestion and travel time" is proven to be true as there is a significant improvement in average speed and travel time after implementing freight distribution model in Vijayawada. The research has addressed the research question and has proved the hypothesis to be true. However, there is a further scope for extending the research hand taking up the task of streamlining the Internal—Internal freight of Vijayawada which can be an extension of this research.

References

Abdelhamid Moutaoukil GNARD (2015) Urban freight distribution: impact of delivery time on sustainability. International Federation of Automatic Control (IFAC), pp 2368–2373

Amaravati Metro Rail Corporation Limited (2017) Comprehensive mobility plan for Vijayawada. S.N., Vijayawada

Anon (2006) Costs of congestion: literature based review of methodologies and nalytical approaches. Tansport Research (Scottish Executive)

Census of India (2011) Census primary abstract. S.L., Census of India

Delhi Development Authority (2007) Transit oriented development policy—proposed landuse, DDA, Delhi

Federal Ministry for Economic Cooperation and Development (2014) Urban Freight and Logistics: the state of practices in India. GIZ, New Delhi

Madhu Errampalli RKLAT (2019) Assessment of urban freight travel charecteristics—a case study of Delhi. Mumbai, Elsevier B.V.

Ministry of Housig and Urban Affairs (2016) Toolkot for urban freight transport planning and management. National Institute of Urban Affairs, Delhi

Ministry of Housing and Urban Affairs (1996) Urban and regional development Plan formulation and implementation guidelines. Governemnt of India, New Delhi

Ministry of Housing and urban Affairs (2014) Urban and regioanl development plan formulation and implementation guidelines. Ministry of Housing and urban Affairs, Delhi

Ministry of Housing and Urban Affairs (2016) Efficient Urban Freight Policy. Governemnt of India, New Delhi(Delhi)

Sri Harsha SA (2020) Regional flood forescasting using SWMM for urban catchment. Int J Adv Tech Eng Explorat 9(3):1027–1031

Primary Survey (2021a) Primary survey classified traffic volume count. S.N., Vijayawada (Andhra Pradesh)

Primary Survey (2021b) Truck operator survey. S.N., Vijayawada(Andhra Pradesh)

Transport corporation of India (2015) Operational efficiency of freight transport by road in India. Transport Corporation of India, Kolkata

Valerio Gatta EMMNAS (2019) Sustainable urban freight transport adopting public transport based croed shipping for B2C deliveries. European Transport Research Revirew, Rome, Italy

Vijayawada Municiapall Corporation (2010) Vijayawada master plan. S.N., Vijayawada

Chapter 38
Incorporating Crowdsourced Social Media Footprint in Delhi Metro's Service Quality Assessment

Apoorv Agrawal and Paulose N. Kuriakose

Abstract In today's competitive environment, assessing service quality has emerged as a strategic instrument for enhancing efficiency and persuading users to opt for the service. But the service provider's challenge is ascertaining the commuter perception, especially on qualitative aspects of perceived service quality. In public transport, a comprehensive service quality assessment (SQA) framework has proven effective in assessing service performance when 'commuter perception' is the measuring unit of service quality. Most developing countries, including India, struggle to actively incorporate commuter perspectives when assessing the qualitative aspects of service quality. To aid, social media data can prove to be a game shift in this modern digital era to offer an insight into the commuter perception of service delivery. The chapter aims to incorporate social media data for integrating qualitative aspects based on commuters' perceptions into the public transport SQA framework for the Delhi metro. The study extracts Twitter data, performs semantic and sentiment analysis to comprehend commuters' concerns and assesses commuters' sentiments on the predicted concerns. Further, the service performance score is calculated using a weighted SERVPERF scale, and an Importance-Performance analysis is performed to identify the priority areas. The benefit of this method is twofold; first, it allows for establishing a real-time feedback structure that benefits both the service provider and commuters, and second, it allows for the periodic assessment of commuters' perceptions of service delivery.

Keywords Commuter perception · Semantic analysis · Sentiment analysis · Latent Dirichlet allocation (LDA) · Service quality assessment · Bidirectional encoder representations from transformers (BERT)

A. Agrawal (✉) · P. N. Kuriakose
Department of Urban and Regional Planning, School of Planning and Architecture Bhopal, Bhopal, Madhya Pradesh, India
e-mail: apoorvagr96@gmail.com

P. N. Kuriakose
e-mail: paulosenk@spabhopal.ac.in

U. Chatterjee et al. (eds.), *Urban Commons, Future Smart Cities and Sustainability*, Springer Geography, https://doi.org/10.1007/978-3-031-24767-5_38

Introduction

Rapid urbanisation, particularly in developing countries, has resulted in urban sprawl, leading to an exponential demand for mobility infrastructure (Yaya et al. 2014). Ideally, people should rely on public transport rather than private modes for movement, but various factors have resulted in a travel pattern favouring private modes over public transport (Cipriani et al. 2012; Cheng and Chen 2015). Aside from the obvious advantages of using public transport, such as reduced congestion and pollution, research has shown that it has a more significant impact on developing a healthy and prosperous community (Gershon 2005). But even these motives are proving inadequate to persuade people to use public transport for their everyday commute, especially in a developing country like India (Cipriani et al. 2012). According to Matas (2004), a public transport policy centred on offering low-cost travel and enhancing service quality can counteract the declining trend in public transport ridership and motivate more people to opt for it. Research points out that nowadays, what entices people is not merely the availability of services but the service quality offered (Chen 2008; Das and Pandit 2013).

In this regard, Eboli and Mazzula (2010) observed that most quality improvements have a limited impact on commuter satisfaction with public transport since it is difficult to determine which aspects will lead to more extensive improvements. This necessitates a thorough evaluation of 'where' the service provider should earmark resources to enhance service quality (Eboli and Mazzulla 2010; Das and Pandit 2013). The rationale for this could be that each of the service quality aspects is perceived differently by each commuter (Friman 2004). Hence, the core premise for efficient public transport is to understand how commuters perceive the current system and what they expect of the system (Matas 2004; Morton et al. 2016). The best way to assess system performance and check whether it aligned with the service delivery goals is to develop a comprehensive service quality assessment (SQA) framework as it aspires to improve the efficiency of the existing system (Friman 2004; Fisk et al. 2010; Das and Pandit 2013). It is critical to emphasise that in an SQA, the commuter's perspective must be given equal weightage to that of the service provider's since the commuter is endured unsatisfactory service performance, and so 'user perception' must be the unit of measurement for perceived service quality (Fisk et al. 2010). However, in today's fast-paced environment, where commuters' demands change rapidly, the present framework of conducting a customer satisfaction survey (at best once a year) is proving inadequate. Given this, the digital age presents numerous opportunities for assessing commuters' perceptions of service delivery, which must be capitalised on.

The advent of Internet 2.0 has manifested in a surge of crowdsourced social media data, in which the users are not only mere information receivers but also creators of the volume of data, which provides new opportunities for engaging with and understanding users (García-Palomares et al. 2018; Martí et al. 2019). Social media refers to a set of web-based platforms that allow users to communicate with one another and share their experiences, views and knowledge, most of which is location embedded (Kandt and Batty 2020). Researchers believe that social media platforms are generating a massive social data stream containing information about user's behaviour, movement and feelings about places; the representation and interpretation of social media data provide the ability to evaluate various urban dynamics, including transport planning (Osorio-Arjona et al. 2021; Hatuka et al. 2020).

In India, the Delhi metro, the country's largest metro network, also makes use of the possibilities of social media and employs a social media management agency for social media-related responsibilities. However, the current focus of the Delhi Metro Rail Corporation (DMRC) on social media is information dissemination (near real-time) and immediate response to commuters' grievances. On the other hand, commuters primarily use social media to voice their grievances about their commute. With advances in machine learning models, social media data could be utilised to analyse commuters' perceptions regularly over a more extended period rather than merely responding to grievances during the commute. Assessing commuters' perceptions using social media data would provide imperative insight to the service provider by allowing them to collect data more frequently, access near real-time data and on-the-ground commuters' perceptions of service delivery.

Against this backdrop, this chapter seeks to assess commuters' perceptions of the Delhi metro's service delivery using Twitter data and attempts to present the method to extract, evaluate and incorporate Twitter data into the existing SQA. As social media data is contextual and time specific, the approach may evolve as different service providers alter it to comply with their requirements. It is important to note that the study used a two-pronged data extraction method: first, from the official Twitter handle of the Delhi metro, and second, from a separate Twitter handle used exclusively for this study. This is since the official handle presently receives more grievances-related tweets from commuters; the second Twitter handle was created to engage commuters in sharing their experiences with the service, essentially to collect the commuters' perceptions. Capturing commuters' perceptions of service delivery will necessitate DMRC's efforts to initiate and engage commuters in regularly sharing their experiences with the service. Moreover, the chapter discusses the opportunities, limitations and future directions for social media data analytics in India for effective public transport decision-making.

As the study focuses on text analysis, therefore, it acquires data from Twitter, a microblogging platform. Twitter has a limit of 280 characters, providing for a concise and explicit representation of the content, reducing noise from the content and allowing for a more in-depth knowledge of the contents (García-Palomares et al. 2018 ; Martí et al. 2019; Osorio-Arjona et al. 2021). Furthermore, one of the most significant benefits is that Twitter data is freely available for research purposes, allowing for near real-time data analysis and interpretation (Lansley and Longley 2016; Haghighi et al. 2018). The study's approach embraces social media commuters' perceptions as an add-on layer to the existing conventional satisfaction survey and not as a substitute for it.

Following the introduction, Section "Defining Service Quality and Comprehending Related Works" presents an overview of the concepts of service quality, particularly perceived service quality. It also sheds light on previous related works related to social media data analytics techniques in an urban scenario. Section "Study Area and Data Collection Strategy" defines the study area by reflecting on the area profile, depicting the current scenario of the Delhi metro, and presents the data collection strategy adopted for the study. Section "Methodology" focuses on the research methodology, beginning with the data pre-processing to data analysis. Section "Analysis Interpretation" comprises the interpretation of the analysis. Section "Discussion" presents the discussion by emphasising the method's benefits and challenges. Section "Conclusion" concludes the study's findings and suggests a way forward for social media data analysis research.

Defining Service Quality and Comprehending Related Works

The part that follows is divided into two pieces; first, it delves into the meaning and significance of perceived service quality, particularly from commuters' perspective; second, it highlights the opportunities and limitations of prior work linked to social media data analysis, particularly in transport planning.

Discerning the Significance of 'User Perception' in Perceived Service Quality

At the outset, it is critical to comprehend the relationship between 'service quality', 'perceived service quality' and 'user perception'. Service quality has been defined in the literature in many ways but simply put, it is an assessment of the service delivered (Das and Pandit 2013; Yaya et al. 2014; Morton et al. 2016). It can, however, be divided into 'objective service quality' and 'perceived service quality'. The former is the sum of all the vector attributes of a service, which deems the technical quality of service but excludes intangible attributes (Parasuraman et al. 1988; Johnson et al. 2001). The latter is an overall assessment of the service's quality concerning the expectation, a service-oriented approach that considers intangible aspects (Parasuraman et al. 1988; Johnson et al. 2001). Since perceived service quality focuses on intangible attributes and the user is the sole judge of quality, therefore, it is believed that it must be the criteria for any service quality assessment taking 'user perception' into account (Parasuraman et al. 1988; Schneider and White 2004).

Parasuraman et al. (1988) present 'perceived service quality as global judgement, or attitude, relating to the superiority of the service'. As per Zeithmal et al. (1988), it is a 'user's assessment of the overall excellence or superiority of the service', Parasuraman et al. (1985) assert that 'comprehending these service quality means sufficing user expectations, which implies that users compare their expectations and perceptions of service performance'. The focus of service quality definitions in the literature is on user needs, requirements and the pursuit of how well the delivered service meets users' expectations (Bansal and Taylor 2014; Schneider and White 2004). Disconfirmation arises due to differences between expected and perceived performance; thus, the process of analysing the perceived service quality by the user is known as the 'disconfirmation approach' (Bansal and Taylor 2014; Homburg et al. 2006). These definitions reflect the premise that assessing perceived service quality is a user-centred approach that must be quantified using 'user perception' (Dagger and Sweeney 2006; Fisk et al. 2010). However, it is vital to stress that user perception is very subjective; even for the same service delivery, multiple individuals may have different perceptions (Cheng and Chen 2015; Morton et al. 2016).

Opportunity in Social Media Data

In the current digital age, social media data analysis provides an opportunity to delve into understanding, hence the urban environment (García-Palomares et al. 2018; Martí et al. 2019; El-Diraby et al. 2019; Osorio-Arjona et al. 2021). Researchers believe that since it is user-generated content, an insight into the data provides a diverse perspective on various aspects of urban life that reflect the user's interests and behaviour (Stelzer et al. 2016; Haghighi et al. 2018; El-Diraby et al. 2019).

The frequency of the crowdsourced data for analysis is one of the most significant opportunities provided by the social media data (Gal-Tzur et al. 2014; García-Palomares et al. 2018). It simplifies the entire data collecting process by eliminating many imitations associated with conventional approaches, such as collection time and accurate geolocation markings (Martí et al. 2019; Osorio-Arjona et al. 2021). Likewise, it enables public participation, precisely e-public participation, in decision-making, which is at the heart of any decision-making process (Blanc 2020). As social media data is a volunteered data offering medium, it allows people to voice their opinions without being evaluated by anyone, bringing to light unique concerns that would never be discussed in a conventional survey (Schweitzer 2014; Campagna 2016; Walden-Schreiner et al. 2018). This also permeates the Hawthorne effect, which asserts that volunteers in research may change their behaviour when they realise, they are being observed (McCarney et al. 2007).

Presently, the main limitations of using social media data are that it does not provide an accurate representation of the population and does not provide convincing evidence of catering to the digital divide because it assumes that social media users are only a subset of the population whose social media usage is aligned with a specific interest (Dijk 2006; Solan and Quan-Haase 2017; Martí et al. 2019). Besides, it is critical to interpreting the social media analysis findings with conventional surveys, which provide more realistic representations of the population. Moreover, social media data occasionally exhibits inconsistency in providing an adequate amount of geocoded data (Campagna 2016; Casas and Delmelle 2017; Schweitzer 2014). However, this might be attributed to a lack of a practical framework for reviewing the social media data; it can be assumed that once a structure is in place, more participants will be motivated to use social media platforms to express their opinions (Gal-Tzur et al. 2014; Haghighi et al. 2018; El-Diraby et al. 2019). Future research can focus on increasing the data sample size by adding data from alternative crowdsourcing platforms to augment or integrate with conventional data collection methods since it provides novel insights into the situation on the ground (Songchon et al. 2021). One point worth noting is that social media analytics is still in its infancy, and limitations such as user privacy, resource needs for analysis and record retention will evolve as it becomes mainstream for service providers to assess social media data (Osorio-Arjona et al. 2021).

Study Area and Data Collection Strategy

Delhi Metro Overview

The Delhi metro commenced in December 2002 with a 65-km route between Shahdara and Tis Hazari, which has expanded to 389 kms (in 2019), making it the world's eighth-largest metro train network (DMRC 2019). It adheres to colour codes, with each of its ten lines having a distinct colour. As of January 2019, the Delhi metro has a total average daily ridership of 29.87 lacs and a fleet of 336 trains, classified by route based on ridership, with the blue line having the most, followed by the yellow line (DMRC 2019). The metro and buses are the two main modes of public transport in Delhi, with the metro accounting for roughly 40% of overall public transport ridership. It is crucial to emphasise that the pandemic affected both the average wait time and the average travel time. During peak rush hours (8 a.m. to 12 p.m. and 4 p.m. to 8 p.m.), travel time on main routes was increased by at least 40–45 min, while waiting times were roughly doubled (Pillai 2021).

Data Collection Strategy

The study's data collection technique was twofold: first, from the official Twitter handle of the Delhi metro (@OfficialDMRC), and second, from the handle explicitly created for the study (@Users'Perception). Tweets were extracted from both handles for a month, from 1 to 31 July 2021, using the Twitter API and codes were written in Python employing the Tweepy library. It is important to note that the data was extracted using the search by username method, which obtained tweets with the hashtag because commuters frequently tweet directly to transport providers' Twitter handles when they criticise or praise the service offered (Haghighi et al. 2018). Moreover, two types of tweets were extracted: original tweets, in which commuters communicate concerns directly to the service provider, and reply tweets, in which commuters express their experience as nudged by the provider. Below are some sample tweets from both handles to demonstrate how the content and quality of tweets differed in an unsolicited (current structure) and solicited (nudged to share experiences) method:

1. The official handle is currently receiving grievance-related tweets; informally conveyed.
   (a) Plz see Green linesituation no social distance r getting fallowed mrng & eveg.. kripiya action le… https://t.co/4HEw3af2Um @OfficialDMRC @CMODelhi
2. The commuter perception handle received tweets about a specific niche of service delivery; semi-formally conveyed.
   (b) Evening the trains are crowdy & the temperature of the coaches is not regulated.*! feeling uncomfortable in blue line.. @Users'Perception @ OfficialDMRC https://t.co/4HEw3afcdv.

Methodology

This section discusses a method for data pre-processing, data preparation, semantic analysis to predict topics (commuters' concerns) and sentiment analysis to determine the sentiments of the predicted topics for the study area setting. Moreover, it outlines a method for structuring commuters' perceptions to assess perceived service quality and a matrix for prioritising commuters' concerns to enhance service delivery.

Data Pre-processing and Geocoding

Data pre-processing, a critical stage in natural language processing (NLP), converts text into a more comprehensible form, allowing the model to predict better results. For instance, in the context of this study, tagged profiles in a tweet other than the official handle of the Delhi metro were undesirable information and hence needed to be eliminated (Lansley and Longley 2016; Haghighi et al. 2018). Python's NLTK and Spacy libraries were used for data pre-processing. A two-step approach was employed, with the first step data cleaning and the second data preparation. Data cleaning consists of multiple steps, such as converting text to lowercase, eliminating patterns (tags), punctuation, special characters, links, duplicate tweets and tweets with less than four characters. All the preceding steps reduce the size of the tweet's unique words to make the data semantically coherent (Osorio-Arjona et al. 2021).

Further, geocoding, a method of converting addresses (station names, line names) to geographic information (latitude and longitude) to place markers on a map, was performed by employing the Geopy library in Python (Osorio-Arjona et al. 2021). The study did not geotag the tweets based on the extracted tweet's coordinates because it believes commuters express their concerns when they have the time rather than tweeting from a specific location when they encounter an issue (Haghighi et al. 2018; Osorio-Arjona et al. 2021). The study developed a keyword dictionary including the names of all metro stations to map tweets with their spatial locations.

Moreover, the data preparation was divided into three main steps: first, tokenisation; dividing a sentence into meaningful segments and identifying the individual segment within the sentence. For this study, word tokens were created from the extracted tweet. Second, stop words were removed from tweets, which are words like 'the', 'we' and 'and' that do not contribute meaning to a sentence along with some transport-specific most frequent words in the tweets such as 'metro' and 'delhi' and third, lemmatisation; the process of reducing inflected words to their root form, such as 'crowding' to 'crowd' (Manning et al. 2009).

Semantic and Sentiment Analysis

From the extracted tweets, semantic analysis was performed to uncover the concerns or topics commuters express regarding service delivery. An unsupervised modelling technique was used for this study, and the unclassified tweets were categorised using a probabilistic modelling method known as Latent Dirichlet allocation (LDA) (Blei et al. 2003; Jia and Chen 2020). Further, Mallet's LDA model was used as it employs Gibbs sampling, which is much more dependable than the Genism LDA model for the study's context. It finds topics based on word frequency in a collection of documents, where a topic is defined as a weighted list of words (García et al. 2015).

Next, sentiment analysis was performed to determine how commuters feel about a topic based on the extracted tweets and label them as positive, negative, or neutral. Bidirectional Encoder Representations from Transformers (BERT), a deep learning model, was employed as it is used to achieve high-accuracy sentiment analysis (Devlin et al. 2019). Except for changing the tweet to lowercase, the data pre-processing procedures for sentiment analysis were similar to those for semantic analysis. It is because a cased BERT was employed in this study since it can distinguish between 'metro' and 'METRO', which shows emotions as commuters write in capital letters when they want to emphasise something (Bird et al. 2009; Haddi et al. 2013). As BERT is a supervised learning model, it was trained using a training dataset that included input text and sentiments classified on a five-point scale. The model's accuracy was then assessed using a confusion matrix, and finally, the extracted tweets were fed into the model to predict the sentiment class of the tweet.

Structuring the Data

In social media, commuters share their experiences on service delivery for the topics they believe need to be addressed, both positively and negatively, and not for every topic. Hence, several topics lacked sentiment values, which were accounted for through imputation. Imputation is a method for dealing with the issue of missing data in which the values of the missing columns are replaced by a computed value (Farhangfar et al. 2008). The K-nearest neighbour (KNN) imputation approach, which involves matching a point with its closest K-neighbours in a multi-dimensional space, was employed for this study (García et al. 2015).

Further, exploratory factor analysis (EFA) was performed to validate topics predicted by the semantic analysis and to explain the multi-dimensional dataset using fewer factors (Chen 2008; Yaya et al. 2014). Under EFA, Common factor analysis (CFA) was adopted, which seeks the least factors which can explain the common variance (correlation) of a set of variables (topics) (Morton et al. 2016). Initially, the prerequisite tests were carried out to assess the feasibility of using factor analysis. First was Bartlett's test of sphericity, which determines redundancy between the topics that can be summarised with a few factors (P-values < 0.001) (Morton et al. 2016). The second was the Kaiser–Meyer–Olkin (KMO) test, which determines the sampling adequacy for each topic in the structure (Yaya et al. 2014; Morton et al. 2016). Further, a scree plot was plotted between the eigenvalues and the number of topics to ascertain the ideal range of factors; permutations were performed within the predicted range of factors to determine the ideal number of factors for the extracted data (Bird et al. 2009). Following that, the topics were grouped under the confirmed factors, and topics with factor loading values less than 0.5 were excluded using the item loading inspection (Chen 2008; Yaya et al. 2014). The factors were validated using the Kaiser criterion, eigenvalues greater than one and overall variance greater than 60% for each factor (Chen 2008; Yaya et al. 2014). To test for reliability, Cronbach Coefficient Alpha, a metric used to assess how well the factors are correlated or internally consistent, was performed. For this study, a value greater than 0.7 was deemed appropriate (Chen 2008; Yaya et al. 2014). Besides, content validity was performed to test for validity which refers to the extent to which the survey topics pertain to and reflect the targeted assessment purpose (Chen 2008). It was performed by referring to DMRC's existing customer satisfaction survey and having experts review it.

Calculating the Perceived Service Quality and Identifying the Priority Issues

The SERVPERF (SERVice PERFormance) scale was used to calculate the perceived service quality of the factors and topics (Cronin and Taylor 1994). Cronin and Taylor (1994) developed the SERVPERF model in response to the limitations presented by researchers to the SERVQUAL model. The SERVPERF model only assesses users' perceptions, not expectations and hence, uses the perceptions portion of the SERVQUAL scale (Cronin and Taylor 1994; Cheng and Chen 2015). Using the SERVPERF scale, as in the Twitter data, was ideal, and commuters tend to share their perception of the service they encountered more often than their expectations.

Further, as not all service quality topics are equally important to all commuters, the study considers the importance weightage of the topics to create the final weighted SERVPERF scale. A Twitter poll for commuters was (in the second Twitter handle) used to collect the importance score for all the predicted topics. The weighted SERVPERF scale equation used was

$$SQ_w = I_1[P] \tag{38.1}$$

where SQ_W = perceived service quality of topic, P = mean performance of topic and I_1 = importance factor.

Moreover, Importance-Performance analysis (IPA), a method for prioritising the topics for improvement, was undertaken to determine the topics that require priority to be addressed by the DMRC. According to Grujičić et al. (2014), 'the IPA identifies areas where improvements will have the greatest impact on the overall system'. Besides, Deng et al. (2008) defined the quadrants 'QI Keep up the good work, QII Possible overkill, QIII Low priority, and QIV Concentrate here'. A confidence interval of 95% was defined for the study, as decision-making based on point estimates for a topic may not be accurate.

Analysis Interpretation

Evaluating the Tweets

Approximately 16,000 tweets are extracted throughout the data extraction period from the official Twitter handle of the Delhi metro. However, about 57% of the tweets are retrieved following the data pre-processing because of significant noise in the extracted data. During the same period, 1800 tweets are extracted from the second Twitter handle intended to collect commuter perception, and because the tweets are semi-structured, approximately 90% of the tweets are retrieved. The commuter perception data is then linearly extrapolated to obtain a proportionate mix of data from both data extraction handles for further analysis.

Further, Mallet's LDA predicted 13 topics with a satisfactory overall coherence score of 0.72 that are manually labelled based on the word corpus. For instance, examining the words in topic 0, it is observed that it has words such as 'signage', 'display', 'guide' and 'board'. Therefore, it appears to incorporate tweets related to the Information Display System. Table 38.1 presents the semantically coherent words as predicted by the model, highlighting only the top six most important words from which the topics are deciphered. It is crucial to notice that some words in topics overlap, such as 'work' in both topic 0 (Information Display System) and topic 7 (Ride Comfort), suggesting that the word is being used in both contexts.

Further, the BERT model predicted each tweet's sentiments, which are classified on a five-point scale and aggregated as per their dominant topic (Fig. 38.1).

Table 38.1 Predicted topics with associated words

Predicted topic	Words corpus (in decreasing order of impact score)					
T0 — Information display system	(w.r.t signage & other assistance system)					
	signage	wrong	display	work	digital	board
T1 — Frequency	(w.r.t metro management & wait time)					
	delay	wait	service	time	frequency	cause
T2 — Punctuality	(w.r.t adherence to schedule)					
	time	late	schedule	office	poor	follow
T3 — Personal safety	(w.r.t safety against abuse, theft & health-related measures)					
	unsafe	guard	night	women	mask	platform
T4 — Miscellaneous	(w.r.t unanticipated terms)					
	hot	covid	smell	charge	function	service
T5 — Personnel's response	(w.r.t emergency response staffing)					
	help	medical	fast	emergency	unavailable	issue
T6 — Information dissemination	(w.r.t information while commute, real-time information)					
	update	kiosk	twitter	notice	slow	correct
T7 — Ride comfort	(w.r.t commute convenience & breakdowns)					
	breakdown	fail	comfort	interrupt	work	suspend
T8 — Customer care assistance	(w.r.t redressal of grievances & knowledge)					
	complaint	support	kiosk	solve	response	expertise
T9 — Crowding	(w.r.t overcrowding in metro)					
	entrance	social	seat	platform	stand	covid
T10 — Universal accessibility	(w.r.t availability of ramps, lifts etc.)					
	ramp	wheelchair	stairs	effort	lift	crowd
T11 — Facilities & amenities	(w.r.t primary facility provided at the stations)					
	toilet	clean	water	feel	drink	light
T12 — Ticketing ease	(w.r.t ticketing system, methods & provisions)					
	card	ticket	recharge	refund	queue	scan

Source Author.

Topics 2 (Punctuality) and topic 12 (Ticketing Ease) have the highest percentages of very negative sentiment, while topics 0 (Information Display System) and topic 8 (Customer Care Assistance) have the highest percentages of very positive sentiment. However, for the overall scoring, the sentiment of the topics is measured with the importance score to get an insight into the topic's impact.

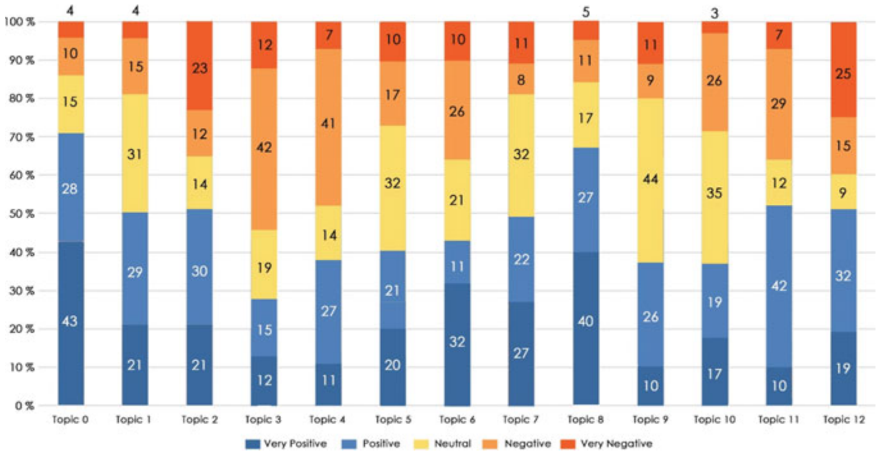


Fig. 38.1 Sentiment analysis classification. *Source* Author

Table 38.2 presents a prediction of sentiment as well as the dominant topic for each tweet in the dataset. For the first tweet in the example, the LDA model predicts dominant topic 8, and the BERT model predicts positive sentiment.

Moreover, the overall negative word cloud, having the most frequent negative sentiment words and their impact factor, presents an understanding of commuters' concerns (Fig. 38.2). It is observed that 'unsafe', 'delay', 'ticket' and 'entrance' are some of the high-impact words contributing to the negative sentiments.

Figure 38.3 depicts the temporal tweet activity trend for aggregated weekly assessment. The five-point classification scale is reduced to a three-point classification scale to observe the trend. After a week of analysing the data, it was observed that weekdays, particularly Tuesday and Wednesday, have relatively high tweet volumes compared to weekends. On weekdays, the percentage of negative tweets is relatively high (more than 50% on Wednesdays); however, on weekends, the percentage of positive tweets is significantly higher. This may be because more leisurely weekend excursions lead to less congestion and a better commuting experience. Further semantic analysis for weekdays and weekends reveals that topic 2 (Punctuality) and topic 9

Table 38.2 Example for semantic and sentiment output

Original tweet	Dominant topic	Predicted sentiment
Staff is approachable and kind towards helping the passengers!!:) #Rajiv Chowk #Blueline @OfficialDMRC https://t.co/4HEw3afdbgnn	8	Positive
In the mrng hours the token counters and metro get crowded, more trains are needed to run rushhour #Anand Vihar #Saket #Yellow @OfficialDMRC https://t.co/4FFw3afdbgnn	9	Negative

Source Author.

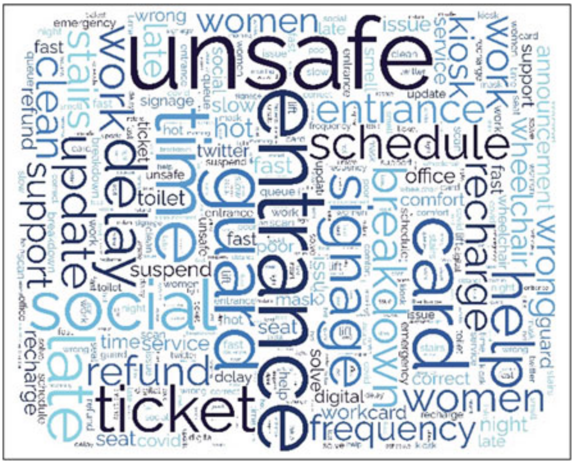


Fig. 38.2 Overall negative sentiment word cloud. *Source* Author

(Crowding) are the most frequently tweeted topics during the weekdays. In contrast, topic 3 (Personal Safety) and topic 7 (Ride Comfort) are the most frequently tweeted topics on the weekends.

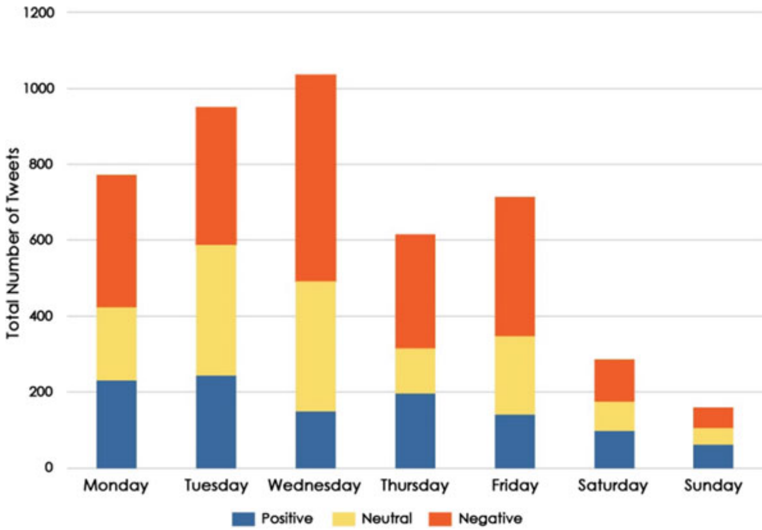


Fig. 38.3 Temporal tweet activity—weekly. *Source* Author

Structuring the Commuters' Perception

The 13 predicted topics are classified into four factors on performing the factor analysis using the scree plot method. Two topics, topic 4 (Miscellaneous) and topic 11 (Facilities and Amenities), have factor loading less than 0.5 and are thus eliminated. The overall variance is greater than 61%, indicating that the factors are acceptable (Hair et al. 2010 ; Chen 2008). Also, the Cronbach alpha reliability test shows that the coefficient is between 0.7 and 0.8, signifying that the scale is reliable (Hair et al. 2010 ; Yaya et al. 2014). Table 38.3 presents the overall service quality framework for the Delhi metro having four factors defining the topics, namely 'Commuter Interaction Quality', 'Physical Ambience Quality', 'Service Output Quality' and 'Information Communication Quality'. The factors were rationally given a name to comprehend the topics it presents more effectively.

Assimilating the structure, the first factor of the measurement scale, Commuter Interaction Quality, is about the service delivery process; the emphasis is on how effectively the commuter-personnel interaction takes place, having topics of 'Personnel's Response' and 'Customer Care Assistance'. This factor explains the

Table 38.3 Exploratory factor analysis of the service quality

Topic	Factor	Factor loading	Eigen value
	Factor 1 commuter interaction quality (Variance = 16.79%, ronbach alpha = 0.728)		1.432
Topic 5	Personnel's response	0.878	
Topic 8	Customer care assistance	0.554	
	Factor 2 physical ambience quality (Variance = 15.41%, Cronbach alpha = 0.7)		2.202
Topic 3	Personal safety	0.612	
Topic 9	Crowding	0.538	
Topic 10	Universal accessibility	0.537	
Topic 12	Ticketing ease	0.515	
	Factor 3 service output quality (Variance = 15.26%, Cronbach alpha = 0.792)		1.813
Topic 1	Frequency	0.522	
Topic 2	Punctuality	0.543	
Topic 7	Ride comfort	0.748	
	Factor 4 information communication quality (Variance = 13.82%, Cronbach alpha = 0.84)		1.674
Topic 0	Information display system	0.684	
Topic 6	Information dissemination	0.99	

The KMO measure = 0.81; Bartlett's sphericity test = *p*-value < 0.001; total variance = 61.28%.
Source Author.

significant variance in the measurement of about 16.79%. The second factor, Physical Ambience Quality, is about the physical ambience of the service setting; the emphasis is on how good the service provides tangible attributes. This finding parallels the results observed in previous works, with public transport commuters considering the physical environment of the vehicles to be an essential aspect of service quality considering topics of 'Personal Safety', 'Crowding', 'Universal Accessibility' and 'Ticketing Ease'. The third factor, Service Output Quality, is about the output of the service delivery; the emphasis is on how efficiently the service delivery, as expected, is implemented. It reflects the topic concerning the metro operations such as 'Frequency', 'Punctuality' and 'Ride Comfort'. The final factor, Information Communication Quality, is about the information provided during the travel and before/after the travel; the emphasis is on how effectively the service provides information to the commuters reflecting topics of 'Information Display System' and 'Information Dissemination'.

Identifying the Priority Issues

The perceived service quality score is determined by employing the weighted SERVPERF scale based on the sentiment analysis of each predicted topic (Table 38.4). Topics such as 'Information Display System' and 'Customer Care Assistance' have the highest positive commuter perception, including sentiments and an important factor. Similarly, topics of 'Personal Safety' and 'Ticketing Ease' have the least commuter perception score. Further, the difference between the factors is marginal, with the factor 'Information Communication Quality' having the highest perceived service quality and the factor 'Physical Ambience Quality' having the lowest perceived service quality.

Moreover, Fig. 38.4 depicts the IPA matrix by plotting the perceived service quality scores (performance score) on the y-axis and the importance scores on the x-axis to prioritise the issues that will most impact improving the overall structure. Topic 2 (Punctuality), topic 3 (Personal Safety), topic 9 (Crowding) and topic 12 (Ticketing Ease) fall in quadrant four (concentrate here) and hence should be prioritised because they are essential to commuters, yet performance score is less. Topic 1 (Frequency), topic 7 (Ride Comfort) and topic 10 (Universal Accessibility) fall in quadrant one (keep up the good work) hence highlighting commuters' satisfaction with the topics. As per commuters, DMRC is focusing its efforts more on topic 0 (Information Display System) and topic 8 (Customer Care Assistance) than what they believe is essential as it falls in quadrant two (possible overkill). At the same time, topic 5 (Personnel's Response) and topic 6 (Information Dissemination) are both in quadrant three (low priority) and hence are low performance but also of low importance to the commuters. However, most of the topics are inside the 95% confidence interval, indicating that the topics have the potential to fall into either quadrant as samples change. For example, given a different sample, topic 6 (Information Dissemination) currently in quadrant three may fall into any other quadrants.

Table 38.4 Perceived service quality

Topic number	Topic	Performance score (P)	Importance factor (I_1)	Weighted SERVPERF $SQ_W = I_1(P)$
Factor 1—Commuter interaction quality (P1)				
5	Personnel's response	3.24	0.902	2.922
8	customer care assistance	3.88	0.884	3.430
		Factor score (SQP_1)		**3.176**
Factor 2—Physical ambience quality (P2)				
3	Personal safety	2.73	0.966	2.637
9	Crowding	3.15	0.952	2.999
10	Universal accessibility	3.21	0.928	2.979
12	ticketing ease	3.05	0.938	2.861
		Factor score (SQP_2)		**2.869**
Factor 3—Service output quality (P3)				
1	Frequency	3.49	0.934	3.260
2	Punctuality	3.14	0.936	2.939
7	Ride comfort	3.46	0.958	3.315
		Factor score (SQP_3)		**3.171**
Factor 4—Information communication quality (P4)				
0	Information display system	3.96	0.868	3.437
6	Information dissemination	3.29	0.926	3.047
		Factor Score (SQP_4)		**3.242**
Perceived Service Quality (PSQ) $(SQP_1 + SQP_2 + SQP_3 + SQP_4)/4] =$ **3.115**				

Source Author.

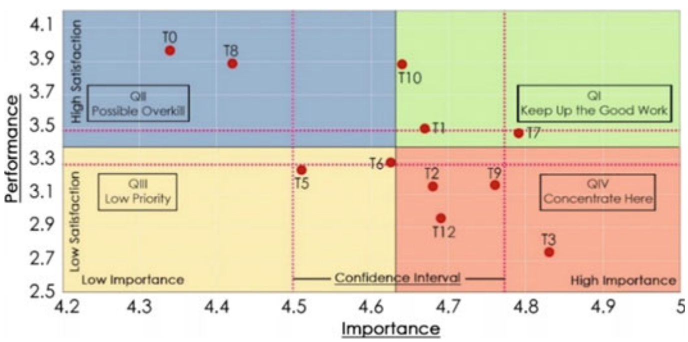


Fig. 38.4 IPA matrix—overall metro network. *Source* Author

Comprehending the Spatial Set-Up

Figure 38.5 depicts the tweet volume mapped using geocoding of tweets based on the station name. Botanical Garden, Hauz Khas, Rajiv Chowk, New Delhi, and Kashmere Gate stations have the highest tweet volume. One reason is their strategic location, as four of the five stations are metro interchanges, while New Delhi station is an Indian Railways and metro station interchange.

Further, on performing the hotspot analysis, spatial clustering of positive and negative tweet density is mapped (Fig. 38.6). It calculates the Getis-Ord Gi* statistic (for high/low clustering) for each dataset value. The resultant z-score represents the high or low values cluster (for both positive and negative) spatially. In the overall Delhi metro service, no established negative and positive clustering pattern was observed when the hotspot analysis was performed at the station level. This means that the positive and negative sentiment for the service delivery is spread throughout.

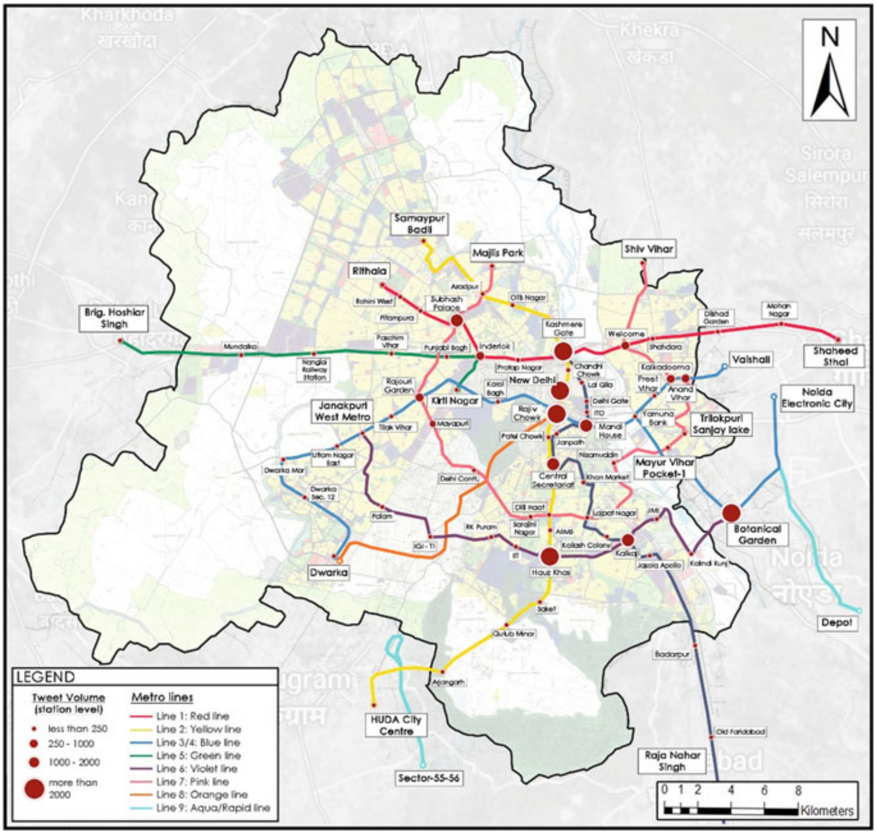


Fig. 38.5 Tweet volume at station level. *Source* Author

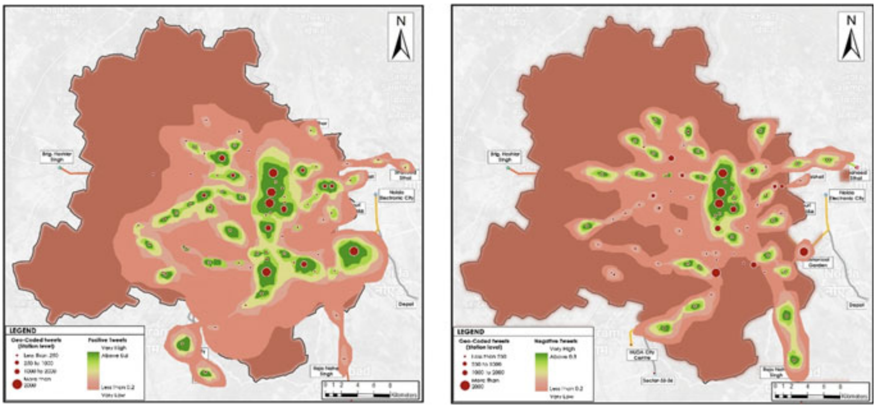


Fig. 38.6 Positive and negative tweet density *Source* Author

To further delve into the volume of the tweets extracted and to check if it depends on the metro's ridership, a correlation is tested between average monthly ridership (in lacs/km) and the extracted tweets at a route level (Fig. 38.7). From the analysis, the correlation comes out to be 0.92, and the value shows that the feedback tweets received are highly correlated to the average monthly ridership. Also, a positive sign implies that as the ridership increases, feedback tweets also increase. Besides, a correlation between average monthly ridership (in lacs/km) and the extracted negative sentiment tweets also showed a strong positive correlation. However, a correlation between average monthly ridership (in lacs/km) and the extracted positive sentiment tweets showed a weak positive correlation. In the current scenario, the negative sentiments rely on the ridership of the lines, unlike the positive sentiments.

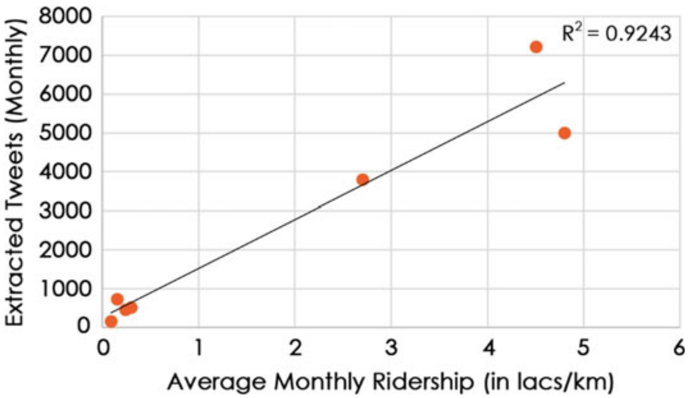


Fig. 38.7 Relationship between average monthly ridership (in lacs/km) and extracted tweets (route wise). *Source* Author

On discerning the commuters' concerns at a route level, it is observed that similar ridership routes present similar concerns. Hence, for further analysis, based on the average daily ridership (in lacs/km, Jan 2019), the routes are classified under three categories. The blue and the yellow lines are the high ridership routes, with the average daily ridership (in lacs/km) being over 0.10 lakhs. Likewise, the pink, red and magenta line is medium ridership routes with the average daily ridership (in lacs/km) between 0.05 and 0.10 lakhs. In contrast, the green and violet lines are low ridership routes with average daily ridership (in lacs/km) less than 0.05 lakhs. Figure 38.8 depicts an overlay map showing the relationship between the average daily ridership per km for the route classification mentioned above and the extracted data. It also presents the top three frequently tweeted topics per classified route. It can be observed that the commuters' concerns in the low ridership routes are luggage safety (regarding theft and abuse), station amenities (regarding water and toilet) and personnel's response (regarding assistance). While in the medium ridership routes, most tweeted concerns are crowding (regarding seating in trains), breakdowns (regarding operational breakdown) and ticket ease (regarding ATVM), whereas in high ridership routes, crowding (regarding bottlenecks at the entrance), punctuality (regarding adherence to schedule) and ticket ease (regarding ATVM, token recharge) are the most tweeted concerns.

Discussion

In this information age, where commuters' interests and needs constantly evolve, service providers must leverage digital technologies and seek out novel methods of comprehending commuter behaviour to manage commuters' services effectively. To that end, the main contribution of this chapter is developing a methodology for assessing commuters' perceptions of the Delhi metro using Twitter. The research emphasises the process and challenges of extracting, analysing and interpreting Twitter data in an Indian setting.

The study adopted two-step data extraction process that provided better insights into both commuters' grievances and their perceptions of how well the service was delivered. The tweets on the Delhi metro's official Twitter handle show that people are more inclined to convey what they encountered rather than how they feel about a particular aspect of service delivery. However, when commuters are encouraged to share their experiences on the latter part, as done in the study on the second Twitter handle, they are offered information that could be extremely useful in understanding their perception. Hence, to obtain informative data, it is crucial to assert that commuters must be encouraged to share their experiences which could be achieved via the Delhi metro's efforts to promote the usage of Twitter.

On the technical front, one crucial observation is that the present tweets under the official handle of the Delhi metro have a high level of noise, with only 57% of the extracted tweets maintained after pre-processing, owing to the use of languages other than English. On the other hand, the second Twitter handle produced a lower noise

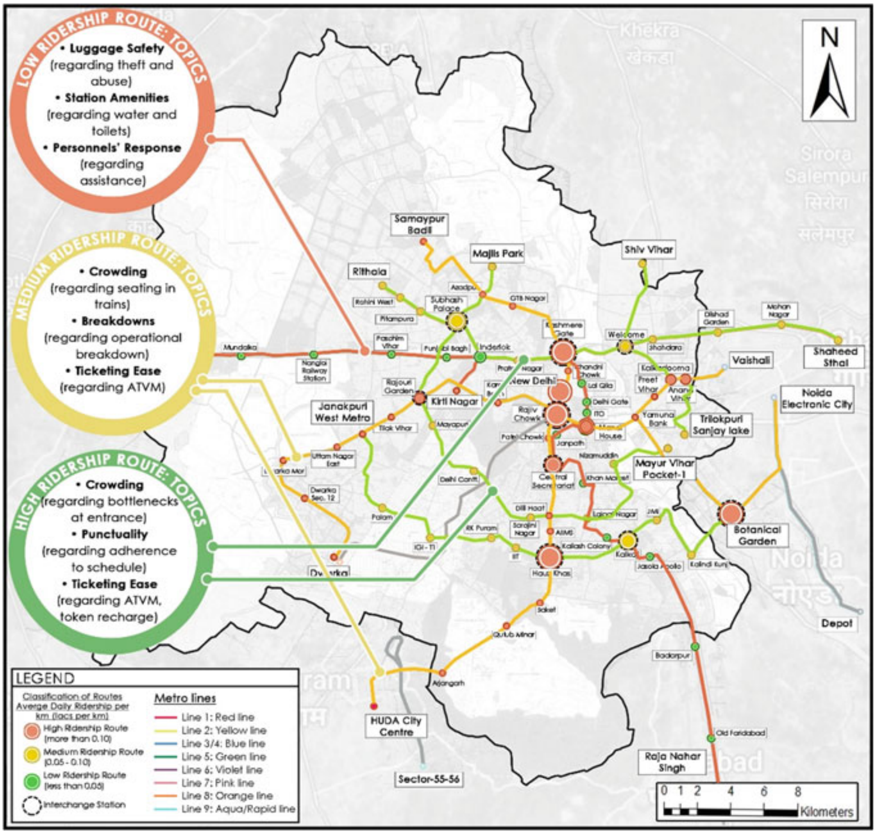


Fig. 38.8 Overlay map between routes classification based on average daily ridership (in lacs/km) and extracted tweets. *Source* Author

level as commuters were encouraged to share their experiences. Given the sophistication of the models, assessing additional Indian languages or adding a context-specific vocabulary would be a solution to address this concern and provide a complete interpretation. Further, it is observed that employing imputation is another critical step in assessing commuters' perceptions based on social media data. It is significant to highlight that the social media assessment increases commuters' convenience and offers a setting where commuters can choose to share their experience on the topics they feel are crucial or essential to them. Therefore, some sentiment values must be imputed to include commuter-level sentiment scoring in the SQA framework. By not requiring commuters to express their opinions on every survey issue and preventing the environment from becoming just another online survey, imputation aids in maintaining the fundamental purpose of social media data analysis.

On performing semantic and sentiment analysis on the extracted tweets, it is observed that 'Personal Safety', 'Crowding' and 'Ticketing Ease' are the lowest scoring topics. However, the IPA matrix revealed that, in addition to the preceding lowest scoring topics, commuters also prioritise the topic of 'Punctuality'. The spatial study showed that currently, the tweets are highly correlated to the ridership of the route, with the positive and negative sentiments dispersed throughout the network. However, to understand the issues better, a route-by-route analysis is essential because, depending on the ridership, different routes highlight different concerns to the commuters. For example, a breakdown issue on a route with a medium ridership is a concern that is not frequently raised on routes with lower ridership.

One advantage of employing social media data is pinpointing the niche of concern within each predicted topic based on the word corpus. Based on the word corpus, it could be deciphered that in the topic of 'Personal Safety', women may be concerned about security because some metro stations have multiple gates, leaving some areas unattended; security checks are occasionally conducted deep inside the stations, and a sizable amount of the station's entryway is left unattended. Similarly, when it comes to 'Ticketing Ease', commuters frequently complain about metro card recharges, such as top-ups, failing to process even after a successful transaction. On a larger scale, social media offers a platform for involving commuters, maintaining the central tenet of any public decision-making process, namely e-public participation. In a sense, it addresses commuters' concerns and occasionally offers solutions to a wide range of commuters with various backgrounds and unique personality traits.

Since social media data usage is still in its early stages, some limitations must be considered when employing social media analytics. First and foremost, the digital divide, a disparity between those who have and those who do not have access to digital technologies, is an issue in the context of India. As stated in earlier studies, other limitations include user profile knowledge and a lack of precise population representation. Another limitation could be a lack of delineation between a rider and a non-rider profile, leading to data bias. For the time being, it is believed that social media data should be used as an additional layer to the current framework by integrating it with the results of conventional satisfaction surveys or other public transport surveys. Moreover, some limitations can be addressed by increasing the sample size from social media and collecting crowdsourced data from multiple sources to understand the scenario better. Additionally, the data shows that social media has a higher percentage of negative feelings since people tend to only express their negative experiences with service delivery rather than positive feedback. Commuters may complain or offer feedback about service delivery to intensify the problems they are experiencing. However, it is essential to analyse Twitter data because a negative mood does not always indicate poor service. So, before taking any decision, the ground truth and the conventional customer satisfaction survey should be referred to. To sum up, the exponential increase in Internet penetration in India and the government's vision of digitally driven governance have created a favourable environment for further research in this area.

Conclusion

The chapter outlines a method for assessing commuters' perceptions of the Delhi metro using social media data from Twitter. It uses Mallet's LDA model for semantic analysis to determine the topics commuters are tweeting about and the BERT model for sentiment analysis to determine the sentiments of the predicted topics. It also provides a structure that might be added to the existing conventional satisfaction survey findings and highlights the priority topics using an IPA matrix. The benefits of social media data analysis are considerable, but they must be approached with prudence. On a larger scale, the method used in the study has two benefits: first, it can be used by commuters to voice their concerns during their commute in near real time, and by the provider to keep track of on-the-ground concerns that the commuter is encountering; second, it can be used to monitor the service based on the commuters' perception over a more extended period for SQA.

Future research in this area should focus on gathering demographic information to have a deeper understanding of a particular route's problems. In addition, the study is required on how to scale (horizontally and vertically) the usage of social media data to assess commuter perception. This is possible across various platforms, including Google Reviews, Instagram and other LBSN, for the intermodal integration of public transport and even micro-mobilities. Integrating commuter perception into decision-making benefits service providers and commuters since it streamlines the collection of comprehensive insights and allows for long-term service quality assessment.

References

Bansal HS, Taylor S (2014) Investigating the relationship between service quality, satisfaction and switching intentions. Dev Market Sci Proc Acad Market Sci 304–313. https://doi.org/10.1007/978-3-319-13141-2_107

Bird S, Klein E, Loper E (2009) Natural language processing with Python. O'reilly

Blanc DL (2020) E-participation: a quick overview of recent qualitative trends. DESA Working Paper, 163, 1–33. United Nations- Department of Economic and Social Affairs

Blei DM, Ng AY, Jordan MI (2003) Latent Dirichlet allocation. J Mach Learn Res 3:993–1022

Campagna M (2016) Social media geographic information: why social is special when it goes spatial? Eur Handb Crowdsourced Geog Inf 45–54. https://doi.org/10.5334/bax.d

Casas I, Delmelle EC (2017) Tweeting about public transit—Gleaning public perceptions from a social media microblog. Case Stud Transp Pol 5(4):634–642. https://doi.org/10.1016/j.cstp.2017.08.004

Chen C-F (2008) Investigating structural relationships between service quality, perceived value, satisfaction, and behavioral intentions for air passengers: evidence from Taiwan. Transp Res Part a: Pol Pract 42(4):709–717. https://doi.org/10.1016/j.tra.2008.01.007

Cheng Y-H, Chen S-Y (2015) Perceived accessibility, mobility, and connectivity of public transportation systems. Transp Res Part a: Pol Pract 77:386–403. https://doi.org/10.1016/j.tra.2015.05.003

Cipriani E, Gori S, Petrelli M (2012) A bus network design procedure with elastic demand for large urban areas. Publ Transp 4(1):57–76. https://doi.org/10.1007/s12469-012-0051-7

Cronin JJ, Taylor SA (1994) Servperf versus Servqual: reconciling performance-based and perceptions-minus-expectations measurement of service quality. J Mark 58(1):125–131. https://doi.org/10.1177/002224299405800110

Dagger TS, Sweeney JC (2006) The effect of service evaluations on behavioral intentions and quality of life. J Serv Res 9(1):3–18. https://doi.org/10.1177/1094670506289528

Das S, Pandit D (2013) Importance of user perception in evaluating level of service for bus transit for a developing country like India: a review. Transp Rev 33(4):402–420. https://doi.org/10.1080/01441647.2013.789571

Delhi Metro Rail Corporation Ltd. (2019). DMRC | About us. www.delhimetrorail.com. http://www.delhimetrorail.com/about_us.aspx#Introduction

Deng W-J, Kuo Y-F, Chen W-C (2008) Revised importance–performance analysis: three-factor theory and benchmarking. Serv Ind J 28(1):37–51. https://doi.org/10.1080/02642060701725412

Devlin J, Chang M-W, Lee K, Toutanova K (2019) BERT: Pre-training of deep bidirectional transformers for language understanding. In: Proceedings of the 2019 conference of the north. https://doi.org/10.18653/v1/n19-1423

Grujičić D, Ivanović I, Jović J, Đorić V (2014) Customer perception of service quality in public transport. Transport 29(3):285–295. https://doi.org/10.3846/16484142.2014.951685

Eboli L, Mazzulla G (2010) How to capture the passengers' point of view on a transit service through rating and choice options. Transp Rev 30(4):435–450. https://doi.org/10.1080/01441640903068441

El-Diraby T, Shalaby A, Hosseini M (2019) Linking social, semantic and sentiment analyses to support modeling transit customers' satisfaction: towards formal study of opinion dynamics. Sustain Cities Soc 49:101578. https://doi.org/10.1016/j.scs.2019.101578

Farhangfar A, Kurgan L, Dy J (2008) Impact of imputation of missing values on classification error for discrete data. Pattern Recogn 41(12):3692–3705. https://doi.org/10.1016/j.patcog.2008.05.019

Fisk R, Grove S, Harris LC, Keeffe DA, Daunt KL, Russell-Bennett R, Wirtz J (2010) Customers behaving badly: a state of the art review, research agenda and implications for practitioners. J Serv Mark 24(6):417–429. https://doi.org/10.1108/08876041011072537

Friman M (2004) Implementing quality improvements in public transport. J Public Transp 7(4):49–65. https://doi.org/10.5038/2375-0901.7.4.3

Gal-Tzur A, Grant-Muller SM, Minkov E, Nocera S (2014) The impact of social media usage on transport policy: issues, challenges and recommendations. Procedia Soc Behav Sci 111:937–946. https://doi.org/10.1016/j.sbspro.2014.01.128

García S, Luengo J, Herrera F (2015) Dealing with missing values. In: Kacprzyk J, Jain LC (eds) Data Preprocessing in Data Mining. Springer, pp 59–106

García-Palomares JC, Salas-Olmedo MH, Moya-Gómez B, Condeço-Melhorado A, Gutiérrez J (2018) City dynamics through twitter: relationships between land use and spatiotemporal demographics. Cities 72(B):310–319. https://doi.org/10.1016/j.cities.2017.09.007

Gershon RRM (2005) Public transportation: advantages and challenges. J Urb Health: Bullet New York Acad Med 82(1):7–9. https://doi.org/10.1093/jurban/jti003

Haddi E, Liu X, Shi Y (2013) The role of text pre-processing in sentiment analysis. Proced Comput Sci 17:26–32. https://doi.org/10.1016/j.procs.2013.05.005

Haghighi NN, Liu XC, Wei R, Li W, Shao H (2018) Using Twitter data for transit performance assessment: a framework for evaluating transit riders' opinions about quality of service. Publ Transp 10(2):363–377. https://doi.org/10.1007/s12469-018-0184-4

Hair J, Black WC, Babin BJ, Anderson RE (2010) Multivariate data analysis: a global perspective. Pearson Education, Cop

Hatuka T, Zur H, Mendoza JA (2020) The urban digital lifestyle: an analytical framework for placing digital practices in a spatial context and for developing applicable policy. Cities 111:102978. https://doi.org/10.1016/j.cities.2020.102978

Homburg C, Koschate N, Hoyer WD (2006) The role of cognition and affect in the formation of customer satisfaction: a dynamic perspective. J Mark 70(3):21–31. https://doi.org/10.1509/jmkg.70.3.021

Jia F, Chen C-C (2020) Emotional characteristics and time series analysis of Internet public opinion participants based on emotional feature words. Int J Adv Rob Syst 17(1):172988142090421. https://doi.org/10.1177/1729881420904213

Johnson MD, Gustafsson A, Andreassen TW, Lervik L, Cha J (2001) The evolution and future of national customer satisfaction index models. J Econ Psychol 22(2):217–245. https://doi.org/10.1016/s0167-4870(01)00030-7

Kandt J, Batty M (2020) Smart cities, big data and urban policy: towards urban analytics for the long run. Cities 109(102992):102992. https://doi.org/10.1016/j.cities.2020.102992

Lansley G, Longley PA (2016) The geography of Twitter topics in London. Comput Environ Urban Syst 58:85–96. https://doi.org/10.1016/j.compenvurbsys.2016.04.002

Manning CD, Raghavan P, Hinrich Schütze, University of Cambridge (2009) Introduction to information retrieval. Cambridge University Press

Martí P, Serrano-Estrada L, Nolasco-Cirugeda A (2019) Social media data: challenges, opportunities and limitations in urban studies. Comput Environ Urban Syst 74:161–174. https://doi.org/10.1016/j.compenvurbsys.2018.11.001

Matas A (2004) Demand and revenue implications of an integrated public transport policy: the case of Madrid. Transp Rev 24(2):195–217. https://doi.org/10.1080/0144164032000107223

McCarney R, Warner J, Iliffe S, van Haselen R, Griffin M, Fisher P (2007) The Hawthorne effect: a randomised, controlled trial. BMC Med Res Methodol 7(1). https://doi.org/10.1186/1471-2288-7-30

Morton C, Caulfield B, Anable J (2016) Customer perceptions of quality of service in public transport: evidence for bus transit in Scotland. Case Stud Transp Pol 4(3):199–207. https://doi.org/10.1016/j.cstp.2016.03.002

Osorio-Arjona J, Horak J, Svoboda R, García-Ruíz Y (2021) Social media semantic perceptions on Madrid metro system: using Twitter data to link complaints to space. Sustain Cities Soc 64:102530. https://doi.org/10.1016/j.scs.2020.102530

Parasuraman A, Zeithaml VA, Berry LL (1985) A conceptual model of service quality and its implications for future research. J Mark 49(4):41–50. https://doi.org/10.1177/002224298504900403

Parasuraman A, Zeithaml VA, Berry LL (1988) SERVQUAL: a multiple-item scale for measuring customer perceptions of service quality. J Retail 12–40

Pillai S (2021) Waiting and riding time longer but Delhi metro ensures safer ride. Hindustan Times. https://www.hindustantimes.com/cities/others/waiting-and-riding-time-longer-but-delhi-metro-ensures-safer-ride-101623347061136.html#:~:text=As%20against%20the%20average%20one

Schneider B, White SS (2004) Service quality: research perspectives. Sage Publications, London

Schweitzer L (2014) Planning and social media: a case study of public transit and stigma on Twitter. J Am Plann Assoc 80(3):218–238. https://doi.org/10.1080/01944363.2014.980439

Sloan L, Quan-Haase A (2017) The SAGE handbook of social media research methods. Sage Reference

Songchon C, Wright G, Beevers L (2021) Quality assessment of crowdsourced social media data for urban flood management. Comput Environ Urban Syst 90:101690. https://doi.org/10.1016/j.compenvurbsys.2021.101690

Stelzer A, Englert F, Hörold S, Mayas C (2016) Improving service quality in public transportation systems using automated customer feedback. Transp Res Part e: Log Transp Rev 89:259–271. https://doi.org/10.1016/j.tre.2015.05.010

van Dijk JAGM (2006) Digital divide research, achievements and shortcomings. Poetics 34(4–5):221–235. https://doi.org/10.1016/j.poetic.2006.05.004

Walden-Schreiner C, Leung Y-F, Tateosian L (2018) Digital footprints: Incorporating crowdsourced geographic information for protected area management. Appl Geogr 90:44–54. https://doi.org/10.1016/j.apgeog.2017.11.004

Yaya LHP, Fortià MF, Canals CS, Marimon F (2014) Service quality assessment of public transport and the implication role of demographic characteristics. Publ Transp 7(3):409–428. https://doi.org/10.1007/s12469-014-0099-7

Zeithaml VA, Berry LL, Parasuraman A (1988) Communication and control processes in the delivery of service quality. J Mark 52(2):35. https://doi.org/10.2307/1251263

Chapter 39
Smart Geometric Design of Highways Using HTML Programming for Sustainable and Climate Resilient Cities

Aditya Dhanuka, Aman Srivastava, Leena Khadke, and Nand Lal Kushwaha

Abstract Conventional practice for geometric highway design using engineering drawing techniques and mathematical approaches demands heavy iterative manual efforts amidst numerous calculations, which is cumbersome and time consuming. Consequently, it is challenging highway engineers to approach for a broader perspective on geometric design. Given rising trends for advancing intelligent transportation systems for smart, sustainable and climate-resilient cities, a need is felt for developing web application tools for swift and accurate highway design. To this end, present study aims at developing a computer-based conceptual geometric design model called Web Application Tool for Highway Design (WAT-HD) for highway projects using HTML web application-based programming. The software tool comprehensively accounts for designing highway cross-sectional elements, sight distance, horizontal alignment and vertical alignment, along with their detailed components. A comparative assessment of findings from the tool with manual calculations for a two-lane two-way National Highway indicates its high designing accuracy amidst minimal input requirements. The study concludes that computer-based programming approaches could be more efficient while designing highway geometry with ease to modify within economic and environmental parameters. Such applications become more

A. Dhanuka
Department of Civil Engineering, Government College of Engineering, Jalgaon, Maharashtra 425001, India

A. Srivastava
Formerly, Centre for Technology Alternatives for Rural Areas (CTARA), Indian Institute of Technology (IIT) Bombay, Mumbai, Maharashtra 400076, India
e-mail: amansrivastava013@iitb.ac.in

L. Khadke
Department of Civil Engineering, Indian Institute of Technology (IIT) Bombay, Mumbai, Maharashtra 400076, India
e-mail: 204046001@iitb.ac.in

N. L. Kushwaha (✉)
Division of Agricultural Engineering, ICAR–Indian Agriculture Research Institute, New Delhi 110012, India
e-mail: nand.kushwaha@icar.gov.in

U. Chatterjee et al. (eds.), *Urban Commons, Future Smart Cities and Sustainability*, Springer Geography, https://doi.org/10.1007/978-3-031-24767-5_39

pronounced when pressure is more on achieving goals of smart city design, intelligent urban transportation and reduced vehicular-emission-based greenhouse gas release amidst changing climate.

Keywords Highway engineering · Intelligent transportation · Smart city planning · Climate change · Computer science · Computer-aided programming · Artificial intelligence · Machine learning

Introduction

One of the most pressing issues facing municipal and urban authorities since the twenty-first century is the rise in carbon dioxide (CO_2) and greenhouse gas (GHG) emissions. The reasons have been primarily attributed to traffic congestion, which results in longer travel times, delays and undesirable fuel consumption, even on national highways. Metropolitan transportation planning and management organisations at the district, state and central levels find it challenging to address congestion in urban regions due to the growing population, economic expansion and personal leisure (Bibri and Krogstie 2017; IPCC 2022; Lwasa et al. 2022). Recurrent traffic congestion on highways is frequently caused by a regional imbalance between excessive demand and insufficient capacity. In contrast, non-recurring congestion is impacted mainly by frequent traffic accidents and poor weather conditions (Afrin and Yodo 2020; Chang et al. 2020). There is a pressing recommendation for advancing intelligent transportation systems for sustainable city planning to enable more sophisticated control of traffic demand and a more effective selection of efficient traffic mitigation strategies (Chowhan et al. 2022; Saharan et al. 2020; Telang et al. 2021). One of the approaches to achieving intelligent transportation systems could rest on improving the procedures involved in the geometric design of highways.

Highway geometric design is an inherent theme for introductory transportation engineering (Cafiso et al. 2021; Kanellaidis and Vardaki 2011). A civil engineer or, more specifically, a highway engineer witnesses many challenges while designing essential highways such as National Highways connecting states or provinces. As the concerned engineer undertakes several design controls and criteria, it often happens that the engineer is supposed to go beyond regulatory design standards. Some challenges may include traffic alterations, vehicle changes, construction capital investment limits, critical road establishment locations and environmental and ecological attention (Janssen et al. 2022; Shaaban 2022). In general, a highway engineer is mandated to duly comply with safety issues amidst achieving optimal mobility without compromising the highways' quality and the environment therein. Apparently, it becomes imperative for the present study to investigate difficulties that exist while designing important highways for any nation.

The highway design accounts for drivers' expectations, optimises traffic operations and minimises construction costs and environmental impacts (Othman et al. 2019). The highway design fundamentally includes safe sight distance, overtaking sight distance, horizontal curve, transition curve and vertical curve, along with their detailed components (Garcia and Pastor-Serrano 2022; Justo et al. 2015). Engineering drawing techniques are one of the most widely used traditional approaches for designing highway geometry (mentioned above) over contour maps (Liao and Levinson 2013). However, engineering drawing techniques suffer from a significant limitation of being manual and iterative alongside cumbersome and time consuming. Several commercial software packages and modelling techniques have been developed to overcome the limitations of drawing techniques. These packages mainly employed active digital maps, three-dimensional design models, artificial intelligence (AI) and machine learning (ML) techniques and virtual reality walkthroughs to boost the geometric design of the highway processes (Das 2022; Goswami and Sarkar 2021; Liao and Levinson 2013). Nevertheless, these commercial packages are generally not user friendly (demanding in-depth expertise in computer-based coding), usually complicated and costly to purchase and install. Hence, a need is felt to develop a simple web application tool that essentially executes similar to commercial packages and accurately yields the geometric designs of the highway. Coherently, Liao and Levinson (2013) attempted in the past to improve the understanding of engineering students on geometric design principles of roadways by developing a new software tool called ROAD: Roadway Online Application for Design. However, such attempts to design highways remained limited, and a research gap still exists in using computer-aided programs to replace the cumbersome design processes. Nevertheless, as far as other fields of civil engineering are concerned, attempts to develop web application-based models and employ AI-ML-based approaches have risen in the recent decade (e.g. Chang et al. 2020; Elbeltagi et al. 2022, 2023; Pande et al. 2022; Ezhilarasi et al. 2020; Kumar et al. 2022; Moradi et al. 2019; Sarkar et al. 2020; Srivastava et al. 2021; 2022a, b; Zhang et al. 2020). Thus, these recent advancements in deploying web applications motivated the present study.

Coherently, a non-Internet-based geometric design application called Web Application Tool for Highway Design (WAT-HD) has been developed using HTML programming language with the purpose of reducing numerous cumbersome roadway planning and design calculations. WAT-HD assists in conducting geometric design on a computer screen with minimal numeric inputs. The tool will allow for a more effective and swift design of the geometry of a highway, thereby paving the scope for advancing intelligent transportation systems for future smart cities. The novelty of this work is the integration of computer-aided advancements with highway engineering principles, yielding more sophisticated designed outputs using the former than the traditional manual approach. The study contends that giving professionals or, as such, any user access to geometric design that uses online tools can allow them to explore and evaluate various cause-and-effect scenarios. Such attempts may enable professionals to comprehend better the possible effects of their highway geometric designs in the real world.

Materials and Methods

Development of Web Application Tool for Highway Design (WAT-HD)

Due to their success in fusing computer-aided assistance with practical execution, web-based apps have been increasingly used in education, business, industry and other sectors, as previously mentioned. Platform and location freedom are the benefits of web-based learning resources. Users may virtually access these online apps utilising computers at any time, wherever in the globe. To this end, this investigation attempted to abridge the research gap that indicated limited avenues for geometric highway design. With client-side logic programmed in JavaScript and jQuery, the WAT-HD is created using HyperText Markup Language (HTML) and Cascading Style Sheets (CSS) (an open-source framework of JavaScript). It is linked to a web server that gives clients or users static files (Fig. 39.1). It has access to a MySQL database-connected Application Programming Interface (API). The API was created using Lumen, a PHP (Hypertext Pre-processor) micro-framework, and its primary function is to save the results of WAT-HD computations (as a backup). Representation State Transfer Web Services are used to establish communication between the client and the API server (RESTful Web Services). Create, Read, Update or Delete (CRUD) requests sent by the client over the HTTP (HyperText Transfer Protocol) are answered by the API server. Figure 39.2 shows the output of this programming—WAT-HD's menu page depicting operational tools for conducting geometric highway design.

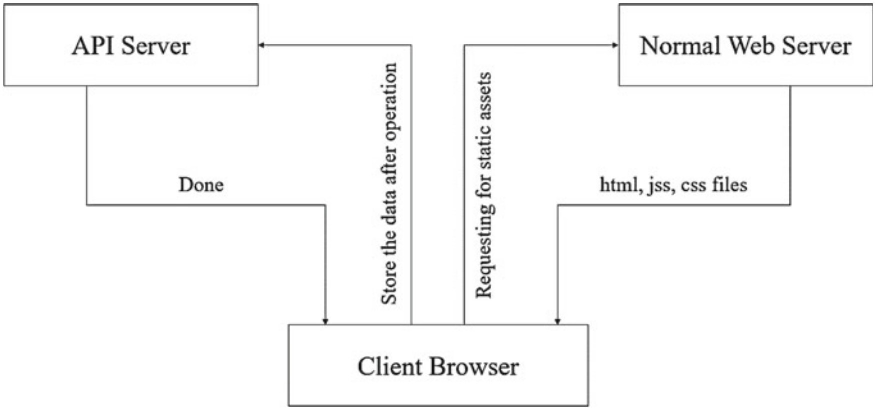


Fig. 39.1 Development of Web Application Tool for Highway Design (WAT-HD) (Methodological framework adapted from Srivastava et al. 2021)

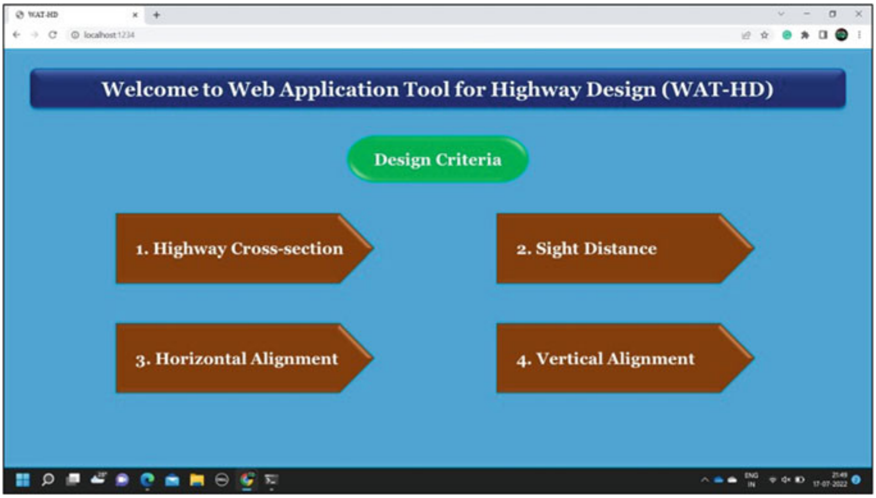


Fig. 39.2 Opening page of Web Application Tool for Highway Design (WAT-HD) showing basic operations

Geometric Highway Design Considerations in WAT-HD

The critical elements of highway geometric design include highway cross-sectional elements (Sect. "Highway Cross-sectional Design"), sight distance (Sect. "Sight Distance Design") and horizontal and vertical alignments (Sects. "Horizontal Alignment Design" and "Vertical Alignment Design") and are shown in Fig. 39.2. Careful consideration of their components allows for designing geometric characteristics of highways in the context of future traffic growth and for apparent road widening or upgrade. The factors influencing geometric design are design speed, topography, traffic, design hourly volume and capacity and environmental and economic factors. The considerations behind geometric highway design are discussed below and summarised in Table 39.1.

Highway Cross-sectional Design

The key cross-section elements include pavement surface characteristics, cross slope or camber, carriageway width, traffic separators, kerbs, road margins, formation width, right of way and land width. Pavement surface depends on pavement type and is characteristically determined through friction or skid resistance, unevenness, light reflecting characteristics and surface water drainage. As per the recommendation of the Indian Road Congress (IRC), the coefficient of longitudinal friction is between 0.35 and 0.40 for stopping distance calculations. At the same time, the lateral coefficient of friction is 0.15 for horizontal curve design. The unevenness index is low for good pavement surfaces, preferably less than 1500 mm per kilometres (mm/km),

Table 39.1 Geometric highway design consideration for developing Web Application Tool for Highway Design (WAT-HD)

Particulars	Web Application Tool for Highway Design (WAT-HD) control and criteria			
Design criteria	Highway cross-section	Sight distance	Horizontal alignment	Vertical alignment
Design components	Pavement surface characteristics	Stopping sight distance: reaction time, velocity, slope, braking efficiency, longitudinal friction factor	Design speed	Longitudinal gradient
	Camber: parabolic and straight line	Safe sight distance	Overturning and transverse skidding effect	Ruling, limiting, exceptional and minimum gradient
	Carriageway width	Overtaking sight distance: traffic-type, velocity, reaction time, distance, acceleration	Maximum and minimum superelevation: friction, horizontal curve radius, velocity	Grade compensation on horizontal curves
	Traffic separators	Absolute minimum sight distance	Pavement widening: mechanical and psychological	Vertical curves: summit curve depends on deviation angle, curve length, stopping sight distance, height of eye level and object
	Road margins: kerbs	Overtaking zones	Horizontal transition curves: Spiral, lemniscate and cubic parabola for plain and hilly terrains	Vertical curves: valley curve depends on deviation angle, stopping sight distance, velocity
	Roadway width and land width	Intermediate sight distance: traffic-type, velocity, reaction time, distance, acceleration	Setback distance: sight distance, length and radii of horizontal curve	
			Curve resistance: tractive force and horizontal curve angle	

Note Any standard highway engineering textbook can be referred to for equations and derivations of design consideration used here; some mathematical calculations are shown in Sect. "Performance Evaluation of WAT-HD and Its Scope in Smart City Planning" and Table 39.2

while for satisfactory pavement surfaces, a value of 2500 mm/km is taken. Regarding light reflectivity, a light-coloured (say white) pavement is considered for better night visibility.

Drainage and quick disposal of the rainwater, etc., is essential, for which cross slope or camber is provided. Usually, a flat camber, ranging from 1.7% to 2%, is usually preferred for relatively impervious pavement. For the width of the carriageway, influencing factors include the number of traffic lanes and each lane width, along with considering the width of the largest vehicle class and lateral clearance required therein. Comprehensively, the width of the carriageway is estimated averagely at around 3.5 m (m) per lane. Besides, traffic separators or medians are provided to prevent head-on collision, usually having a width of 8–14 m. The road margins such as footpaths are provided as kerbs which can be categorised as low kerb (100 mm above the pavement edge), semi-barrier type kerb (150 mm above) and barrier type kerb (200 mm above). Roadway width comprises the width of the carriageway, traffic separators and road margins. Furthermore, additional land is acquired along the road alignment called the land width (or right of way) to meet the future demand for the widening of highways.

Sight Distance Design

Highway design is objected to adopting safe and efficient design for smooth operations. For example, the road length to overcome the obstacle becomes essential when the obstruction becomes visible to the driver while driving on the highway. Knowledge of this road length paves the way for safe vehicle operation. Sight distance, which can be measured along the road surface, thus can be defined as road length ahead of the driver during any moment of the driver's journey. In the context of geometric design of highways and traffic control, sight distance can be categorised as absolute minimum sight distance (which is called stopping sight distance (SSD)], passing sight distance [also called safe overtaking sight distance (OSD)] and safe sight distance. Highway geometry generally demands safe stopping, safe overtaking and safety at an uncontrolled intersection. In the case of SSD, factors affecting the sight distance and the distance at which the driver can stop the vehicle include reaction time, speed, brake efficiency, friction between tyre and road and the road gradient. In contrast, for OSD, for safe overtaking, factors include the speed of overtaking vehicle, speed of an overtaken vehicle, the speed of the vehicle from the opposite direction; acceleration rate of overtaking vehicle, the distance between overtaken and overtaking vehicles, reaction time of the driver and road gradient. Besides, IRC defines two more categories of sight distance: intermediate sight distance (ISD) and headlight sight distance. The former is required when OSD cannot be provisioned in the geometric design, while the latter measures the distance visible to the driver under the illumination of vehicle headlights during night-time.

Horizontal Alignment Design

The obligatory points in the highway pathway (to be established) or the topographic challenges necessitate changes in the direction of highway alignment. Horizontal alignment ensures vehicles' safe and comfortable movement by not accounting in design for sudden turns on the road with sharp or reverse curves. Since horizontal alignment decides the design speed, therefore, while designing highways, the alignment must not provoke drivers to undergo abrupt speed changes, which may increase accident rates. Different design components influencing horizontal alignment include design speed, circular curve radius, transition curves type and length, superelevation, pavement widening on curves and setback distance. Design speed is the critical factor in geometric design, such that sight distance, other components of horizontal alignment and summit and valley curve lengths are dependent. Design speed is estimated based on the road class and terrain. Fundamentally, four types of terrain are considered in a geometric design of highways: plain, rolling, mountainous and steep. Furthermore, geometric designing is done mainly by considering the ruling design speed (and not the minimum design speed) because it is regarded as the guiding criterion. However, if the ruling design speed cannot be adopted for design, may be due to topographic restrictions, minimum design speed can be used for horizontal curve design. The horizontal curve in the highway provides directional change concerning the road's centre line. The vehicle negotiating a horizontal curve due to centrifugal force results in overturning and transverse skidding effects. To overcome the negative effect of centrifugal force alongside overturning and transverse skidding effects, superelevation is accounted for while designing highway geometry, wherein the outer edge is raised with reference to the inner edge.

Besides, when the horizontal curve is not of higher radii, pavement width is slightly widened while designing and is categorised as mechanical widening and psychological widening. Also, transition curves are introduced when it is required to introduce a smooth transition between a straight highway and a circular curve highway, which allows for controlling the adverse effects of centrifugal force. They are further categorised as spiral, lemniscate and cubic parabola transition curves. Regarding challenges for horizontal curves, the sight distance at the inner curve is needed to be considered while designing, such that either the obstacle is removed or alignment is redesigned to meet reasonable sight distance requirements. Designers are also supposed to consider curve resistance in the geometric design since the front wheels of the vehicle move but not the rear wheels, thereby generating additional tractive forces resulting in high friction.

Vertical Alignment Design

Since the vertical profile of the highway to be designed is challenging to be uniform, it instead comprises slopes of varying magnitudes along the profile. Thus, varying slopes demand deep cuttings or high embankments. The geometric design requires minimising high cutting and filling, for which knowledge of grades and vertical curves from the highway's vertical alignment is essential. Different variables, such as vehicle speed, acceleration, stopping distance, sight distance, comfort and economic aspects, are governed by the vertical alignment of highways. Grade or the gradient of the vertical alignment can be defined as the rate of fall or rise along the highway length. The gradient can be classified as ruling, limiting, exceptional and minimum. It is imperative to highlight that in horizontal curves, it is not only the tractive force due to the fixed rear wheel of the vehicle but also the gradient that may add in, thereby increasing the gross tractive force to cause discomfort while driving. To overcome this difficulty, the designer reduces the gradient to compensate for the loss of tractive effort due to a sharp horizontal curve. The reduction in gradient at the horizontal curve is defined as grade compensation. Given convexity and concavity in the highway alignment, information on vertical curves is also required. They are categorised as summit and valley curves.

Results and Discussion

Two-Lane Two-Way Geometric Highway Design Analysis Using Manual Approach

A two-lane two-way National Highway is geometrically designed via a manual approach and also executed by employing WAT-HD to validate the functionality and performance of WAT-HD against the manual procedure. Four problem statements, viz. design problem on highway cross-section elements, sight distance, horizontal curve and transition curve, are described step-wise, followed by its manual solution in Sect. "Two-Lane Two-Way Geometric Highway Design Analysis Using Manual Approach". Comparative assessment between manual estimations and WAT-HD output, thereby discussion on the user-friendliness of WAT-HD, are documented in Sect. "Performance Evaluation of WAT-HD and Its Scope in Smart City Planning". For uniformity, each design component's recommendations are based on IRC's prescribed values (https://morth.nic.in/sites/default/files/1-volume-1.pdf, accessed 17 July 2022).

Problem statement—1

In a district located in a high rainfall region having plain and rolling terrain, a two-lane ($n = 2$) National Highway is to be paved. Assuming the straight line camber with a bituminous concrete surface, design the height of the crown concerning the highway edges.

Solution—1: A two-lane National highway for plain and rolling terrain is recommended to have a roadway width of 12 m and a carriageway with raised kerbs of 7.5 m, while the road surface, having cement concrete and a high type bituminous surface, is recommended to attain camber in the range of 1 in 50 (or 2%) for heavy rainfall conditions.

- The rise of crown concerning highway edges is estimated as $= (7.5 \div 2) \times (1 \div 50) = 0.09$ m

Problem statement—2

Design the safe stopping sight distance (SSD), headlight sight distance and intermediate sight distance (ISD) for the same conditions as in problem statement—1, and if the designed speed (V) is 80 km/hours (or kmph; such that $v = 22.2$ m/s), two-way traffic prevails on the two-lane National Highway. Also, design safe overtaking sight distance (OSD) and a minimum and desirable length of overtaking zone: if the velocity of overtaking and overtaken vehicle (i.e. V_a and V_b) is 70 kmph ($v_a = 19.4$ m/s) and 40 kmph ($v_b = 11.1$ m/s), respectively. Following IRC recommendations, the coefficient of friction (f) is assumed to be 0.37, the driver's reaction time (t) is 2.5 s (s), the driver's overtaking reaction time (t_o) is 2 s, and the average overtaking vehicle acceleration (a) is 0.99 m/s^2.

Solution—2: The SSD for two-lane, given conditions mentioned above and acceleration due to gravity (g) as 9.81 m/s^2, is estimated as follows:

- $\text{SSD} = vt + \frac{v^2}{2gf} = (22.2 \times 2.5) + \frac{22.2^2}{2\times 9.81\times 0.37} = 123.5\,\text{m}$

While the headlight sight distance will be the same as SSD (=123.5 m) and ISD will be twice SSD (=247 m), OSD is estimated by incorporating the given values in the following equation:

-
$$\begin{aligned}\text{OSD} &= (v_b \times t_0) + \left[\left(v_b\sqrt{\frac{4(0.7v_b+6)}{a}}\right) + 2(0.7v_b+6)\right] \\ &+ \left(v_a\sqrt{\frac{4(0.7v_b+6)}{a}}\right) = (11.1\times 2) \\ &+ \left[\left(11.1\sqrt{\frac{4(0.7\times 11.1+6)}{0.99}}\right) + 2(0.7\times 11.1+6)\right] \\ &+ \left(19.4\sqrt{\frac{4(0.7\times 11.1+6)}{0.99}}\right) = 277.6\ \text{m}\end{aligned}$$

The minimum length of overtaking zone is three times OSD (=834 m), and the desired length of overtaking zone is five times OSD (=1390 m).

Problem statement—3

Following the information in problem statements—1 and 2, design the superelevation (e) rate for a mixed traffic condition having a horizontal curve radius (R) of 480 m. Also, determine by how much the outer edge should be raised against the inner edge of the highway. Besides, design the ruling minimum radius (R_r) of the horizontal curve if the design speed considered for the current highway design is the ruling design speed. Similarly, design the horizontal curve's absolute minimum radius (R_a)

if the current highway's minimum design speed ($V_{\min}$) is 60 kmph. For this horizontal curve ($R = 480$ m), design the extra widening (W_e) if the vehicle's most extended wheelbase (l) expected on this highway is 6.5 m. In addition, design the length of the transition curve (L_s) for this horizontal curve if the allowable rate of introduction of the superelevation (e_{rate}) is 1 in 150, such that the pavement is rotated about the inner edge (because the highway is located on heavy rainfall area where better drainage is required). For the minimum sight distance (S) of 240 m, assuming the length of the curve (L_c) to be greater than S, and considering extra widened road and other details as mentioned above, estimate setback distance (m).

Solution—3: As per the recommendation for mixed traffic conditions, the superelevation should counteract the centrifugal force for 75% of the design speed ($V = 80$ kmph). Therefore:

- The superelevation can be designed using: $e = V^2 \div (225R) = 80^2 \div (225 \times 480) = 0.059$

The superelevation of 0.059 may be adopted because it is lower than 0.07, which is considered safe for the given design speed and other conditions. Also, the carriageway width (B) for the present design is 7.5 m.

- Raising of outer edge w.r.t. the inner edge can be determined using $= B \times e = 7.5 \times 0.059 = 0.44$ m

For designing the ruling minimum radius (R_r) and absolute minimum radius (R_a) of the horizontal curve, IRC recommends the following equation:

- $R_r = \frac{V^2}{127(e+f)} = \frac{80^2}{127(0.059+0.37)} = 117.5\,\text{m}$ and $R_a = \frac{\text{V}_{\min}^2}{127(e+f)} = \frac{60^2}{127(0.059+0.37)} = 66\,\text{m}$

Considering the mechanical (W_m) and psychological (W_p) widening of the two-lane National Highway, the total extra widening (W_e) can be designed using the following relations:

- $W_e = W_m + W_p = \frac{nl^2}{2R} + \frac{\text{V}}{9.5\sqrt{R}} = \frac{2\times 6.5^2}{2\times 480} + \frac{80}{9.5\sqrt{480}} = 0.088 + 0.384 = 0.47\,\text{m} \sim 0.5\,\text{m}$

After designing extra highway widening at the horizontal curve, the new carriageway width (B_n) is $= 7.5 + 0.5 = 8$ m. For this, the length of the transition curve can be designed using the following relation:

- $L_s = B_n \times e \times e_{\text{rate}} = 8 \times 0.059 \times 150 = 70.8\,\text{m}$

For estimating setback distance (m), the given condition is the length of the curve, $L_c > S$, $B_n = 8$ m, $R = 480$ m, and the highway is two-lane. Therefore, the distance between the centre line of the two-lane highway and the centre of the inner curve $(d) = B_n \div 4 = 8 \div 4 = 2\,\text{m}$. The subtended angle and thereby m can be estimated by employing the following equation:

- $\frac{\alpha}{2} = \frac{180\text{S}}{2\Pi(R-d)} = \frac{180\times 240}{2\Pi(480-2)} = 14.4^\circ$ and $m = R - (R - d)\cos\frac{\alpha}{2} = 356\,\text{m}$

Problem statement—4

Considering all the conditions and design criteria estimated in the previous problem statements, determine grade compensation and compensated gradient for the horizontal curve (as designed in problem statement—3) if the ruling gradient (*RG*) in the highway location is 6%. Besides, design a summit curve at the intersection of two gradients, +3% and −5%, and a valley curve at the junction of descending grade of 1 in 25, meeting an ascending grade of 1 in 30.

Solution—4: Grade compensation (*GC*) and the maximum limit of grade compensation ($GC_{\max}$) are estimated using the following relation. At the same time, the difference between the ruling gradient (provided) and $GC_{\max}$ yields compensated gradient (*CG*).

- $\mathrm{GC} = \frac{30+\mathrm{R}}{R} = \frac{30+480}{480} = 1.06\%$; $\mathrm{GC}_{\max} = \frac{75}{R} = \frac{75}{480} = 0.16\%$; $\mathrm{CG} = \mathrm{RG} - \mathrm{GC}_{\max} = 5.84\%$

For the design of the valley curve, there is a need to estimate SSD (estimated in problem statement—2 and estimated as 123.5 m), deviation angle (*N*), followed by summit curve length (L_{sum}), such that it is assumed that $L_{\mathrm{sum}} >$ SSD, described below:

- N = Ascending gradient − Falling gradient = 0.03 − (−0.05) = 0.08
- $L_{\mathrm{sum}} = \frac{N \times \mathrm{SSD}^2}{4.4} = \frac{0.08 \times 123.5^2}{4.4} = 277.3\,\mathrm{m}$

As per the IRC guidelines, the minimum summit curve length for $V = 80$ kmph should not be less than 50 m. Hence, the present value of $L = 277$ m suffices for the geometric design criteria. Similarly, for the design of the valley curve, there is a need to estimate *N*, valley curve length for the comfort condition ($L_{\mathrm{val\_com}}$), SSD, and valley curve length (L_{val}), such that it is assumed that $L_{\mathrm{val}} >$ SSD and centrifugal acceleration (*C*) is 0.6 m/s^2, while $v = 22.2$ m/s is already known; steps are described below:

- $N = -(1 \div 25) - (1 \div 30) = -(11 \div 150)$
- $L_{\mathrm{val\_\,com}} = 2\left[\frac{\mathrm{N}v^3}{C}\right] = 2\left[\frac{11 \times 22.2^3}{150 \times 0.6}\right] = 73.1\,\mathrm{m}$
- $L_{\mathrm{val}} = \frac{N \times \mathrm{SSD}^2}{(1.5 + 0.035\,\mathrm{SSD})} = \frac{11 \times 123.5^2}{150(1.5 + 0.035 \times 123.5)} = 192\,\mathrm{m}$

As per the guidelines, to accept L_{val}, it should be greater than $L_{\mathrm{val\_com}}$, which is the present case, and thus $L_{\mathrm{val}} = 192$ m may be accepted in the geometric design.

Performance Evaluation of WAT-HD and Its Scope in Smart City Planning

All the design calculations conducted against each criterion and component of the two-lane two-way National Highway in the previous section are also performed using

WAT-HD. The findings of both manual analyses and the same obtained from WAT-HD are compared in Table 39.2. Results indicate that the values obtained from WAT-HD match the manual calculations. In fact, the load behind rigorous manual design calculations performed in Sect. "Two-Lane Two-Way Geometric Highway Design Analysis Using Manual Approach" is handled very conveniently using WAT-HD, so the design measures are obtained with minimal input and less duration. For example, concerning Table 39.2 and Fig. 39.3, for sight distance design, with minimal inputs like design speed, different velocities of the vehicle and its acceleration, reaction time and friction coefficient, WAT-HD can design SSD, ISD, OSD and minimum and desirable overtaking zones. Similar frameworks can be observed for designing horizontal and vertical alignments.

To summarise, applying computer science applications in core civil engineering sectors such as transportation and, more specifically, highway engineering can do wonders when handling cumbersome and tediously long mathematical calculations. Such applications then become more pertinent when there is a pressing demand for bringing down traffic congestion, road accidents and rising GHG emissions amidst climate change (Bibri and Krogstie 2017; IPCC 2022; Lwasa et al. 2022; Srivastava et al. 2022c). Besides, sustained transit is one of the critical engines of growth and a long-standing phenomenon. Effective transportation networks must be established to ensure sustainable development in smart cities (Chowhan et al. 2022; Saharan et al. 2020; Telang et al. 2021). Imperatively, modern advancements in computer science and engineering, given laying down platforms of web application software development and other approaches such as AI, ML and Internet of Things (ToT), have revolutionised transportation engineering in general and highway geometric design

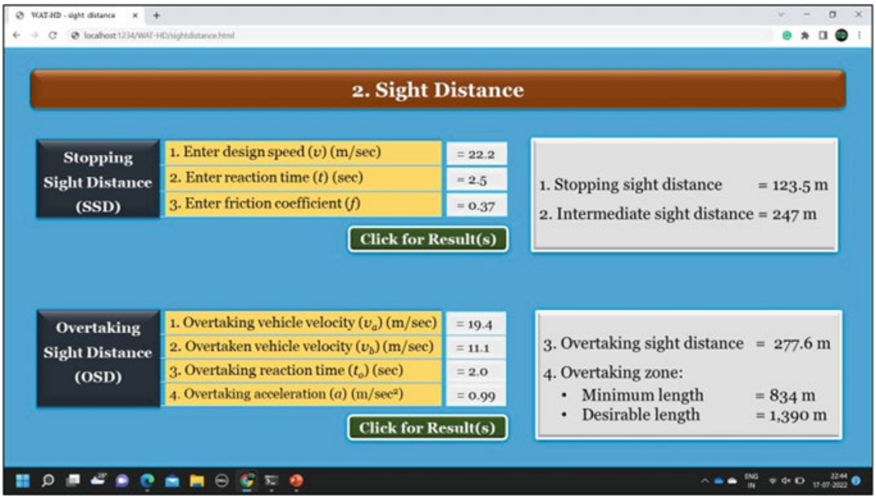


Fig. 39.3 Web Application Tool for Highway Design (WAT-HD) demonstrating sight distance design for two-lane two-way National Highway as per the guidelines of Indian Road Congress (IRC)

Table 39.2 Comparative assessment of manual calculations with Web Application Tool for Highway Design (WAT-HD) for a two-lane two-way Geometric Highway Design by following the considerations of Indian Road Congress (IRC)

Geometric Criteria	Input variables	Data or conditions applied	Equations and IRC considerations	Manual output	WAT-HD output
Highway cross-section design					
• Straight line camber: to estimate a rise of crown w.r.t. the edges	Rainfall conditions	Heavy	2% camber	0.09 m	0.09 m
	Road surface type	High-type bituminous surface			
	Lane width	3.75 m	7.5 m		
	Number of lanes (n)	2			
Sight distance design					
• Stopping sight distance (SSD)	Design speed (V or v) or vehicle velocity	80 kmph or 22.2 m/s	$= vt + \frac{v^2}{2gf}$	123.5 m	123.5 m
	Reaction time (t)	2.5 s			
	Friction coefficient (f)	0.37			
• Intermediate sight distance (ISD)	Stopping sight distance (SSD)	123.5 m	$= 2 \times \text{SSD}$	247 m	
• Overtaking sight distance (OSD)	Overtaking vehicle velocity (v_a)	19.4 m/s	$= (v_b \times t_0) + \left[\left(v_b\sqrt{\frac{4(0.7v_b+6)}{a}}\right) + 2(0.7v_b + 6)\right] + \left(v_a\sqrt{\frac{4(0.7v_b+6)}{a}}\right)$	277.6 m	277.6 m
	Overtaken vehicle velocity (v_b)	11.1 m/s			
	Overtaking reaction time (t_o)	2 s			
	Overtaking acceleration (a)	0.99/s^2			

(continued)

Table 39.2 (continued)

Geometric Criteria	Input variables	Data or conditions applied	Equations and IRC considerations	Manual output	WAT-HD output
• Overtaking zone	Overtaking sight distance (OSD)	Minimum length	$= 3 \times \text{OSD}$	834 m	834 m
	Overtaking sight distance (OSD)	Desirable length	$= 5 \times \text{OSD}$	1390 m	1390 m
Horizontal alignment design					
• Superelevation (e)	Traffic conditions	Mixed traffic	Counteract centrifugal force for 75% of V	0.059	0.059
	Horizontal curve radius (R)	480 m	$= V^2 \div (225R)$		
	Design speed (V)	80 mph			
• Raising of outer edge w.r.t. the inner edge	Carriageway width (B)	7.5 m	$= B \times e$	0.44 m	0.44 m
	Superelevation (e)	0.059			
• Ruling minimum radius (R_r)	Ruling design speed (V)	80 kmph	$= \frac{V^2}{127(e+f)}$	117.5 m	117.5 m
	Superelevation (e)	0.059			
	Friction coefficient (f)	0.37			
• Absolute minimum radius (R_a)	Minimum design speed (V)	60 kmph	$= \frac{\text{V}_{\min}^2}{127(e+f)}$	66 m	66 m
	Superelevation (e)	0.059			
	Friction coefficient (f)	0.37			
• Mechanical widening of the highway (W_m)	Number of lanes (n)	2	$= \frac{nl^2}{2R}$	0.088 m	0.088 m
	Length of wheelbase (l)	6.5 m			

(continued)

Table 39.2 (continued)

Geometric Criteria	Input variables	Data or conditions applied	Equations and IRC considerations	Manual output	WAT-HD output
	Horizontal curve radius (R)	480 m			
• Psychological widening of the highway (W_p)	Design speed (V)	80 kmph	$= \frac{V}{9.5\sqrt{R}}$	0.384 m	0.384 m
	Horizontal curve radius (R)	480 m			
• Extra widening (W_e)	Mechanical widening of the highway (W_m)	0.088 m	$= W_m + W_p$	0.47 m or ~0.5 m	0.47 m or ~0.5 m
	Psychological widening of the highway (W_p)	0.384 m			
• Transition curve length (L_s)	Carriageway width (B)	New carriageway width (B_n) = 8 m	$= B_n \times e \times e_{\text{rate}}$	70.8 m	70.8 m
	Extra widening (W_e)				
	Superelevation (e)	0.059			
	Superelevation induction rate (e_{rate})	150			
• Setback distance (m)	Is $m > SSD$?	Yes	$\frac{\alpha}{2} = \frac{180S}{2\Pi(R-d)} = 14.4°$ $m = R - (R - d)\cos\frac{\alpha}{2}$	356 m	356 m
	New carriageway width (B_n) = 8 m	Centre of the inner curve (d) = $\frac{B_n}{4}$ = 2 m			
	Number of lanes (n) = 2				
	Horizontal curve radius (R)	480 m			
	Horizontal curve sight distance (S)	240 m			

(continued)

Table 39.2 (continued)

Geometric Criteria	Input variables	Data or conditions applied	Equations and IRC considerations	Manual output	WAT-HD output
Vertical alignment design					
• Grade compensation (GC)	Horizontal curve radius (R)	480 m	$= \frac{30+R}{R}$	1.06%	1.06%
• Maximum limit of grade compensation (GC_{max})	Horizontal curve radius (R)	480 m	$= \frac{75}{R}$	0.16%	0.16%
• Compensated gradient (CG)	Ruling gradient (RG)	6%	$= \mathrm{RG} - \mathrm{GC}_{\max}$	5.84%	5.84%
	Maximum limit of grade compensation (GC_{max})	0.16%			
• Length of summit curve (L_{sum})	Is $L_{sum} > SSD$?	Yes	$N = G_a - G_d$ $L_{\text{sum}} = \frac{N \times \text{SSD}^2}{4.4}$	277.3 m	277.3 m
	Stopping sight distance (SSD)	123.5 m			
	Ascending gradient (G_a)	0.03			
	Descending gradient (G_d)	0.05			
• Length of valley curve for comfort condition (L_{val_com})	Descending gradient (G_d)	0.04	$N = G_d - G_a$ $L_{\text{val\_com}} = 2\left[\frac{Nv^3}{C}\right]$	73.1 m	73.1 m
	Ascending gradient (G_a)	0.03			
	Centrifugal acceleration (C)	0.6 m/s^2			
	Design speed (v)	22.2 m/s			

(continued)

Table 39.2 (continued)

Geometric Criteria	Input variables	Data or conditions applied	Equations and IRC considerations	Manual output	WAT-HD output
• Length of valley curve (L_{val})	Is L_{val} > SSD?	Yes	$\mathrm{N} = G_d - G_a$ $L_{\mathrm{val}} = \frac{N \times \mathrm{SSD}^2}{(1.5 + 0.035\,\mathrm{SSD})}$	192 m	192 m
	Descending gradient (G_d)	0.04			
	Ascending gradient (G_a)	0.03			
	Stopping sight distance (SSD)	123.5 m			

in the recent decade. Furthermore, the driving force behind creating smart cities is to warrant the link between social capital, infrastructure and human capital in order to promote higher economic growth and high quality of life for the residents of these regions. The future scope of making transportation systems resilient to climate disasters such as floods and earthquakes is significant and essential for ensuring sustainable and safe mobility in the face of climate change (IPCC 2022; Srivastava et al. 2022c; Khadke and Pattnaik 2021). It requires a comprehensive and integrated approach involving infrastructure design, technology implementation, emergency response systems, and green transportation strategies. Therefore, one of the factors advancing smart cities is sustainable transportation. There is a need to exploit sustainability in innovation, science and technology for highway design to result in local and global prosperity through the constant movement of capital.

Conclusions

This research introduces and assesses the use of the Web Application Tool for Highway Design (WAT-HD) in executing the geometric design of highways. As observed from the present findings, WAT-HD comprehensively accounted for safe sight distance, overtaking sight distance, horizontal curve, transition curve and vertical curve, along with their detailed components. For each unit, the tool yielded precisely the same output as the manual calculations when employed for designing a two-lane two-way National Highway. The execution of the WAT-HD allowed overcoming limitations of conventional practice for geometric highway design; for example, engineering drawing techniques, when employed for highway design, are found iterative, manual, cumbersome and time consuming. Nevertheless, the aim of augmenting WAT-HD into practice is not to overlook the essence of equations and calculations behind the geometric design; instead, to sensitise the challenges that exist for highway engineers. Coherently, introducing computer-aided programs in highway engineering could drastically speed the design process with more flexible options, such as modifying within economic and environmental parameters. Through the backing of WAT-HD, the concerned stakeholders, such as transportation engineering students and professional highway engineers, can better understand the procedures behind geometric highway design. Software tools like WAT-HD pave the scope for exploring different geometric designs that can satisfy given design constraints and requirements in real-world applications. In fact, such applications become more pronounced when pressure is more on achieving goals of smart city design, intelligent urban transportation and reduced vehicular-emission-based greenhouse gas release amidst changing climate.

Declaration

Acknowledgements The authors thank Mr. Sandeep R. Mahajan's Lead India Jalgaon Group for providing the research infrastructure to conduct this research.

Technical assistance provided by Mr. Ankush Patil in developing the web application tool is highly acknowledged. Thanks to Vijay Motamwar and Sushant Shinde for sharing their comments on the first draft of this research.

Authorship Contribution AD and AS collected the data and developed the web application tool, while LK contributed to the study's conception and design. NLK guided the material preparation, data collection and analysis. The first draft of the manuscript was written by AS, while all authors commented on previous versions of the manuscript. AD and AS contributed equally to this work and shared the first authorship. All authors read and approved the final manuscript.

Conflict of Interest The authors declare that the research was conducted without any commercial or financial relationships that could be construed as a potential conflict of interest.

References

Afrin T, Yodo N (2020) A survey of road traffic congestion measures towards a sustainable and resilient transportation system. Sustainability 12(11):4660. https://doi.org/10.3390/su12114660

Bibri SE, Krogstie J (2017) Smart sustainable cities of the future: an extensive interdisciplinary literature review. Sustain Cities Soc 31:183–212. https://doi.org/10.1016/j.scs.2017.02.016

Cafiso S, Montella A, D'Agostino C, Mauriello F, Galante F (2021) Crash modification functions for pavement surface condition and geometric design indicators. Accid Anal Prev 149:105887. https://doi.org/10.1016/j.aap.2020.105887

Chang J, Nimer Kadry S, Krishnamoorthy S (2020) Review and synthesis of big data analytics and computing for smart sustainable cities. IET Intel Transport Syst 14(11):1363–1370. https://doi.org/10.1049/iet-its.2020.0006

Chowhan G, Sen A, Mukherjee J (2022) Sustainable and "smart" restructuring around the making of mega and world-class cities in India: a critical review. GeoJournal 1–14. https://doi.org/10.1007/s10708-022-10644-1

Das S (2022) Artificial intelligence in highway safety, 1st edn. CRC Press. https://doi.org/10.1201/9781003005599

Elbeltagi A, Raza A, Hu Y, Al-Ansari N, Kushwaha NL et al (2022) Data intelligence and hybrid metaheuristic algorithms-based estimation of reference evapotranspiration. Appl Water Sci 12(7):1–18. https://doi.org/10.1007/s13201-022-01667-7

Elbeltagi A, Srivastava A, Kushwaha NL, Juhász C, Tamás J, Nagy A (2023) Meteorological data fusion approach for modeling crop water productivity based on ensemble machine learning. Water 15(1):30. https://doi.org/10.3390/w15010030

Ezhilarasi TP, Dilip G, Latchoumi TP, Balamurugan K (2020) UIP—a smart web application to manage network environments. In: Raju K, Govardhan A, Rani B, Sridevi R, Murty M (eds) Proceedings of the third international conference on computational intelligence and informatics. Advances in intelligent systems and computing, vol 1090. Springer, Singapore. https://doi.org/10.1007/978-981-15-1480-7_8

Garcia A, Pastor-Serrano D (2022) Determination of minimum horizontal curve radius for safe stopping sight distance of vehicles overpassing truck platoons. Comput-Aided Civ Infrastruct Eng 37(5):539–557. https://doi.org/10.1111/mice.12758

Goswami S, Sarkar P (2021) Computer-aided highway engineering, 1st edn. CRC Press. https://doi.org/10.1201/9781003045830

IPCC (2022) Climate change 2022: mitigation of climate change. Contribution of working group III to the sixth assessment report of the intergovernmental panel on climate change. Cambridge

University Press, Cambridge, UK and New York, NY, USA. https://doi.org/10.1017/9781009157926

Janssen MA, Anderies JM, Baeza A, Breetz HL, Jasinski T, Shin HC, Vallury S (2022) Highways as coupled infrastructure systems: an integrated approach to address sustainability challenges. Sustain Resilient Infrastruct 7(2):100–111. https://doi.org/10.1080/23789689.2019.1708181

Justo CEG, Khanna AVS, Veeraragavan DA (2015) Highway engineering. Khanna Publication, Delhi

Kanellaidis G, Vardaki S (2011) Highway geometric design from the perspective of recent safety developments. J Transp Eng 137(12). https://doi.org/10.1061/(ASCE)TE.1943-5436.0000322

Khadke L, Pattnaik S (2021) Impact of initial conditions and cloud parameterization on the heavy rainfall event of Kerala (2018). Model Earth Syst Environ 7:2809–2822. https://doi.org/10.1007/s40808-020-01073-5

Kumar P, Vishwakarma DK, Markuna S, Ali R, Kumar D, Jadhav N et al (2022) Evaluation of Catboost method for predicting weekly pan evaporation: case study of subtropical and subhumid regions of India. PREPRINT (Version 1) available at Research Square. https://doi.org/10.21203/rs.3.rs-1538970/v1

Liao CF, Levinson DM (2013) ROAD: an interactive geometric design tool for transportation education and training. American Society of Civil Engineers. Retrieved from the University of Minnesota Digital Conservancy, https://hdl.handle.net/11299/180039

Lwasa S, Seto KC, Bai X, Blanco H, Gurney KR, Kilkiş S, Lucon O, Murakami J, Pan J, Sharifi A, Yamagata Y (2022) Urban systems and other settlements. In: IPCC, 2022: climate change 2022: mitigation of climate change. Contribution of working group III to the sixth assessment report of the intergovernmental panel on climate change. Cambridge University Press, Cambridge, UK and New York, NY, USA. https://doi.org/10.1017/9781009157926.010

Moradi Vartouni A, Teshnehlab M, Sedighian Kashi S (2019) Leveraging deep neural networks for anomaly-based web application firewall. IET Inf Secur 13(4):352–361. https://doi.org/10.1049/iet-ifs.2018.5404

Othman B, De Nunzio G, Di Domenico D, Canudas-de-Wit C (2019) Ecological traffic management: a review of the modeling and control strategies for improving environmental sustainability of road transportation. Annu Rev Control 48:292–311. https://doi.org/10.1016/j.arcontrol.2019.09.003

Pande CB, Al-Ansari N, Kushwaha NL, Srivastava A, Noor R, Kumar M, Moharir KN, Elbeltagi A (2022) Forecasting of SPI and meteorological drought based on the artificial neural network and M5P model tree. Land 11(11):2040. https://doi.org/10.3390/land11112040

Saharan S, Bawa S, Kumar N (2020) Dynamic pricing techniques for intelligent transportation system in smart cities: a systematic review. Comput Commun 150:603–625. https://doi.org/10.1016/j.comcom.2019.12.003

Sarkar D, Patel H, Dave B (2020) Development of integrated cloud-based Internet of Things (IoT) platform for asset management of elevated metro rail projects. Int J Constr Manag 1–10. https://doi.org/10.1080/15623599.2020.1762035

Shaaban K (2022) Challenges and lessons learned from building a new road drainage system in a developing country. In: Intermountain Engineering, Technology and Computing (IETC), pp 1–4. https://doi.org/10.1109/IETC54973.2022.9796861

Srivastava A, Khadke L, Chinnasamy P (2021) Web application tool for assessing groundwater sustainability—a case study in rural-Maharashtra, India. In: Vaseashta A, Maftei C (eds) Water safety, security and sustainability. Advanced sciences and technologies for security applications. Springer, Cham. https://doi.org/10.1007/978-3-030-76008-3_28

Srivastava A, Khadke L, Chinnasamy P (2022a) Developing a web application-based water budget calculator: attaining water security in rural-Nashik, India. In: Kolathayar S, Mondal A, Chian SC (eds) Climate change and water security. Lecture Notes in Civil Engineering, vol 178. Springer, Singapore. https://doi.org/10.1007/978-981-16-5501-2_37

Srivastava A, Jain S, Maity R, Desai VR (2022b) Demystifying artificial intelligence amidst sustainable agricultural water management. In: Zakwan M, Wahid A, Niazkar M, Chatterjee U (eds)

Water resource modeling and computational technologies. Current directions in water scarcity research, vol 7. Elsevier. https://doi.org/10.1016/B978-0-323-91910-4.00002-9

Srivastava A, Maity R, Desai VR (2022c) Assessing global-scale synergy between adaptation, mitigation, and sustainable development for projected climate change. In: Chatterjee U et al (eds) Ecological footprints of climate change. Springer Climate. https://doi.org/10.1007/978-3-031-15501-7_2

Telang S, Chel A, Nemade A, Kaushik G (2021) Intelligent transport system for a smart city. In: Tamane SC, Dey N, Hassanien AE (eds) Security and privacy applications for smart city development. Studies in systems, decision and control, vol 308. Springer, Cham. https://doi.org/10.1007/978-3-030-53149-2_9

Zhang S, Hou D, Wang C, Pan F, Yan L (2020) Integrating and managing BIM in 3D web-based GIS for hydraulic and hydropower engineering projects. Autom Constr 112:103114. https://doi.org/10.1016/j.autcon.2020.103114

Chapter 40
Towards Seamless Urban Mobility Through Smartphone-Based Mobility Apps: Insights from India

Purnima Kumari Chowdhury, Namrata Ghosh, and Paulose N. Kuriakose

Abstract Economic mobilisation of wireless connectivity has brought a nascent change in the functioning of cities and will soon rule the future. In the age of increasing availability of wireless cloud technologies, smartphone applications have become an integral part of our daily life, offering myriad opportunities to simplify our lives and influencing our everyday decisions; transforming urban mobility by providing a wide array of information like real-time public transit arrival predictions, multi-modal trip-planning apps, availability of parking, real-time data on traffic, etc. The mobility apps are rapidly challenging the conventional travel pattern and generating new patterns and travel behaviour. Therefore, this chapter produces a condensed review of the endless opportunities IoT can bring for a better tomorrow through various mobile apps and how policy measures can reinforce the benefits in the following approaches of these apps. It will also highlight how the transportation apps may impact the travel choices of people in India and the challenges associated with transport authorities, service providers and other stakeholders. The study intends to use the mixed explanatory method with comparative studies of various cities using mobility apps and how they function in isolation without any integration. Integration in tangible entities like fare, modes, schedules, etc., has long been emphasised, but digital integration can bring forward momentum in achieving multiple goals of a successful transport system. The chapter will end with several key inferences, recommendations and suggestions to help researchers and transport authorities consider the role of mobile apps in our transportation network.

P. K. Chowdhury (✉)
Department of Architecture and Regional Planning, Indian Institute of Technology (IIT), Kharagpur, West Bengal 721302, India
e-mail: purnimachowdhury@iitkgp.ac.in

N. Ghosh
Public System Group, Indian Institute of Management (IIM), Ahmedabad, Gujarat 380015, India

P. N. Kuriakose
Department of Urban and Regional Planning, School of Planning and Architecture, Bhopal, Madhya Pradesh 462030, India
e-mail: paulosenk@spabhopal.ac.in

U. Chatterjee et al. (eds.), *Urban Commons, Future Smart Cities and Sustainability*, Springer Geography, https://doi.org/10.1007/978-3-031-24767-5_40

Keywords Smartphone applications · IoT · MaaS · On-demand transport · Urban mobility

Introduction

The proliferation of smartphone mobility apps is gaining momentum worldwide. In the recent decade, these smartphone mobility apps have emerged in India, making people change their views on mobility services and travel. These apps are active tools for aggregated information about myriad transportation options. The ubiquitous access to smartphone mobility apps and Internet facilities has enabled embedded information systems to produce novel opportunities and challenges. IoT has introduced limitless possibilities in the transport field by altering the data collection methods, generating countless real-time information for better mobility practices and efficient decision-making by multiple stakeholders and commuters. The rising concern of traffic congestion in urban areas in developing economies is on the cusp of worsening as the demand for travel increases. With the burgeoning travel demand, the need for monitoring travel behaviour has become significant for transport service providers and policymakers. The monitoring phenomena require the measurement of data coupled with either fixed or mobile sensors. Deployment of fixed devices for monitoring is expensive, and smartphones are an exceptionally inexpensive solution (Lei and Minbaev 2019; Wang and Wang 2019).

Conventional methods of data analysis require observation of travel patterns typically from data collected through households' surveys, origin–destination surveys or travel diaries that incur a considerable cost with several errors and with a limitation of samples and period of the survey, etc., are soon being replaced by data collected from mobility applications. The use of mobility apps can bring the desired transition to achieving the sustainability goals of the transport system. Necessary policy measures and initiatives to expand the commuter benefits through mobility apps can incentivise multi-modal trips, encouraging varied modes and services. Thus, this chapter contributes towards understanding the emerging mobility apps in four metro cities, focusing on the types of apps used by people, benefits and creases that need to be filled for improved transport and their effect on changing travel mode choice and patterns.

IoT refers to a network of sensors and connected devices that collect data and transmit to the cloud and can be accessed through smartphone apps. Mobile phones play an important role in enhancing the growth of IoT and also integrate sensor. The mobile app allows IoT platforms to handle various applications, systems and data under one umbrella, which leads to increase demand for smart and intelligent mobile apps. Presently, mobile apps are used for many transport-related applications, which includes travel information, navigation traffic data, transport emission, route planning and ride-sharing. Recognising the importance of software packages in the transport area, several Public Agencies of Transport have already established mobile apps that show real-time travel information to the city dwellers. Although several smartphones' apps offer prevalent transport-related applications, no research was found that documented their advantages and disadvantages. For this present limitation, the chapter investigated mobile applications listed on the Apple App Store, Google Android Market, Samsung App Store and Windows Store with potential transportation applications and their key features.

In India, a country with rising urbanisation level and the concomitant induced derived demand for app-based mobility, scanty research has been undertaken on the implications of IoT and its applications in transport governance. However, most of the innovation is done by the private sector which continues to be a very regulated space and needs support from the government. While tele-connectivity has improved, the roads are still congested. Knowledge and data about public transportation system are still restricted and therefore defeating the purpose of open and globally accepted payment and e-ticketing mechanisms. India has a vibrant start-up and tech ecosystem. With the direction of 'digital India' if certain hurdles are removed, the country can advance in the urban mobility innovation. The objective of this chapter is an attempt to understand the existing situation of the adoption of smart technologies in ensuring equitable seamless mobility opportunities for the commuters. It also assesses various levels of integration of information technology in transport governance.

Literature

In the last decade, mobile applications encompass persuasive components to enable consumers to use environmentally sustainable modes of transportation. Incorporating attributes in mobility apps mainly promotes positive progress in travel behaviour which has received significant attention from scholars in recent years. The primary objective of these mobility apps is to promote environmental sustainability, healthier travel and make a significant contribution to livable cities. Table 40.1 summarises the main findings from various studies on the travel attributes and characteristics that persuade people to use urban travel apps that are real or used for pilot studies and choose more sustainable transportation.

Methods and Study Area

Four cities were selected for which the smartphone mobility apps were observed. Table 40.2 summaries the travel-related information about each city. The four cities were selected as these cities are highly populated cities that survives on various modes of transport. Thus, taking a look into these cities will help us understand the flaws and gaps in their currently existing smartphone mobility apps.

Table 40.1 Studies on urban mobility apps

Study	App	Country	Finding/inference
Karlsson et al. (2017)	UbiGo and SMILE	Vienna (Austria)	The service has a payment platform, information on multi-modal mobility services and customer service; high rate of user satisfaction: 75% of users are satisfied with the service; 21% of users report a reduction in car usage, and 48% depend on public transport
Sochor et al. (2015)	UbiGo	Gothenburg, Sweden	The service has a payment platform, monthly pass on multi-modal mobility services and incentives for not using private vehicles. 97% of users want to continue the service, 49% find it cost effective and 44% report less dependency on private cars
Tang et al. (2020)	DIDI	China	The service is cost effective and attracts people to use eco-friendly transport modes. It is also used as it saves time for users. The ride-hailing includes taxis, private car companies and carpooling ("hitching service") services
Chang et al. (2019)	Umanji	Taipei	The service has a payment platform, information and monthly pass on multi-modal mobility services like buses, public bikes and urban rail
Lopez-carreiro et al. (2020)		Madrid (Spain)	Most users have expectations like travel time, mode, route, cost and real-time information from MaaS mobile technologies

(continued)

Table 40.1 (continued)

Study	App	Country	Finding/inference
Storme et al. (2020)	Touring	Ghent (Belgium)	The service provides a budget required for several modes of travel. Some modes have a payment platform. This service led to a reduction in the use of private cars for daily commute
Zhao et al. (2020)	CorporateMaaS	Sweden	The service provides a booking platform for employees for multi-modal services. It led to 50% of users being willing to shift to shared mobility if good incentives were provided
Hensher et al. (2021)	Tripi	Sydney, Australia	The service provides a payment platform and monthly passes for different modes (PT, Uber, taxi, car share, car rental)

Type of Mobility Apps and Their Role in the Study Area

Transportation is an integral part of urban living. Whether you ride the train, subway/underground /tube, bus, light rail, ferry or metro, use bikes, or ride-sharing like Uber, getting the best urban mobility information is critical. Thus, the existing smartphone apps in India offer many opportunities to the users, which are categorised in areas of transport data collection, route planning, ride-sharing/carpooling/vanpooling and travel information. The following sections overview these challenges and opportunities for some of the apps discussed in the for-study area selected. Table 40.3 summarises some of the key smartphone apps for route planning, ride-sharing and travel information. The table provides key features of each app.

Route Planning Apps

Route planning applications are developed to help users to navigate cities conveniently, quickly and effectively from the point of origin to the point of destination (Borole et al. 2013). The most route planning app is Google apps which are used by users across India. The other apps provide information regarding route optimisation of multiple destinations, which would cover modes of transportation available in a

Table 40.2 Summary of study area

	Delhi	Mumbai	Hyderabad	Bangalore
Population	17 million+	24.4 million	10.8 million+	8.5 million
Bus service	DTC	BEST	TSRTC	BMTC
Mode share				
Public Transport	27%	18%	31%	48%
Metro	3%	2.1%	–	–
Two-wheeler	14%	7.1%	42%	24%
Car	9%	9.8%	9%	21%
Taxi	9%	1.6%	–	
Auto rickshaw	5%	10.3%	8%	8%
Bus service				
Fleet size	7001 in 2022	3800	2856	6634
No of routes	368	400	795	–
Ridership				
Metro	24 lakhs/day in 2015	8 lakhs/day	2.2 lakhs per day	4.05 lakhs/day
Public bus	32 lakhs/day in 2020	33 lakhs/day in 2015	33.04 lakhs/day	50 lakhs/day
Suburban rail	–	7.81 million passenger trips daily	2.5 lakhs/day	–
Average trip length				
Metro	15.6 km	–	Data unavailable	–
Bus	10.7 km	8 km	"	10.7 km
Auto	9.5 km	2.9 km	"	3.7 km
Taxi	9 km	5.1 km	"	13.1 km

Source Compiled by author
Source Comprehensive mobility plan

particular area. Most of the apps provide basic information like schedule and metro station locations and bus route information, and few apps provide commuters with real-time arrival times, stop locations and real-time vehicle delays. These apps use the GPS inbuilt into a mobile device to provide commuters with their present location and then recommend the closest location and when the next few trains will leave the station.

Table 40.3 Description of smartphone mobility apps currently operating in the selected study area

NAME OF MOBILITY APPS	Delhi	Mumbai	Hyderabad	Bangalore	DESCRIPTION OF MOBILITY APP FEATURES
Route planning apps					
Google Apps					Distance and real-time traffic conditions for car, bike, train, walk
One					Real-time location of buses and metro. Schedule and fare info
Bangalore Offline city map					Interactive map with a search index for locating streets
Bangalore Metro Route Planner					Provides various routes to travel from source to destination stations
MyBMTC					Provides accurate, real-time bus information only for BMTC buses.
Moovit					Linked directions of optimal route by bus, train, metro, bike for all trips
m-Indicator					Find connected routes & plan the journey by train and bus
FerryIndicator					Timings of ferry boat services along with bus services.
Hyderabad Guide					All details of MMTS, RTC Buses, and Auto fare without an internet connection.
Tsavaari					Hyderabad metro, SRTC buses, shuttle and rental services booking and payment
Ridesharing/carpooling/vanpooling					
Quick Ride					Carpooling/ride-sharing. Live tracking. Cashless payment.
Uber Pool, Ola Share					Carpooling/ride-sharing; Cost split; Cashless payment
Orahi - Z					Allows women to create a women-only group for carpooling.
sRide					Users offer their cars to riders for sharing journey with integrated payment
Bla Bla Car					Connects drivers and passengers willing to travel together and share the cost
Shuttle					Provides comfortable AC bus rides
Wunder Carpool					Car owners willing to offer rides to passengers

(continued)

Table 40.3 (continued)

TwoGo					Provides car owners find a passenger through the app
Ridely					It helps people find others travelling in the same direction
Zify					Resolving traffic issues in India for working professional
Meru					Carpooling service
Office Ride					Share your trip from home to office and back together
Travel information apps					
Incredible India					Provides information hub of places of interest.
TripIt					Organizes your travel plans no matter where you book
PackPoint					Travel packing list organizer based on destination and its atmospheric conditions
IRCTC Rail Connect, RailYatri					Online rail ticket booking, checking PNR status, train routes
MakeMyTrip					Provides hotels and travel booking.
RedBus					Booking from a range of bus operators for intercity-travel
Other commonly used apps in these cities					
Oye Rickshaw					Booking from a range of bus operators for intercity-travel
Ola Lite					Riders use public transport cards for payment for auto-share
Rapido bikes					Tracking, booking, and payment; last-minute connectivity
Yulu					India's first bike taxi service for intra-city travel.

Source Compiled by author

Ride-Sharing

Ride-sharing contributes to emissions reduction by reducing the number of vehicles on the roads, accelerating transportation options, decreasing parking demand and, more importantly, lowering travel costs for users (Dutzik, Madsen and Baxandall, 2013). Real-time travel sharing has the opportunity to make a difference by providing a new means of transport that dynamically aligns drivers and riders and inevitably distributes the cost reduction of commute between them and at the same significantly minimising security and safety concerns determined by rating features of drivers. In fact, trip-sharing apps are compatible with drivers and riders of common origin and/or destination.

Travel Information Apps

These apps provide travel information, which gives travellers detailed information and assists them in planning the trips, route optimisation, travel mode options, reservations and payment.

Description of Different Smartphone Mobility Apps

The following section shows the description of smartphone mobility apps that are presently existing in the select study area (Fig. 40.1).

Potential Challenges

App-based transportation services are rapidly gaining momentum. They are easy to use and assign spare transportation resources more effectively than conventional for-hire providers. But their success challenges established regulatory frameworks and transport governance and have caught transport authorities off guard. Regulatory responses have attempted to either block data sharing with app operators or gradually modify rules to allow them to operate. There are a lot of challenges related to data acquisition by private app-based companies, varying from the quality and availability of data to security and privacy concerns once data is collected or obtained (Aayog 2018). The key challenges include the following:

a. **Privacy and data security**: Concerns have been raised about protecting individuals' privacy as big data is becoming more prevalent in developing effective mobility systems. Personally identifiable information (PII) is data that can be used to identify, communicate or locate a particular person, which can be used in conjunction with other data. The proposed Personal Data Protection Act of 2018 restricts the computation of sensitive personal information without explicit approval. Thus, any company or government agency with access to Transportation User Data Points must remove PII.
b. **Poor quality and incomplete data**: Maximum transit agencies in India are inconsistent with stop and route identifiers, or a bus equipped with a GPS may have

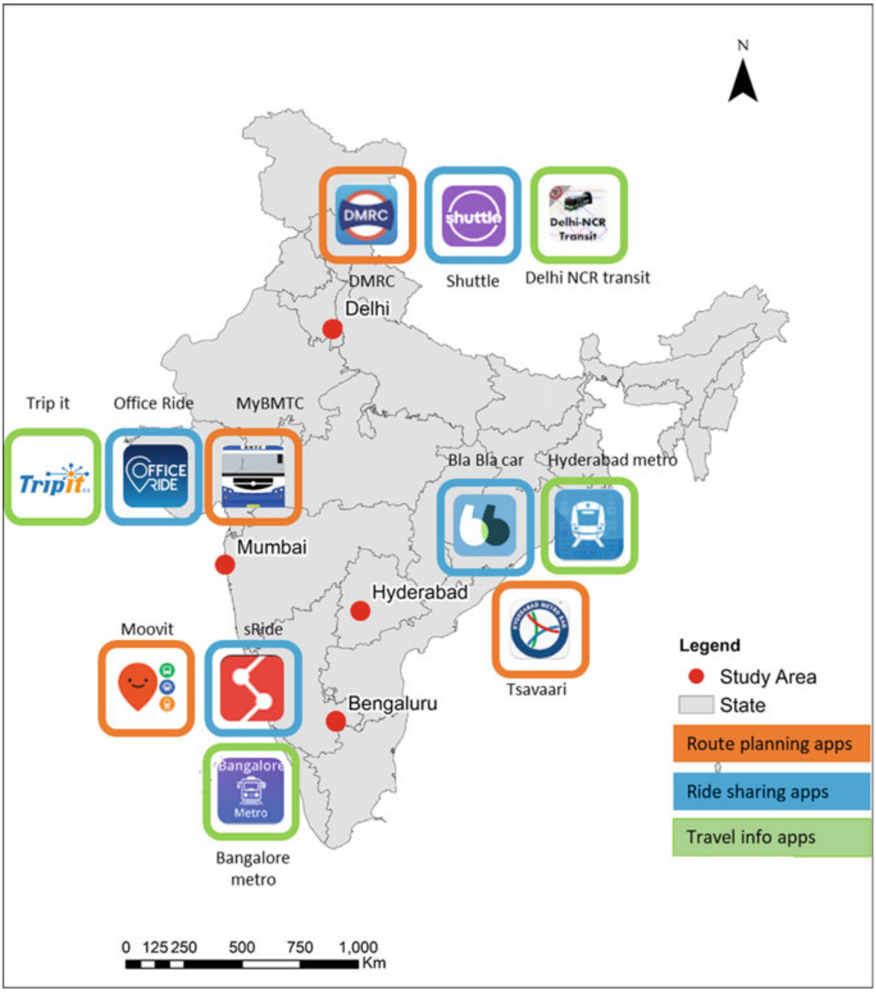


Fig. 40.1 Map showing different types of apps in the chosen study area. *Source* Generated by author

a system broken or incorrect. To develop good mobility systems, better data collection is needed for the future of India.

c. **Acquiring data from private data owners**: Obtaining data from private data owners is often one of the biggest challenges in collecting the data needed for a specific use. These data owners tend to be concerned primarily with jeopardising their competitive advantage by exchanging their collected data.

The other major challenge found in this review is that the apps do not give a one-stop solution to route planning and travel information. Public transit usage can be enhanced by integrating intermediate public transportation with other public transportation modes through offline and online multi-modal interfaces and payment integration. The apps also do not provide first and last-mile connectivity information. Various private and public agencies operate the apps, and there is no coordination between the agencies, which makes the apps fail to provide real-time data on transport services. These apps are currently fragmented at operational boundaries and transport service typology. Several apps are functional at the city, intercity and national levels and with internal division of different travel modes with a disintegrated interface, tools and commuter options.

Decision-Making by Demand and Supply Side

In unprecedented market competition and continuous zest for global development, a new set of information that assists in the better decision-making process, improving the efficacy of our choices is of central importance. Smartphone mobility apps have become the epicenter of myriad details and the bedrock of everyday decisions by daily commuters revealing their ever-changing travel pattern. These applications have facilitated the real-time data mining and identification of a pattern of a different set of the population in high frequency at a large scale, beneficial for both the demand and supply side. The decision required to formulate policies and mitigation measures to achieve market equilibration is mainly distinguished as short term and long term (Chow 2018b). The short-term decision occurs within a day time frame. For example, mobility apps can help reroute your trip to improve the travel time to CBD. The decision by supply-side makers for the long term includes a variety of actions like adding new links to the network, setting the service frequency, setting the fare and rescheduling the timetables. Other examples of supply-side decision-making include rebalancing the bikes at rentals, a price adjustment for ride-hailing services, etc. (Fig. 40.2).

Smartphone mobility apps assist in mitigating various cognitive challenges and burdens by minimising the efforts of the commuters to plan their trip route with an all-in-one user interface for five major travel activities: information regarding arrival and departure times, choosing suitable mode for various activities, planning, booking

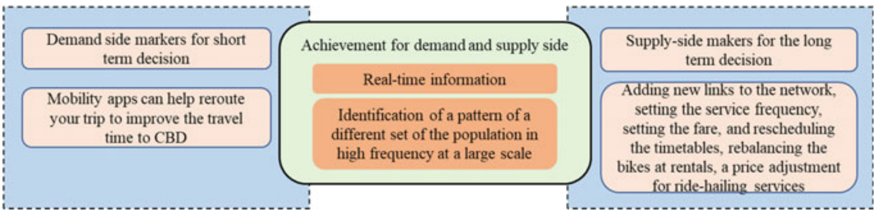


Fig. 40.2 Benefits for both demand and supply side using smartphone mobility apps. *Source* Compiled by author

and paying the fares (Jamal and Habib 2020). Commuters benefit from such apps in several ways. For instance, if fare payment is of the highest priority to a commuter, the apps are enabled to display possible options of different combinations of mode choices to fulfil the requisite demand of the customer.

Mobility as a Service

Mobility as a service is recognised as the new paradigm shift in the urban transport system and a powerful tool for the replacement of car-centric travel behaviour. The foundation of MaaS lies in the promotion of multi-modal travel facilitated by a comprehensive digital service for real-time travel information, trip planning, booking and payment with the central aim of distributing the mobility choices and offering a chain of modes within origin and destination (Matyas and Kamargianni 2019; Alyavina et al. 2020). The 'as-a-service' aspect of mobility stands firm on the capitalisation of the data-driven business model promised by the mobility apps challenging the conventional model of isolated transport service operation (Matyas and Kamargianni 2019). Transport at its core understanding indicates remaining connected and mobile within the network. Smartphone mobility apps are a bedrock for mobility as a service that offers constant connectedness to commuters through numerous travel and payment modes available at the fingertip. One particular mode cannot be a one-stop solution to all the mobility issues as population heterogeneity makes it impossible to develop one size-that-fits-all solution. Because of this heterogeneity, there is a pressing need to understand how various transport systems perform. Even though at their nascent stage, smartphone mobility apps are consistently bridging the gap between the public and private transport providers, irrespective of geographical boundaries. Several apps are functional at the city, intercity and national levels and with internal divisions of different travel modes with the disintegrated interface, tools and options for commuters.

MaaS for Better Mobility Practices and Environment

The transport sector is one of the significant contributors to global climate change, with almost 18% of CO_2 emissions from road transport alone, and is expected to be responsible for one-third by 2050 (UNEP 2010; Suzuki et al. 2013). Better mobility practices with a low-carbon strategy can significantly shift greenhouse emissions. The multi-modal transport model can assist India in achieving the intended nationally determined contribution promised to the UNFCCC with a target of 33–35% deterioration in the emission intensity per unit of GDP by 2030. In the backdrop of this, several cities are now shifting from the 'predict and provide' concept and avoiding the spiral trap of increased congestion and implicit externalities (Mulley 2017) and taking their steps towards new opportunities served by technological advancements where smartphone mobility apps are playing a significant role by replacing the car-centric behaviour to the multi-modal system.

MaaS, Mobile Apps and a New Business Model

Smartphone mobility apps are customer centric and act as facilitators for sustainable mobility practices as they provide a flexible, reliable, economical and sustainable solution. MaaS is a classic example of replacing the fragmented business model by bundled packages of services holistically aiding the customers, parallelly alloying the underutilised services to increase their value. Mobile apps provide the provision of a digital platform operational through a user account where all the transport services are from car sharing, bike sharing, rental and last-mile connectivity options, conjoined with public transport services like buses, metro, monorail, etc., with an attempt to bring awareness of different modes for fulfilling end-to-end connectivity. Conventional planning tends to undercount and undervalue non-motorised travel. All these services cannot thrive alone as much or be fruitful to consumers in completing their trip if continued to be used in isolation, but multiple options amalgamated together and repackaged under one platform can present the increased uptake of other transport services simultaneously, altering the perception of individuals towards these modes (Headicar 2009).

Mobility Management for Change in Behaviour Through Mobility Apps

Evidence from research shows that technological advancements and economic mechanisms alone cannot be relied upon to achieve sustainability (Andersson et al. 2018) as the behaviour gap of the population to the policy instruments is prone to create unsatisfactory results (Winslott and Smidfelt 2016). Mobility management, similar to the approach of travel demand management, is a soft campaign towards altering the traveller's attitude and behaviour to achieve sustainable objectives of transport (Litman 2010) as strong coercive methods of taxation for externality, and strict regulations no longer serve the purpose in all circumstances (Deun et al. 2018). The wide gap between the sustainability goals, transport policies and respective initiatives can be bridged easily by the promotion of MaaS.

Transport Network Equilibrium Through Mobility Apps

Planning and implementation of transport systems incur substantial capital investments and require the rigorous involvement of public agencies. The failure of these capital-intensive projects can cost too much to the transport operators and respective agencies. In the backdrop of this, it is of utmost importance to maintain a stable and long-lasting equilibrium in the system. Mobility apps can bring a radical transformation in achieving the transport network equilibrium as a high-dimensional interface provides the users with the best choices to reach their destination with the least resistance. These apps allow the users to select their preferred route in alignment with their chain of trip destination, purpose and cost range. The user-influent equilibrium within the system replenishes consistently as the number of users deciding to commute within an O-D can choose a path (p_1 or p_2) supplied with transport services (t_1 or t_2) based on duration, cost and the number of chain trips. This cycle helps in maintaining optimised flow in all the routes within the multi-modal transport system. The most beneficial aspect of using these apps is the freedom of scheduling the trips, which implicitly has a much more significant impact on the entire system. These apps help users optimise their generalised travel costs with relevant real-time information. The significance of user scheduling response cannot be neglected in the concept of MaaS as it allows users to adjust their schedules in alignment with the market supply, thereby creating a counterintuitive reaction resulting in market equilibrium. The users using their rationale by default avoid the congested routes or accept the modified combination of choices that reduces the traffic load from the roads and maintains a balance in the system. Individual decision-maker using mobile apps in a multi-modal system brings a steady state in which the aggregated combination of constrained choices for a particular schedule among the dataset of schedule choices available never exceeds the load capacity in any link within the system, thereby achieving a higher performance of the transport system (Chow 2018a).

On-demand Transport

Several private operations are now competing in the transport market to provide efficient services. With the advent of sharing economy, smart cities and the Internet of Things, the need for resource allocation using real-time data is gaining high demand. On-demand transport services like taxis, car sharing, etc., are fulfilling the flexibility gap of public transport, providing better accessibility. Smartphone mobility apps are acting as digital platforms for these on-demand services. These ride-sharing services, primarily operated through smartphone apps, are known to bring relief to commuters when the competition for road space increases more than its capacity (Li et al. 2017). Evidence from studies shows that ride-sharing services are bringing a sweeping change in regulating the dominant car use and replacing it with shared car services.

It is also observed that on-demand transport significantly reduces the frequency of travel as users cut down on futile trips.

The government of India has sued guidelines for Taxi Policy which directs the state government to make respective schemes in order to address the contextual issues for last-mile connectivity. The Motor Vehicle Bill 2017 validates the services of cab aggregators and has listed them as 'digital intermediaries'. Central government is responsible for formulating specific guidelines for licensing and operation common to all the states. Similarly, the Ministry of Road Transport and Highway has issued MoRTH Taxi Policy, 2016, with recommendations regarding deregulating the fares, stringent permit systems and data sharing. The guideline is rooted in some drawbacks that have a limiting definition of shared mobility and integration with other modes, data sharing laws and fare settings (Gadepalli and Singh 2018).

Integration

Lack of Integration in Mobile Apps

The MaaS model allows seamless integration and optimisation of different transport services via the Internet of Things, with the most commonly used entity being smartphone mobility apps. Currently, several mobility services, including public transit, on-demand transport and ride-sharing facilities, are operating in isolation with fragmented structures and disintegrated with public transport in some cases.

a. The commuters have to rely on numerous tools and apps to organise their trip-related information, purchase, etc.
b. There is a lack of ticket integration with other modes within the city, and if available, it is operated for specific routes only, which depreciates the ease of using these apps and impedes the success of the multi-modal transport system.
c. Commuters using different apps now have to go through the hassle of using different payment modes for each transport mode as some operators accept cash, others accept cards, online payment, etc. (Kamargianni and Matyas 2017).
d. Disintegration in the operation of apps at the city and state levels has resulted in the deterioration of intra-city public bus patronage due to the hegemony of smartphone apps by private operators like Shahi in Kerala.
e. Lack of assimilation of all the services at one common platform decreases the appeal of the other even though all services work with a common interest (Figs. 40.3, 40.4 and 40.5).

The above three images extracted from apps that are available in Google Play Store and iOS App Store show how three efficient modes of public transport, i.e. Hyderabad bus service—RTC, MMTS, a suburban rail system and metro rail and self-driving e-scooters catering to millions, operate separate mobility apps with each having its forms of service for information, booking ticketing and payment. All trips

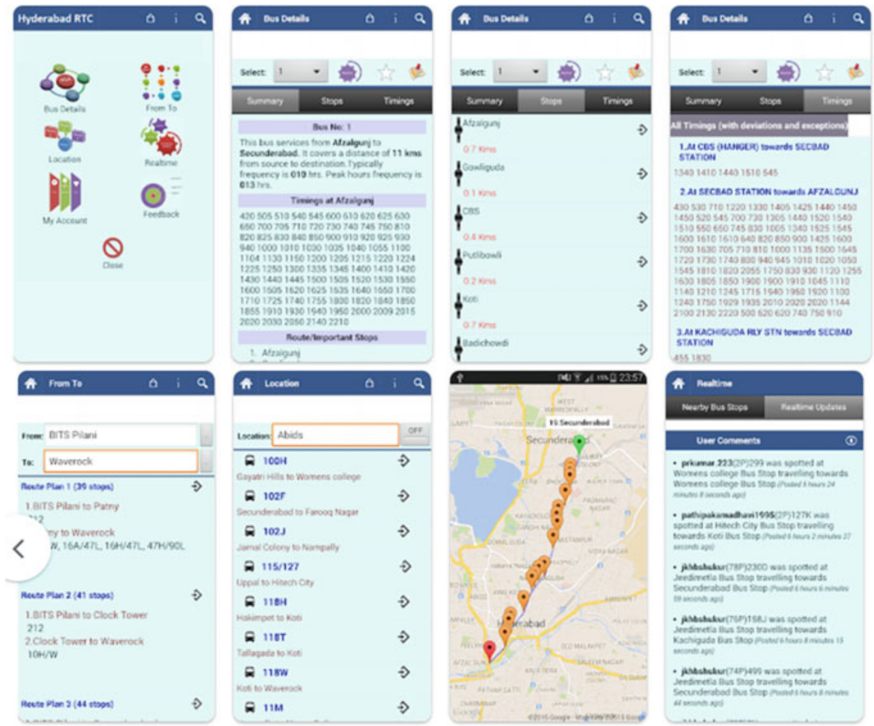


Fig. 40.3 Screenshot of Hyderabad RTC app

cannot be completed by one mode of transport. The provision of a comprehensive platform for integrated smartphone mobility apps for all modes of transportation can help cities achieve the vision of MaaS for sustainable urban transport where commuters can easily plan their trips in order with different modes of transport conveniently. Parking stations for e-bikes and scooters should be planned to locate them in proximity to public transport stops, CBD, public places and significant office hubs to enable commuters to complete their work or other social trips.

Lack of Integration in Agencies

In general, government bodies are responsible for regulating the transport system. The widening gap between the public and private agencies needs to be bridged and coupled with a third-party regulator to benefit from the technological opportunities in the form of services through smartphone mobility apps. Expanding the benefits of such comprehensive services requires designing a cohesive business ecosystem that institutionalises innovation firms and private agencies with increased collaboration with public bodies. An architecture of multiple levels includes the organisation of

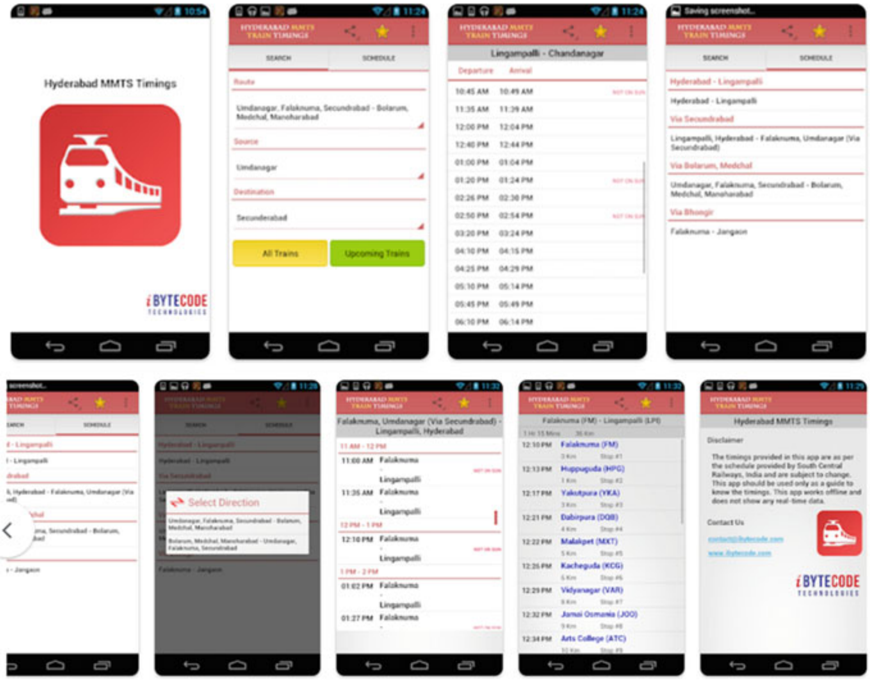


Fig. 40.4 Screenshot of Hyderabad MMTS timing app

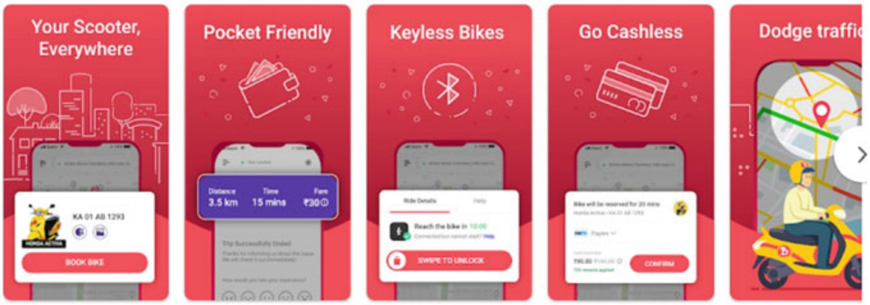


Fig. 40.5 Screenshot of Bounce electric scooter app

digital platforms, developers and economic actors, closely interlinked with governance structures to create a road map towards a common goal. A robust, flexible and highly interacting matrix of professional groups and respective organisations collaborating beyond traditional boundaries provides a common vocabulary for work (Reuver et al. 2013; Kamargianni and Matyas 2017).

Paradoxically, the National Urban Transport Policy suggests the Unified Metropolitan Transport Authority (UMTA) formation in all million-plus cites as a policy reform response to solve the rising issues of transport governance. Effective transport governance is significant for robust and cohesive interaction between the multiple organisations vertically and horizontally. The Government of India has consistently encouraged the formation of UMTAs, but unfortunately, there are only 15 operational in the country out of the expected 53 million-plus cities. The existing plight of the same in the implemented cities is no glorious story as the limited initiative has focused on the long-term decision-making responsibilities for infrastructure projects and sidelined the dynamic shared mobility (MoHUA 2017).

The scope of MaaS is restricted due to regulatory concerns and the lack of an intermediate body that can supervise, monitor and assist in implementing proposals for the promotion of multi-modal transport systems. Failure in the governance structure results in poor decision-making, barriers for parallel organisations, poor accountability of the decisions and failure of already suggested guidelines and measures by the respective government and non-government bodies for better mobility practices. The formation of UMTA or similar agencies should be catalysed by assimilating the requisite powers and skills.

Conclusion

With the sea change in the rampant overconsumption of smartphones, GPS-enabled mobility applications have become mainstream and emerging as a prominent tool for combining numerous information about transportation options available to commuters. The chapter produces a condensed review of the endless opportunities IoT can bring for a better tomorrow through various mobility apps in India's different cities. The main findings of the chapter state how policy measures can reinforce the benefits of these apps' following approaches. It also highlights how transportation apps impact the travel choices of people in India individually or collectively, especially in reducing travel time, travel cost, choosing of transport modes, route planning, etc. The challenges of the existing transport apps are that they function in isolation without integration with very little coordination with transport authorities, service providers and other stakeholders.

Due to the concerns related to data protections, privacy and data sharing, there is an absence of integration of app-based mobility services. Similarly, the ineffectiveness of unified transport authorities also comes as a hurdle. From the assessment of the smart-based mobility apps in the study areas, we found that there is a lack of integration and data is not solely commuters' issue, but the bulk of transit operators, whether public or private, do not collect automated data that might allow them to make more informed business decisions. This has created a vicious circle during which commuters, uninterested in alliance as they await their bus or train, abandon mass transit and seek lower-capacity vehicles, like taxis, rideshares, two-wheelers or autorickshaws, which increases congestion and pollution. Both transit riders and operators would benefit from access to data about public transportation. On the user side, accurate information increases rider satisfaction and improves ridership. While on the operator side, data can be used to enhance the quality of service and better meet the users' needs.

Transport is an everyday need, nearly everybody travels regularly and on a daily basis, be it taking a bus, walking and the use of a vehicle or going via means of train. These trips frequently generate information which could reveal information about the commuter—such as the place of work location of house. This trip information is a private data. Sharing the trip information along with other location can improve our life, since it leads to increased personalisation and access to better and relevant mobility options. But at the same time, misuse of such data needs to be prevented with suitable legal tools.

With a growing population and increasing demand for transport, India stands to benefit tremendously from the collection and sharing of mobility data with app-based transport providers for seamless travel of the commuters. The government should take steps towards increasing the amount of access to open data to unlock the many benefits of real-time data as it will have potential benefits to the mobility sector. These central data portals can add a lot of value by integrating datasets in a single location and making them easily accessible. In order to ensure the maximum benefit of mobility data, measures should be taken to collect and share data and to ensure that the information acquired by the various stakeholders is made accessible as much as possible. Effective communication between data owners and potential beneficiaries is at the core of achieving the MaaS model. All stakeholders must understand the transport system's landscape, motivation and challenges of the departments and agencies involved. Building a comprehensive data collection and sharing practice in India will develop a solid base to support adopting new concepts such as MaaS which will strengthen the integrated mobility system.

Future Directions

This study focuses on technology (specifically smartphone mobility apps) to improve urban mobility services and meet users' needs in India. We are aware of the rapid expansion of research into smart cities, IoT technology and transportation, so it will be essential to review the related literature. In addition, more research is required to keep up with innovation due to the rapid changes in technology and app development. As a result, our analysis provides a snapshot of the practice's current state.

References

Aayog N (2018) Data-driven mobility improving passenger transportation through data

Alyavina E, Nikitas A, Njoya ET (2020) Mobility as a service and sustainable travel behaviour: a thematic analysis study. Transp Res Part f: Psychol Behav 73:362–381. https://doi.org/10.1016/j.trf.2020.07.004

Andersson A, Winslott L, Adell E (2018) Promoting sustainable travel behaviour through the use of smartphone applications : a review and development of a conceptual model. Travel Behav Soc 11:52–61. https://doi.org/10.1016/j.tbs.2017.12.008

Borole N et al (2013) Multimodal public transit trip planner with real-time transit data. In: Procedia—social and behavioral sciences. Elsevier BV, pp 775–784. https://doi.org/10.1016/j.sbspro.2013.11.172

Chang SKJ, Chen HY, Chen HC (2019) Mobility as a service policy planning, deployments and trials in Taiwan. IATSS Res 43(4):210–218. https://doi.org/10.1016/j.iatssr.2019.11.007

Chow JYJ (2018a) Informed urban transport systems—classic and emerging mobility methods toward smart cities, Joe Hayton

Chow JYJ (2018b) Urban transport systems. In: Informed urban transport systems—classic and emerging mobility methods toward smart cities classic and emerging mobility methods toward smart cities, Joe Hayton, pp 1–29

Dutzik T, Madsen T, Baxandall P (2013) A new way to go: the transportation apps and vehicle-sharing tools that are giving more Americans the freedom to drive less

Gadepalli R, Singh J (2018) Regulatory frameworks for integrated shared mobility governance in India. https://doi.org/10.13140/RG.2.2.33997.69604

Headicar P (2009) Transport policy and planning in Great Britain (Edited by J. Glasson). Routledge, UK

Hensher DA, Ho CQ, Reck DJ (2021) Mobility as a service and private car use: evidence from the Sydney MaaS trial. Transp Res Part a: Policy Pract 145:17–33. https://doi.org/10.1016/j.tra.2020.12.015

Jamal S, Habib MA (2020) Smartphone and daily travel: how the use of smartphone applications affect travel decisions. Sustain Cities Soc 53:1–9

Kamargianni M, Matyas M (2017) The business ecosystem of mobility-as-a-service. In: 96th transportation research board.

Karlsson M et al (2017) Deliverable 4: impact assessment of MaaS. MAASiFiE project funded by CEDR

Lei T, Minbaev A, Claudel CG (2019) A privacy-preserving urban traffic estimation system. In: Ukkusuri SV, Yang C (eds) Complex networks and dynamic systems, vol 4, Transportation analytics in the era of big data, pp 81–82

Li Z, Hong Y, Zhang Z (2017) An empirical analysis of on-demand ride-sharing and traffic congestion. In: 50th Hawaii international conference on system sciences, pp 4–13

Litman T (2010) Quantifying the benefits of nonmotorized transportation for achieving mobility management objectives. In: Transportation research record, pp 134–140

Lopez-carreiro I et al (2020) Technology in society urban mobility in the digital era: an exploration of travellers' expectations of MaaS mobile-technologies. In: Technology in society, vol 63. https://doi.org/10.1016/j.techsoc.2020.101392

Matyas M, Kamargianni M (2019) The potential of mobility as a service bundles as a mobility management tool. Transportation 46(5):1951–1968. https://doi.org/10.1007/s11116-018-9913-4

MoHUA (2017) National Transit Oriented Development (TOD) Policy

Mulley C (2017) Mobility as a Services (MaaS)—does it have critical mass?. Transp Rev 1647. https://doi.org/10.1080/01441647.2017.1280932

Reuver MDE, Bouwman H, Haaker T (2013) Business model roadmapping: a practical approach to come from an existing. Int J Innov Manag 17(1):1–18. https://doi.org/10.1142/S1363919613400069

Sochor J, Strömberg H, Karlsson ICM (2015) Implementing mobility as a service: challenges in integrating user, commercial, and societal perspectives. Transp Res Rec 2536:1–9. https://doi.org/10.3141/2536-01

Storme T et al (2020) Limitations to the car-substitution effect of MaaS findings from a Belgian pilot study. Transp Res Part a: Policy Pract 131:196–205. https://doi.org/10.1016/j.tra.2019.09.032

Suzuki H, Cervero R, Iuchi K (2013) Introduction: critical challenges facing cities and urban transport. In: Transforming cities with transit: transit and land use integration for sustainable urban development. World Bank Publications, pp 30–32

Tang BJ et al (2020) How app-based ride-hailing services influence travel behavior: an empirical study from China. Int J Sustain Transp 14(7):554–568. https://doi.org/10.1080/15568318.2019.1584932

UNEP (2010) Cleaner, more efficient vehicle: global fuel economy initiative

Van Deun H et al (2018) Nudging in public policy and public management: a scoping review of the literature. In: 68th annual international conference, pp 1–27

Wang C, Wang P (2019) Data, methods, and applications of traffic source prediction. In: Ukkusuri SV, Yang C (eds) Complex networks and dynamic systems, vol 4, Transportation analytics in the era of big data, pp 105–107. https://doi.org/10.1007/978-3-319-75862-6

Winslott L, Smidfelt L (2016) Mobility management campaigns as part of the transition towards changing social norms on sustainable travel behavior. J Cleaner Prod 123:34–41

Zhao X et al (2020) Key barriers in MaaS development and implementation: lessons learned from testing Corporate MaaS (CMaaS). Transp Res Interdisc Perspect 8:1–9. https://doi.org/10.1016/j.trip.2020.100227

Chapter 41
Assessment of Air Quality Before and After the COVID-19 Pandemic in Indonesia

Waluyo Eko Cahyono, Athena Anwar, Dessy Gusnita, Fahmi Rahmatia, Heru Santoso, Prawira Yudha Kombara, Sumaryati, Wiwiek Setyawati, Wilin Julian Sari, Yuliana Susilowati, Tatik Kartika, Angga Yolanda Putra, and Nur Faizah Romadona

Abstract The emergence of COVID-19 pandemic has forced many countries implement social restrictions, including Indonesia. There has been a growing interest in understanding the impact of the pandemic on air quality. This research analyses the air pollution before and after the COVID-19 pandemic in Jakarta and Banjarmasin, Indonesia, with a detailed analysis. It compared the results with previous years to determine the significant improvement in air quality and related weather factors obtained from Landsat 8 and 9 imagery. OMI and MERRA-2 were analysed for $PM_{2.5}$, NO_2, SO_2, O_3 and WRF-Chem model result especially for $PM_{2.5}$ against the COVID-19 pandemic. As a result, there was a decrease in $PM_{2.5}$ during the pandemic year in Jakarta, although it was not as good as in 2016 conditions. In Jakarta and Banjarmasin, $PM_{2.5}$, NO_2 and SO_2 decreased in 2021 from 2020, which were in line with the high incidence of COVID-19 in 2021. This shows that more air quality increased in the form of healthy days in DKI Jakarta in 2020 than in 2019. In other words, there was an increase in air quality during the implementation Large-Scale

W. E. Cahyono (✉) · A. Anwar · D. Gusnita · F. Rahmatia · H. Santoso · P. Y. Kombara · Sumaryati · W. Setyawati · W. J. Sari · Y. Susilowati
Research Center for Climate and Atmosphere, National Research and Innovation Agency of Indonesia, Jl. Sangkuriang 12, Bandung 40135, Indonesia
e-mail: walu002@brin.go.id

T. Kartika
Research Center for Remote Sensing, National Research and Innovation Agency of Indonesia, Jl. Raya Jakarta Bogor Km 46, Cibinong 16911, Indonesia
e-mail: tatik.kartika@brin.go.id

A. Y. Putra
Directorate of Laboratory Management, Space and Atmosphere Observation Pontianak, Jl. LAPAN No.1, North Pontianak 78242, Indonesia

N. F. Romadona
Department of Microbiology, Indonesia University of Education, Jl. Setiabudhi No. 229, Bandung 40154, Indonesia
e-mail: faizah@upi.edu

U. Chatterjee et al. (eds.), *Urban Commons, Future Smart Cities and Sustainability*, Springer Geography, https://doi.org/10.1007/978-3-031-24767-5_41

Social Restriction (PSBB) policy in 2020 compared to 2019 before the COVID-19 pandemic.

Keywords Air quality · COVID-19 · Landsat · OMI · MERRA-2 model · WRF-Chem

Introduction

At the end of 2019, the world was shocked by the emergence of a new virus in Wuhan, China, named severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2), which causes a disease called coronavirus disease abbreviated COVID with a suffix 19 (COVID-19) to indicate the first year of its appearance. In a short time, the virus spread to all corners of the world. On 11 March 2020, WHO declared it a pandemic, and this is considered the biggest challenge in global health facing mankind since World War II. It is estimated that between 40 and 60% of the population worldwide will be infected with the virus. Based on the Worldometer report, until June 2022, the virus that attacks the respiratory system has infected the world's population of 527.9 million, with the death toll reaching 6.3 million (Worldometer, https://www.worldometers.info/coronavirus/). This pandemic has caused great challenges in countries around the world in terms of social, economic, environmental and obviously health issues. The social and economic challenges are mainly due to the effect of the quarantine applied in almost all capital cities and big cities around the world, from Asia, Europe to America (Suhaimi et al. 2020).

The COVID-19 pandemic has significantly impacted various regions on a global scale. Indonesia is one of the countries affected by the pandemic. The first case was confirmed on 27 February 2020, which started to increase as reported by the Ministry of Health of the Republic of Indonesia. To prevent the virus transmission, the Indonesian government has agreed to introduce Large-Scale Social Restrictions (*Pembatasan Sosial Berskala Besar*, PSBB) to respond to the State of Emergency for Public Health, for example, work-from-home policy implementation. That way, the methods of doing work have changed because now it can be done online and easier from home with applications. This digital application is beneficial in supporting work-from-home so that the continuity of administration, education, economy and culture can be well maintained (Rachmawati et al. 2021). This is thought to have a good influence on the environment, especially air quality. This is because one of the sources of pollution, namely the density of motorized vehicles, has decreased when the PSBB is implemented.

The aims of this research are (1) to determine the air pollutants before and after the PSBB period in Jakarta; (2) to review and measure the status of air quality due to PSBB and strict restrictions during the pandemic phase; (3) to examine the air pollutants in Indonesia 2015–2021 related to the spread of COVID-19 and (4) to examine weather factors during the COVID-19 pandemic. This research has limitation in terms of data analysis, only analysed air quality data in Jakarta and Balikpapan and only used data from 2019 (before the pandemic) and 2020 (after the implementation of PSBB). Other researchers interested in conducting similar research are recommended to analyse data from different cities with more varied condition and analysed them using different analysis tools. This research is believed to be significant as it enriches understanding of the air quality in Jakarta during the pandemic. There were three types of data collected, namely in-site data, model data and satellite data. The findings are rich since the analysis of each data type can confirm or support the other data type, and vice versa.

This research provides credible and valuable results and insights for the scientific community and policymakers about the impact of the national lockdown or PSBB against air pollution. Furthermore, this research provides a roadmap to improve the air quality of Jakarta in particular and Indonesia in general in future.

SARC-CoV-2 Virus as Aerosol

The virus is released from COVID-19 sufferers from secretions when breathing, sneezing, coughing and talking and then transmits in the air. Transmission to other patients through the air can be through an object, such as a ladder held by the patient and then held by someone else (Ranga 2021). What is being debated is whether the virus is in the air as a droplet or aerosol form. The difference between droplets and aerosols is their size. It is said to be in the form of a droplet if its size is greater than 5 m, and vice versa is called an aerosol. Both aerosols and droplets are generally called particles.

Aerosol is one of the air pollutants which, in addition to the composition of the aerosol, the size of the aerosol is essential in discussing pollutants in the form of aerosols. The size of the particle determines how it is transmitted in the atmosphere and its penetration in the respiratory system if the particle is inhaled. Two things are dangerous for smaller particles. The smaller the particle size, the more profound the penetration in the respiratory system, the smaller the particles, the farther the transmission and the longer the lifetime in the atmosphere.

The size of the SARS_CoV-2 virus is indeed tiny, namely 0.1 m (Bar-on et al. 2020), which is included in the aerosol category. However, the virus from mouth and nose excretion comes in a single form or colonies wrapped in saliva so that these particles can be droplets or aerosol sizes (Jayaweera et al. 2020). The size of the salivary droplets containing the virus depends on the process of excretion; when breathing, only tiny droplets tend to be aerosol sized, whereas when coughing or sneezing, many produce large droplets-sized droplets. COVID-19 has become a global pandemic and threatens public health systems worldwide. Several factors, including climatic conditions, can influence virus transmission. A consistent positive relationship has been found between climate variables and COVID-19 (Saputra et al. 2021).

Viruses' transmission and resistance in the air are strongly influenced by weather conditions, especially wind direction, rain, humidity and temperature. Wind plays a role in the proliferation of viruses, especially in the aerosols form. Meanwhile, high temperatures and low humidity will shorten the survival of the virus in the atmosphere, because in such weather conditions the saliva that covers the virus will easily evaporate. Eventually, the virus will be damaged (Bdou and Drikakis 2020). Furthermore, dead viruses only become aerosols of dead matter, no longer bioaerosols that have biological hazards. Precipitation can clean particles in the atmosphere, including particles containing the SARS-CoV-2 virus.

The Impact of Pandemic on the Air Quality

One of the policies to reduce COVID-19 cases is to impose restrictions on mass community activities and reduce activities outside the home, such as lockdown and PSBB. As a result, pollutant emissions are also reduced, thereby improving air quality. From the Mehmood et al. (2022) literature study, there were as many as 990 publications related to COVID-19 and air pollution in 2021 and 830 articles in 2020, all of which indicate that there has been an improvement in air quality during the pandemic.

As an indication of changes in air quality during the pandemic in the $PM_{2.5}$ observation report from the MERRA-2 model, the data of total tropospheric NO_2, total ozone (O_3) and total SO_2 from observations with OMI sensors (ozone monitoring instrument) from 2015 to 2021 in Jakarta and Banjarmasin areas was also recorded. The Special Capital Region of Jakarta is located on the seafront of Java. Jakarta, as a metropolitan city, has a very high and highest population density in Indonesia. Therefore, pollutants in Jakarta were mainly from anthropogenic sources, transportation, industry and household activities. Meanwhile, Banjarmasin, the capital city of South Kalimantan province, is bordered by the sea, has a population density that is still rare and is often affected by forest fires. Based on the 2018 population census from BPS and the province area issued by the Ministry of Home Affairs of the Republic of Indonesia, the population density in Jakarta was 15,928 people/km^2, while South Kalimantan was only 110 people/km^2. The first COVID-19 case was detected on 2 March 2020, and two weeks after that, restrictions on community activities began to be carried out, even to the point of locking down. Until June 2022, reports from the COVID Task Force collected in the provinces, COVID-19 cases per thousand residents in Jakarta and Banjarmasin were 120 and 20.

Several studies have been conducted regarding the air quality index in Indonesia during the COVID-19 outbreak, among others, by Pramana (2020), who concluded that: air quality in three provinces, Jakarta, Banten and West Java, especially in cities located in the Jakarta metropolitan area at this time COVID-19 pandemic and large-scale social restrictions, is getting better. However, in some areas, the reduction of pollutant concentrations took longer because, before the pandemic, it was very high (Pramana 2020). According to He et al. (2020) in China, lockdown did improve air quality, compared to cities without a formal lockdown policy, daily KPI and $PM_{2.5}$ fell by 19.84 points (17%) and 14.07 $\mu g/m^3$ (17%), respectively, when weather control and a series of fixed effects were also taken into account. Many differences can be found in the variation between the loose and strict lockdowns in Spain: CO, SO_2 and $PM_{2.5}$ levels fell in both urban and rural environments. PM_{10} and O_3 levels have increased during the loose lockdown but are more significant in urban areas than in rural stations (Martorell-Marugán et al. 2021).

A statistically significant decrease in NO_2 was observed during the current COVID-19 period compared to historical data: a 25.5% decrease with an absolute decrease of 4.8 ppb. $PM_{2.5}$ also showed a decline during the COVID-19 period, and the decline was statistically significant in both districts and urban areas (Berman 2020). In addition, based on facts and several previous studies, if population mobility and social interaction can be limited, accompanied by public health interventions, the temperature and humidity factors can be supporting factors in mitigating or reducing the risk of spreading the outbreak. Based on the results of air quality modelling, the extension of the stricter PSBB implementation has the opportunity to improve air quality in Jakarta in the next five to 10 days (Jiang and Luo 2020). A study conducted in DKI Jakarta showed a decrease in the concentration of $PM_{2.5}$ and PM_{10} in March 2020 (Rizi et al. 2019). The study's results in Pekanbaru showed a difference in PM_{10} values higher before PSBB with an average of 10–20 g/m^3 compared to PM_{10} concentrations when PSBB was between 5 and 10 g/m^3 (Rakhim and Pattipeilohy 2021).

Materials and Methods

Area Study

The research is located in Indonesia (6 N, 92.5 E to 11 S, 142 E), with a detailed analysis of Jakarta (6.2088° S, 106.8456° E) and Banjarmasin (3.3186° S, 114.5944° E) cities as shown in Fig. 41.1. (NicePNG 2018)). Metropolitan Jakarta is a capital city located on the seafront of Java, having the highest population density (more than 16 thousand/km^2 in 2020) and cases of the COVID-19 spread (16 cases/1000 people) in Indonesia (Fig. 41.2). Banjarmasin, as a comparison, is the capital city of South Kalimantan province, a coastal area with much less population density and is often affected by forest fires. A population density's potential for physical interaction with others does not significantly affect the likelihood that patients may transmit viruses to healthy individuals. Figure 41.2 shows a comparison of the population density in each province in Indonesia and COVID-19 cases per thousand population, in which the population indicator shows a decreasing trend to the right (blue line), while COVID-19 cases show a decreasing value (red line). The data was downloaded from the website Andra Farm (https://m.andrafarm.com). In principle, the public's commitment to the application of health protocols, especially the use of masks, has greatly decreased the possibility of inhaling the virus, both of aerosol and droplet form, to control the rise in COVID-19 cases.

Fig. 41.1 Indonesian territory with the capital city of Jakarta

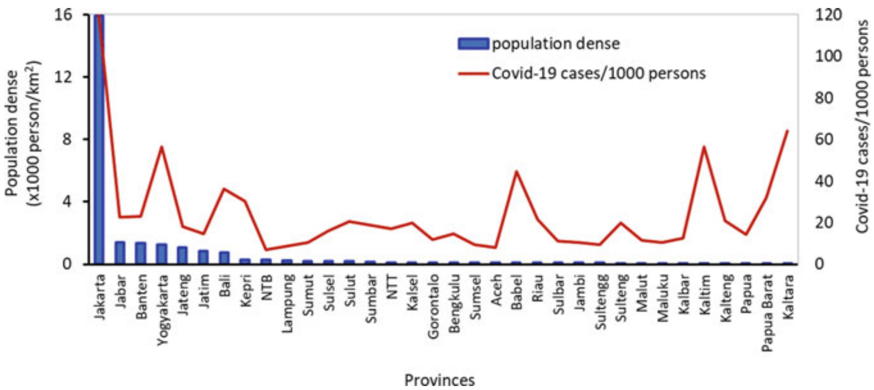


Fig. 41.2 Population density and COVID-19 cases per 1000 population

Observation with OMI, MERRA-2 Model and Simulation with WRF-Chem Model

In this research, the first stage, to find out changes in air quality during a pandemic, this paper presents observations of $PM_{2.5}$ from the MERRA-2 model, total tropospheric NO_2, total ozone (O_3) and total SO_2 from observations with OMI sensors (ozone monitoring instrument) brought by Aura satellite and CO from MOPITT brought by Terra satellite. $PM_{2.5}$ is monthly data with a resolution (0.5 × 0.625), while tropospheric NO_2, total ozone and total SO_2 are daily data with a resolution (0.25 × 0.25) and CO total columns are monthly data with resolution of (1 × 1). Data collection from 2015 to 2021 for the Jakarta and Banjarmasin areas were downloaded from https://giovanni.gsfc.nasa.gov/giovanni/. Data is presented the annual boxplot configuration to distinguish atmospheric environmental conditions before the pandemic (2015–2019) and during the pandemic (2020–2021). $PM_{2.5}$ represents

Table 41.1 Detail of each air quality variable observed

Air quality variables	Unit	Platform/instrument	Resolutions	
			Spatial	Temporal
Total surface mass concentration of $PM_{2.5}$	kg/m^3	MERRA-2 model	0.5° × 0.625°	Monthly
NO_2 total tropospheric	DU	Ozone monitoring instrument (OMI)	0.25° × 0.25°	Daily
Ozone (O_3) total column	DU	Ozone monitoring instrument (OMI)	0.25° × 0.25°	Daily
SO_2 total column	DU	Ozone monitoring instrument (OMI)	0.25° × 0.25°	Daily
CO total column	mol/cm^2	Measurement of Pollution in The Troposphere (MOPITT)	1° × 1°	Monthly

compounds at the surface level, tropospheric NO_2 as well as SO_2 and ozone to see the vertical effect on the stratosphere. Furthermore, to add analysis of the distribution of $PM_{2.5}$ during COVID-19 pandemic especially in Jakarta area, we try to run the simulation by using WRF-Chem model in Jakarta and Borneo areas. For the simulation, we only run the simulation for few days in August 2021 because of the limited computer resource. Table 41.1 presents the detail of each variable investigated here. The data was downloaded from the website Giovanni NASA (https://giovanni.gsfc.nasa.gov/giovanni/).

This research was conducted in several stages. The first stage is to find out changes in air quality during a pandemic by presenting the observation of $PM_{2.5}$ from the MERRA-2 model, total tropospheric NO_2, total ozone (O_3) and total SO_2 from observations with OMI sensors (ozone monitoring instrument) brought by Aura satellite. $PM_{2.5}$ is monthly data with a resolution (0.5 × 0.625), while tropospheric NO_2, total ozone and total SO_2 are daily data with a resolution (0.25 × 0.25). The data collected was from 2015 to 2021 for the Jakarta and Banjarmasin areas sourced from https://giovanni.gsfc.nasa.gov/giovanni/, which was presented in the form of a whiskers boxplot over one year to compare how it differs during the pandemic period (2020–2021) and before the pandemic (2015–2019). In addition, PM2.5 represents compounds at the surface level, tropospheric NO_2 as well as SO_2 and ozone to see the vertical effect on the stratosphere.

Weather Factor

The second stage is to determine the land surface temperature (LST) and humidity using the image data of Landsat 8 and 9 in the DKI Jakarta area using data having little cloud cover and for locations determined through the Normalized Difference Moisture Index (NDMI) (Lastovicka et al. 2020).

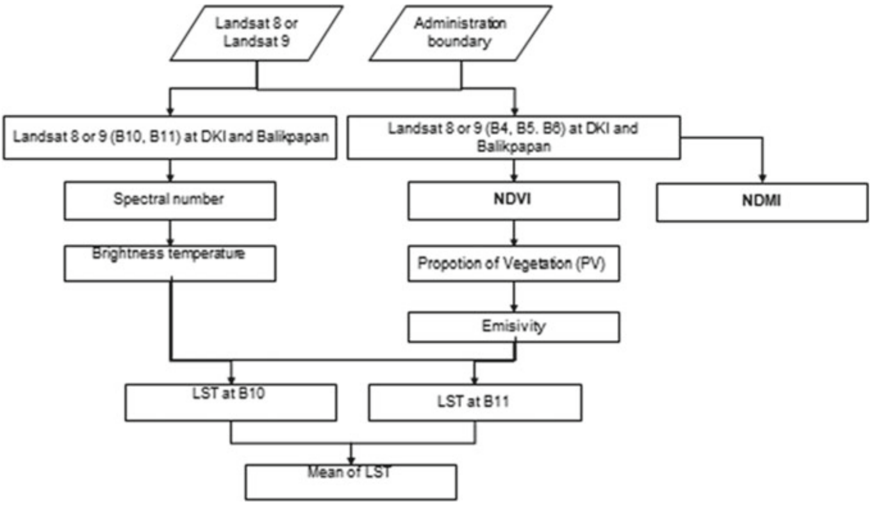


Fig. 41.3 Schematic for determining temperature and humidity with Landsat 8 and 9 imagery

NDMI = (NIR SWIR)/(NIR + SWIR) and determine Vegetation Difference Normalization Index NDVI = (NIR − RED)/(NIR + RED).

The procedure for determining ESG and humidity is as follows (Fig. 41.3).

Air Pollution Standards Index

The final stage is to find out the data changes using Air Pollution Standard Index (ISPU, *Indeks Standar Pencemar Udara*) data originating from the DKI Jakarta Environmental Service for the 2019–2020 period. Then data processing was carried out using statistical analysis. Meanwhile, data on the number of COVID-19 sufferers was downloaded from https://corona.jakarta.go.id/id/data-monitoring. Furthermore, the data was analysed by ISPU in Jakarta for the 2019–2020 period based on the seasonality. In addition, the log transformations data on air pollution and COVID-19 cases was collected to overcome variance problems and differentiating stationarity problems.

Results and Discussion

Analysis of the OMI, MERRA-2 Models and Simulation with WRF-Chem Model

The model results and observations with satellites are presented to see the effect of public restriction policies on public areas on $PM_{2.5}$, NO_2, SO_2 and O_3 compounds, which is shown in the whisker boxplot diagram in Fig. 41.4. In general, air quality conditions in Banjarmasin were better than in Jakarta in the three $PM_{2.5}$, NO_2 and SO_2 parameters. This is related to the high anthropogenic activity in Jakarta, which had a very high population density. In the ozone data, they were not much different because the total ozone affects many things, not only activities on the surface.

The $PM_{2.5}$ boxplot pattern of the two cities shows the same pattern. Before the pandemic, the pattern was positively skewed, i.e. most of the data distribution was on the left or smaller than the median value. In 2020, when the PSBB policy was still implemented and the community was still obedient, the boxplot forms in both cities were in a normal form, which means that the data were normally distributed. In 2021, when the public was bothered with this policy, the boxplot in Jakarta began to show a positive skew, while in Banjarmasin, they were still in a normal form. When viewed in an annual period, 2016 showed the lowest $PM_{2.5}$ value, and 2015

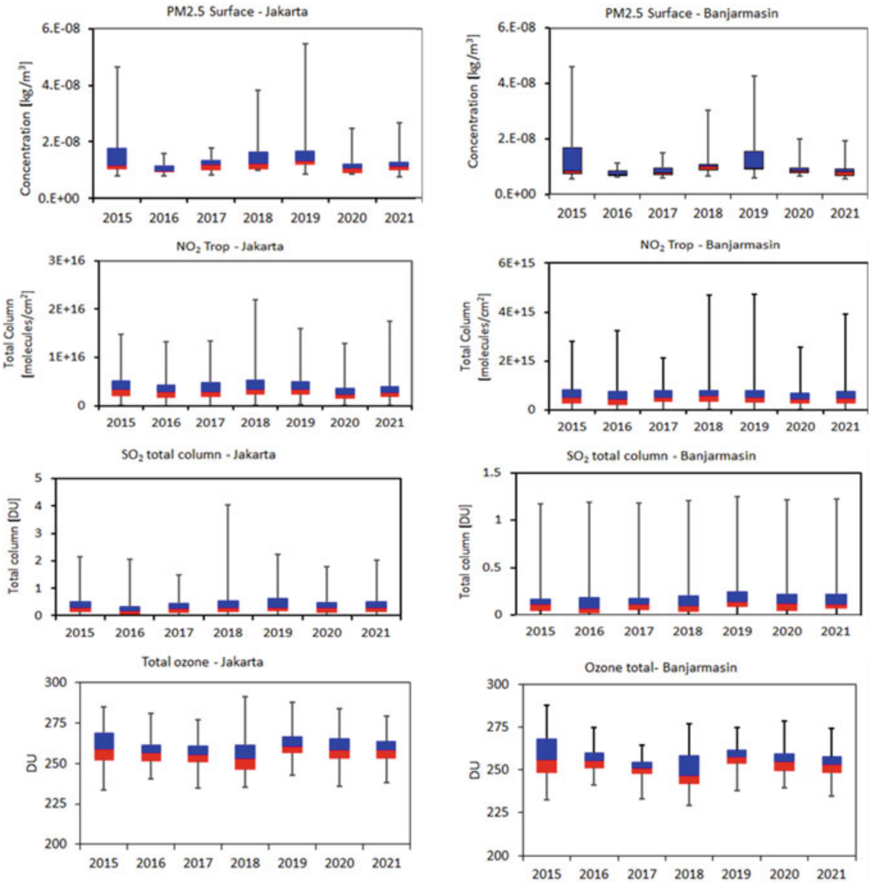


Fig. 41.4 Whiskers boxplot $PM_{2.5}$, NO_2, total SO_2 and total ozone

the highest, which was due to the weather conditions. In 2016, the data on Ocean Nino Index (ONI) value was in moderate La Nina category, which means a lot of rainfall cleared particulates from the atmosphere. However, in 2015, it was indicated that EL Nino was very strong, with a long dry season that supported the occurrence of forest fires, which was also happened in 2019, although not as big as in 2015.

On an annual basis, the concentration weather conditions indicated by La Nina and El Nino phenomena have a significant impact on the of $PM_{2.5}$ in Banjarmasin, as a small town affected devastated by forest fires, $PM_{2.5}$ conditions are strongly influenced by weather conditions indicated by La Nina and El Nino phenomena. There was a decline in $PM_{2.5}$ concentrations during the pandemic (2020–2021), coinciding with moderate La Nina conditions, with resulted in an increase in rainfall which could remove $PM_{2.5}$ from the atmosphere by washing out proses. Therefore, it is supposed that two things caused the decline in $PM_{2.5}$ i.e. the PSBB (Pembatasan Sosial Berskala Besar, Large-Scale Social Restriction) and washout due to high rainfall, which is predominant is unknown clearly. In Jakarta, there was a decline for $PM_{2.5}$ parameter in the pandemic year during the pandemic, although it was not as good as the conditions in 2016.

A spatial analysis of air pollutants distribution differences before and during the pandemic over Indonesia's territory is presented in Fig. 41.5. We produced a time-averaged map by averaging the monthly or daily data over the respective years for air pollutant variables of $PM_{2.5}$, NO_2, O_3, SO_2 and CO.

$PM_{2.5}$ is the particulate matter with an aerodynamic diameter of less than 2.5 microns. $PM_{2.5}$ is very dangerous to human health as it can deeply penetrate vital human organs through the respiration system. The anthropogenic sources of $PM_{2.5}$ emissions are biomass burning, fossil fuel combustion and residential, industrial and energy sectors (McDuffie et al. 2020). During the pandemic, there was a significant decrease in $PM_{2.5}$ distribution over Sumatra and Kalimantan but not in Java (Fig. 41.5a). The primary sources of $PM_{2.5}$ in Sumatra and Kalimantan were peat and forest fires which were much less common during the pandemic due to the wet climate. On the contrary, in Java, the primary sources of $PM_{2.5}$ were transportation, industries and power plants, and their activities did not seem to slow down.

Nitrogen dioxide (NO_2) is an air pollutant produced by high-temperature combustion, such as in motor vehicles, industrial furnaces and boilers and power plants. The spatial distribution of NO_2 over Java before and during the pandemic showed no significant differences except in the Jakarta region (Fig. 41.5b). There were much fewer transportation activities in Jakarta during the pandemic due to mobility restrictions. The spatial distribution of NO_2 over Paiton, the giant power plants and the city of Surabaya in East Java remained the same before and during the pandemic. It shows that there was no change in working and mobility activities.

Tropospheric ozone (O_3) is the secondary pollutant produced by the photochemical reaction between its precursors, i.e. oxide of nitrogen (NO_x) and volatile organic compounds (VOC) in the present of sunlight. On the other hand, stratospheric ozone is formed naturally through the interaction of solar ultraviolet (UV) radiation with molecular oxygen (O_2). The amount of stratospheric ozone is much more enormous than tropospheric ozone. Tropospheric ozone is very harmful, but stratospheric ozone

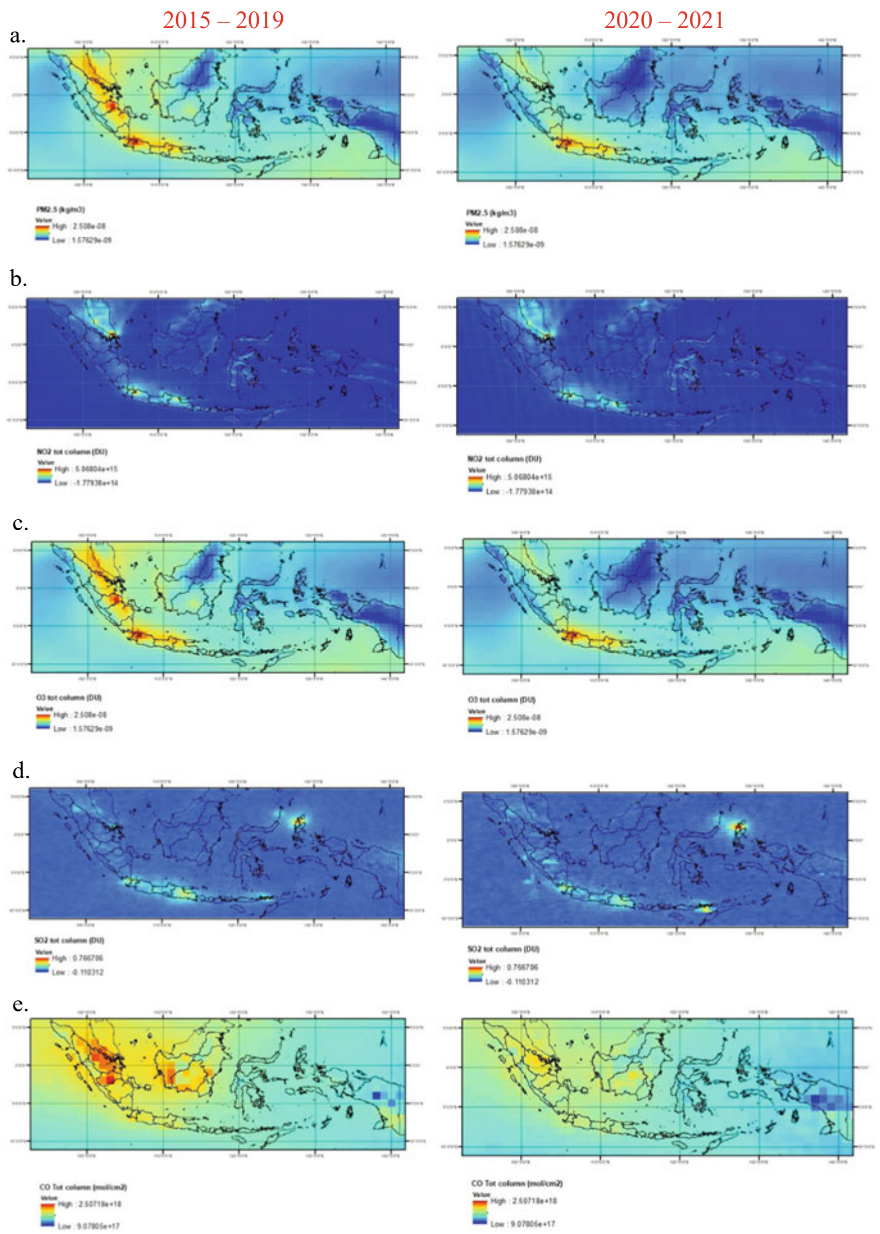


Fig. 41.5 Time-averaged map showing the spatial distribution of **a** $PM_{2.5}$, **b** NO_2, **c** O_3, **d** SO_2 and **e** CO over Indonesia's territory before (left: 2015–2019)and during (right: 2020–2021) pandemic

protects living things from the danger of solar ultraviolet (UV) radiation. The spatial distribution of O_3 over Eastern Sumatra and Southern Kalimantan showed significant differences before and during the pandemic (Fig. 41.5c). Due to long wet seasons, much fewer peat and forest fires produced much fewer ozone precursors. On the other hand, in Java, especially in Jakarta, there is no significant difference in O_3 spatial distribution, proving that there is no less precursor produced before and during the pandemic.

Sulphur dioxide (SO_2) is produced from fossil fuel combustion and burning other materials containing sulphur. The primary anthropogenic sources are transportation, industrial, residential and energy sectors. Furthermore, biomass burning and volcano eruptions also emit a large amount of SO_2 into the atmosphere. There was no significant difference in the spatial distribution of SO_2 over Java before and during the pandemic (Fig. 41.5d). The Paiton power plant in East Java still running as usual emits a large amount of SO_2 that spreads over Eastern Java. Furthermore, the high activities of Mount Krakatoa in the Sundanese strait, Mount Dukono in North Halmahera and Mount Lewotolo in East Nusa Tenggara can be detected well by OMI.

The incomplete combustion of fossil fuels and biomass burning emits carbon monoxide (CO). Before the pandemic, there were big peat fires in Sumatra and Kalimantan, which have the most extensive peatlands in Indonesia (2015–2016 and 2019). The prolonged drought resulting from El Nino during the period enhanced the catastrophe. On the other hand, during the pandemic 2020–2021, there was a long wet season in most of Indonesia's region as the impact of La Nina, thus preventing peat fires. The spatial distribution of CO during the pandemic shows a significant decrease in the west region of Indonesia (Eastern Sumatra and Southern Kalimantan) compared to before the pandemic, as shown in Fig. 41.5e.

Globally, there has been a decrease in NO_x ($NO + NO_2$) during the pandemic (Miyazaki et al. 2021). In these two sampling locations, the total value of the NO_2 column in the troposphere layer showed a positively skewed boxplot shape over time in both cities. The decrease due to restrictions on community activities in Jakarta can be seen in its impact on the decrease in total NO_2 in this troposphere layer. While in Banjarmasin, the lowest NO_2 was found in 2016. The decrease in NO_2 due to restrictions on community activities was more clearly seen in Jakarta as a metropolitan city. The total column SO_2 did not show a decrease during the pandemic period in the two locations reviewed, but if only compared to 2019, there was a decrease.

During the pandemic, there was a decrease in global NO_x emissions, where NO_x is one of the precursors of surface ozone, so it has the potential to reduce surface ozone, even if this decline occurs until the free atmosphere (Miyazaki et al. 2021; Bouarar et al. 2021). However, a short-term study in Jakarta found an anomaly of a decrease in ozone during a pandemic (Rendana 2021). About 90% of total ozone is in the stratosphere, which acts as a protector of life on earth from ultraviolet radiation (Langematz 2019), so changes in ozone concentration in the stratosphere are less significant than total ozone. The reduction in global NO_x emissions occurred during the lockdown, potentially reducing the concentration of NO_x in the stratosphere, where NO_x is one of the compounds that can damage stratospheric ozone (Malienemi et al. 2021). Monitoring of the ozone layer shows that there is a decrease in the ozone layer in 2016–2018, and it started to increase again in 2019–2021; hence, during the pandemic, the condition of the ozone layer in both cities was stable at a higher amount than the previous year. Although the policy of limiting community activities due to COVID-19 cases can improve air quality, this is not a good method for managing air quality. The impact of COVID-19 has had a negative impact on human health, both physical and psychological health, economy and education. However, this incident can be used as a lesson for air quality management.

The distribution pattern of $PM_{2.5}$ on 2–3 August 2021 in the Jakarta area and its surroundings is shown in Fig. 41.6. Based on the WRF-Chem simulation results, it can be seen that the $PM_{2.5}$ distribution in the morning at 07 am is higher than 13 pm generally. The stable atmosphere at 07 am and the active land breeze make $PM_{2.5}$ more dominant in the Jakarta area and the north coast. Then during the day, the concentration of $PM_{2.5}$ is generally reduced due to the mixing process in the boundary layer. In addition, $PM_{2.5}$ which has accumulated on the north coast in the morning is seen starting to enter the mainland again because it is carried away by the sea breeze. It happened like that for the 2 and 3 August 2021.

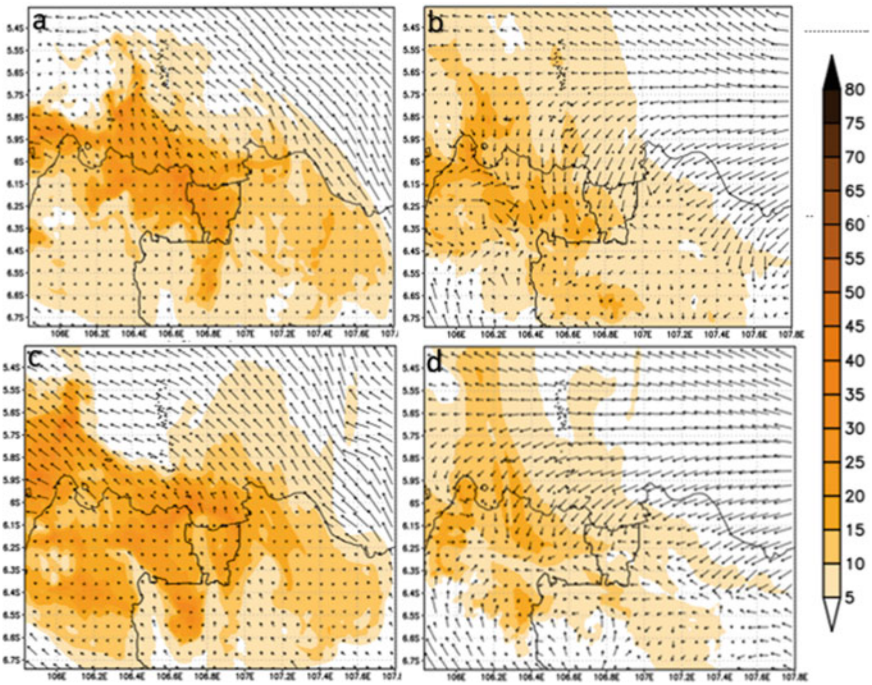


Fig. 41.6 $PM_{2.5}$ distribution is overlaid with 10 m wind vector during 2–3 August 2021, **a** 0700 LT 2 August, **b** 1300 LT 2 August, **c** 0700 LT 3 August and **d** 1300 LT 3 August

Analysis of Weather Factor

Transmission of the coronavirus can be influenced by several factors, including climatic factors (Hemmes et al. 1962). Therefore, it is essential to carefully understand the weather conditions in the transmission of COVID-19. A study in four major Chinese cities showed that the SARS outbreak significantly increased the daily incidence rate with lower temperatures (Tan et al. 2005). Recent studies using national-scale data from countries affected by COVID-19 report that low temperatures accelerate the virus to transmission (Triplett 2020; Wang et al. 2020a, b).

From the pictures above (Fig. 41.7), it can be seen that NDVI tends to be yellow to red, indicating that the vegetation density tends to be low. Likewise, with humidity which is dominated by reddish colour, this indicates that the humidity described by NDMI also tends to be low. Meanwhile, the surface temperature shown by LST tends to be high on 25 July 2019, then decreases on 22 April 2020 and rises again on 1 May 2021, in line with the high incidence of COVID-19 in 2021 with a peak in July (Fig. 41.8). The figure was downloaded from the website Satuan Tugas Penanganan COVID-19 (https://data.covid19.go.id/public/index.html). The peak incidence of COVID-19 in July in Jakarta, as the highest city or province in Indonesia, is very significant with the incidence of COVID-19 per day incident in Indonesia, reaching its peak on July 2021 (Fig. 41.9). The figure was downloaded from the website Jakarta Smart City (https://corona.jakarta.go.id).

The temperature dependence of COVID-19 may be similar to that of SARS-Cov-1, which lost its ability to survive at higher temperatures (Chan et al. 2011), as it would have damaged its lipid layer at higher temperatures (Schoeman and Fielding 2019). The association between COVID-19 and temperature and humidity could also be secondary, and the lower spread in the tropics may be due to long sun exposure. There are preliminary laboratory-based findings suggesting a role for temperature, humidity and UV radiation. However, these need to be confirmed in repeated experiments (Chin 2020; Fredericks 2020).

The incidence rate of positive cases of COVID-19 ranges from 0 to 60%, and the daily maximum temperature is between 12.2 and 22.8 °C. An average increase of 1 °C from the maximum temperature decreased the incidence rate by 7.5%. Temperature is a crucial factor in the human environment. Temperature plays an essential role in public health regarding epidemic development and control (McMichael et al. 2008). There is a specific temperature that is most suitable for the benefits of spreading the virus. Low temperatures contribute to transmission because that is when susceptibility increases. Thus, the arrival of summer can reduce the spread of COVID-19. Our results are in accordance with those already reported in other geographic locations, showing how the number of diagnosed cases increases below the maximum temperature of 10 °C and decreases linearly after that (Triplett 2020; Wang et al. 2020b).

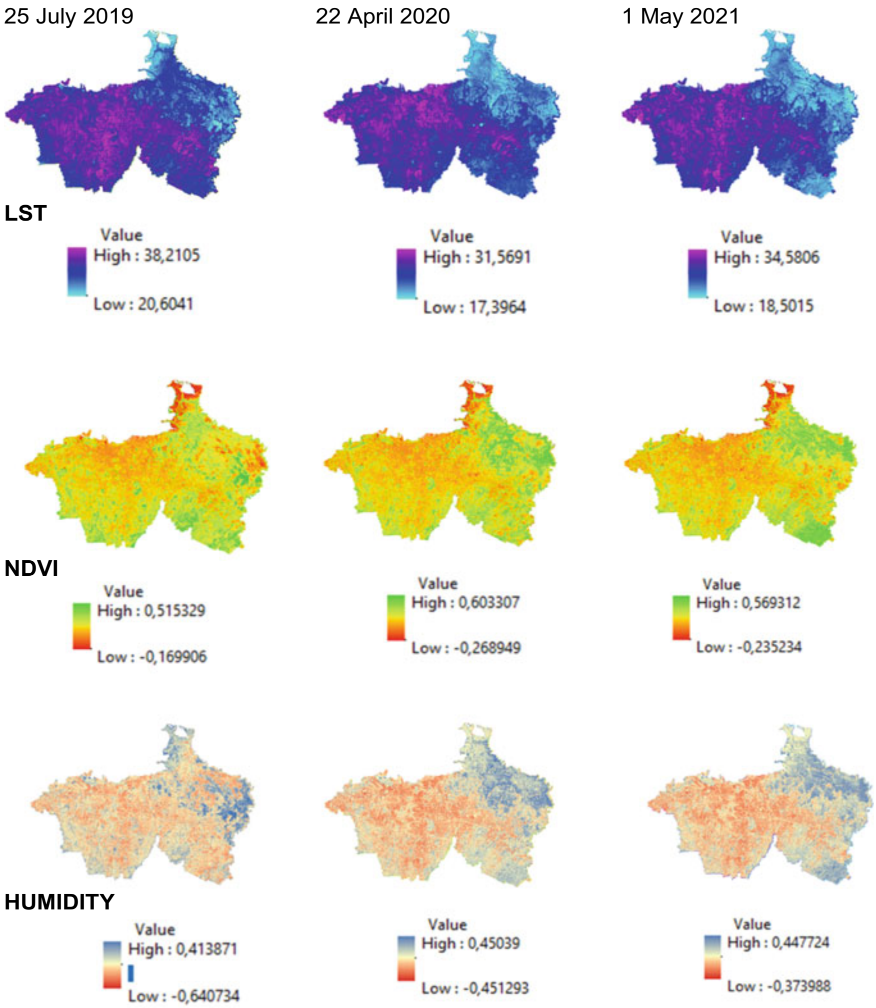


Fig. 41.7 Image of temperature, NDVI and humidity in 2019–2021

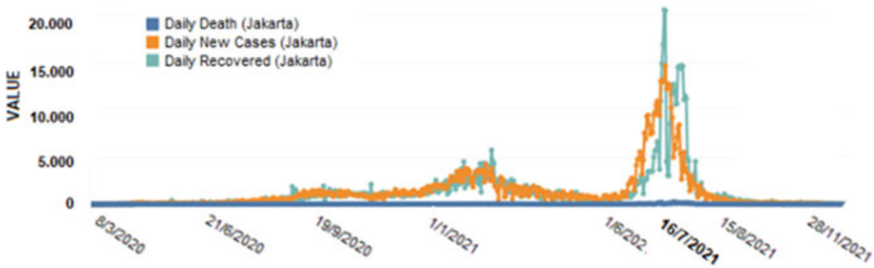


Fig. 41.8 Incidence of COVID-19 cases in Jakarta

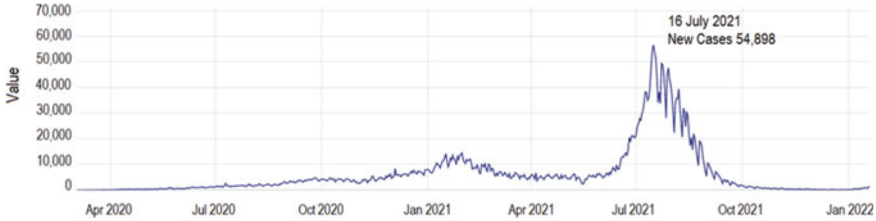


Fig. 41.9 Incidence of COVID-19 cases in Indonesia

Analysis of the Air Pollutant Standard Index

In this research, an analysis of ISPU data was carried out in the city of Jakarta during 2019–2020, which was below PM10 as a pollutant with a critical point (see Fig. 41.10). Therefore, this paper uses an indicator of pollutants in Jakarta. Figure 41.10 presents the ISPU value based on seasonal data in the Jakarta area.

It appears that the ISPU value in the city of Jakarta showed a fairly high value in the MAM transition season (March–April–May) and the dry season (June–July–August). This is presumably because this season was due to the high activity of the community. In addition, it is also suspected that during the transitional season and the dry season, there was generally a decrease in the intensity of rain helping in the process of washing out pollutants (PM_{10}) (Gusnita and Cholianawati 2019).

Figure 41.11 shows the condition of the city of Jakarta during 2019–2020 using the ISPU database from the DKI Jakarta Provincial Environmental Service. Based on Fig. 41.10, in 2019, there were five very unhealthy days and 169 unhealthy days. In 2019, the community mobility activities were still very high and running normally (before COVID-19 pandemic), and there was no need for a lockdown policy. Furthermore, the figure shows that in 2020, there were three very unhealthy days and 110 unhealthy days. This shows an increase in the air quality of healthy days in DKI Jakarta in 2020 compared to 2019; in meaning there was an improvement in air quality. The implementation of PSBB policy in 2020 was compared to 2019 before

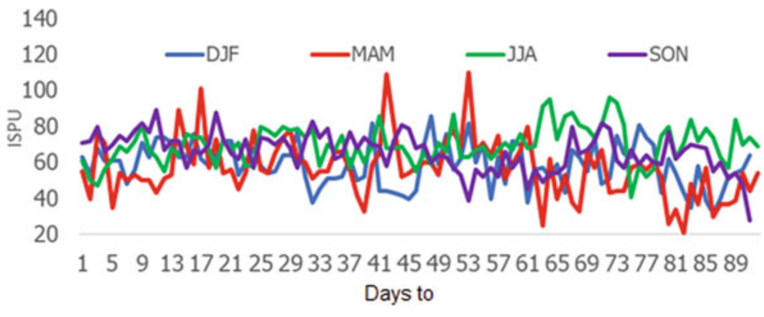


Fig. 41.10 PM10 seasonal pattern in Jakarta in 2019–2020

the COVID-19 pandemic. The results showed that the Indonesian people could obey because they found COVID-19 as a real threat.

Figure 41.12 shows a significant difference in the ISPU value of NO_2, and SO_2, in the September–October–November (SON) period compared to the previous period, which was due to the increase of community mobility after the implementation of the PSBB from March to July 2020. In July 2020, the New Normal policy began to be enforced so that the ISPU parameter values of NO_2 and SO_2 continued to increase. While the maximum value of ISPU O_3 occurred in August 2020, this is presumably due to the increase in ISPU CO in August, which was also high and caused an increase in ISPU for surface ozone. Due to the slow photochemical reaction, CO is known to have an important role in the cycle of O_3 formation, especially on a large scale in the free atmosphere. In contrast, VOCs have an important role in forming O_3 on a local scale. (Coll 2006). PM10 shows that there are different trends in different periods, namely decreasing in the March–April–May (MAM) period, increasing in the June–July–August (JJA) period and again decreasing in the September–October–November (SON) period. The difference was also seen in the plot of data on positive cases of COVID-19, where there was no visible trend in the March–April–May (MAM) period, an upward trend in the June–July–August (JJA) period due to the lifting of the PSBB. Thus, it appears the urgency of controlling PSBB will affect the

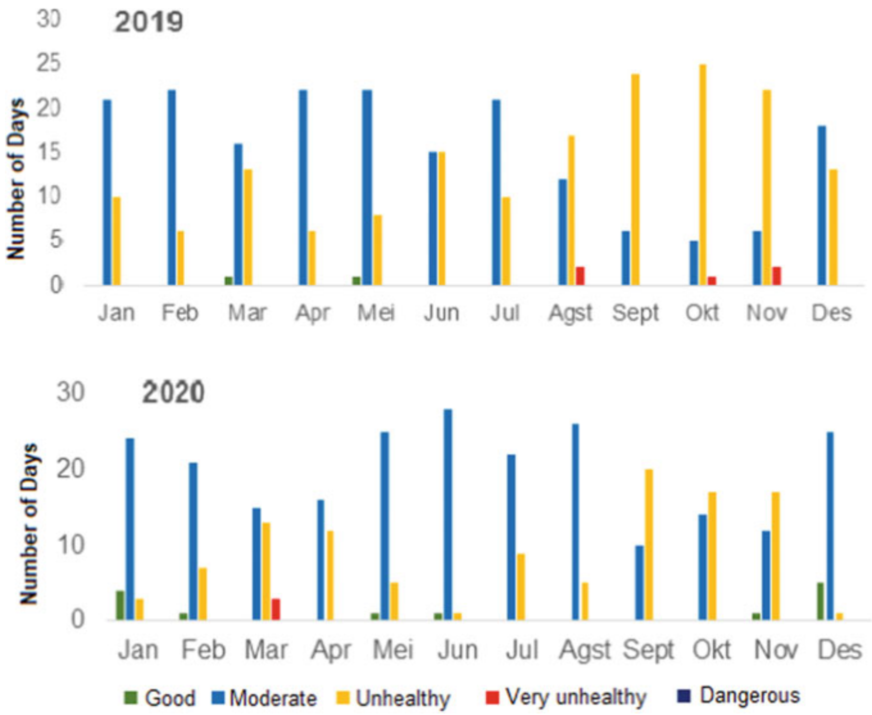


Fig. 41.11 Air quality conditions in the city of Jakarta in 2019 and 2020

spread of COVID-19 and improve air quality with the low values of ISPU NO_2 and SO_2, which are visible due to sharply reduced anthropogenic activities.

The PSBB measure is an effective strategy to break the chain of the spread of the coronavirus. Of course, this must be based on public awareness, not gathering, and still complying with existing protocols outside the home. The PSBB measure is more appropriate when compared to lockdown because people are not allowed to leave their homes at all, any transportation starting from cars, motorbikes, trains or even planes cannot operate, and even office activities can be stopped altogether in the event of a lockdown. Therefore, the PSBB measure is much better implemented since almost all activities have been suspended. This is one of the government's strategies for preventing coronavirus. PSBB can help prevent the spread of the coronavirus to a certain area so that people in an area are expected to avoid the fast-spreading outbreak. This policy can only be carried out by the government by first conducting a thorough inspection previously to several regions and carefully considering the consequences, both from an economic and social point of view (Nasruddin and Haq 2020).

Based on this, then the PSBB policy implementation in the future, it is necessary to pay more attention to community as a target group by providing education that is sustainable. Understanding the benefits of the PSBB policy are good for the citizens itself and for the community, it is expected that the community could carry out PSBB policy properly. It is also recommended to ensure the service provider of public services, such as government offices, modes of public transportation and fixed shopping centres, support the PSBB implementation by carrying out public service activities based on PSBB rules (Herdiana 2020).

Recommendations

The findings clearly show a link between the air quality and the implementation of PSBB policy. This policy restricts the people movement, which at its highest level reduces the industrial activities, building and other infrastructure constructions and in particular the traffic jams in Jakarta and other big cities in Indonesia, which gives benefit for the air quality.

Learning from these experiences, to keep the air quality at the same level as during the implementation of the PSBB, it is recommended to:

- Control and manage the traffic jams, especially in Jakarta and other big cities in Indonesia. Traffic jams are the large source of air pollutant in Jakarta. During the implementation of the PSBB, there were no traffic jams. The 'new normal' condition should be encouraged to keep the people movement low, without sacrificing work productivity. All sectors that were known able to maintain productivity during the PSBB are encouraged to limit their movement after PSBB. Communication technology that supports the distant work and services should be maintained and enhanced. New creative industries or economy that support the productivity

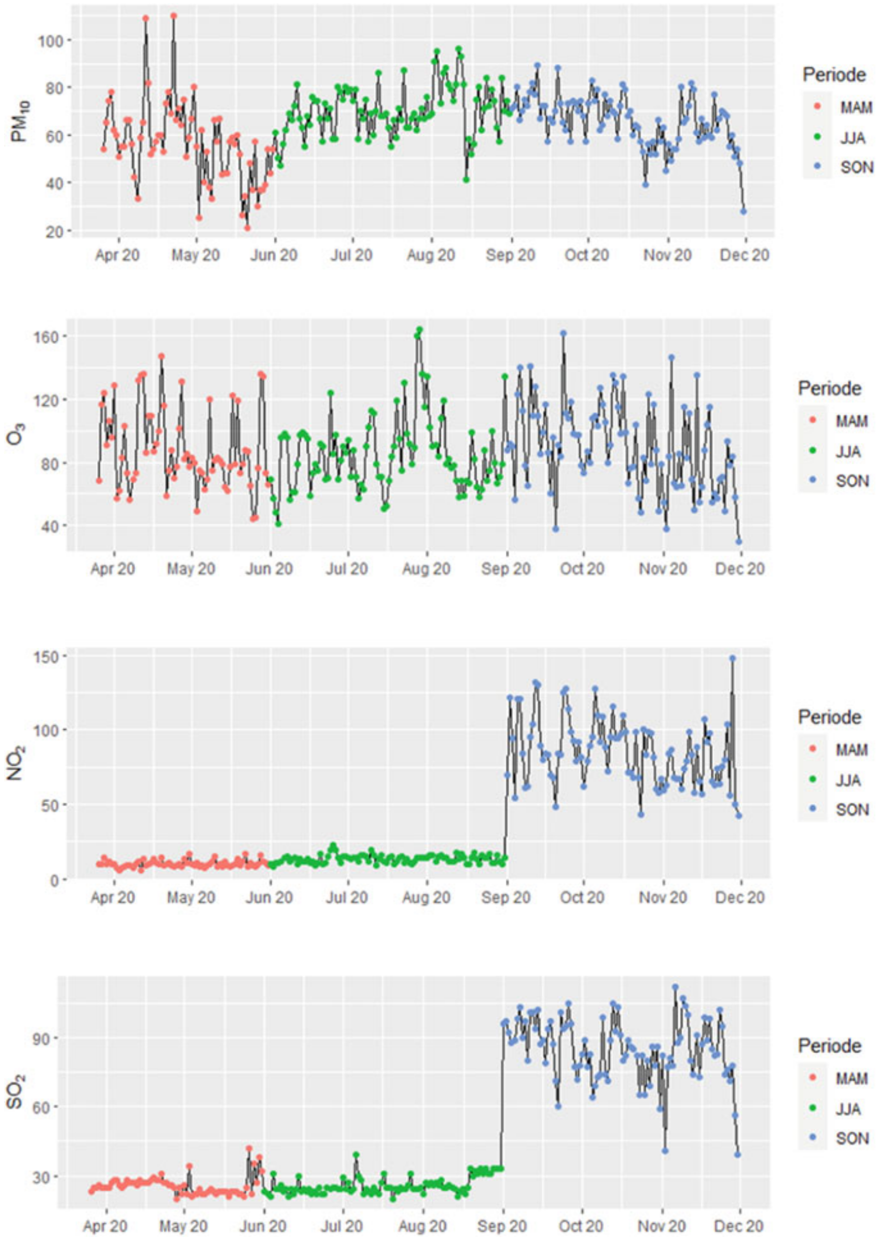


Fig. 41.12 ISPU of CO, NO_2, SO_2, CO and Ozone pollutants in Jakarta

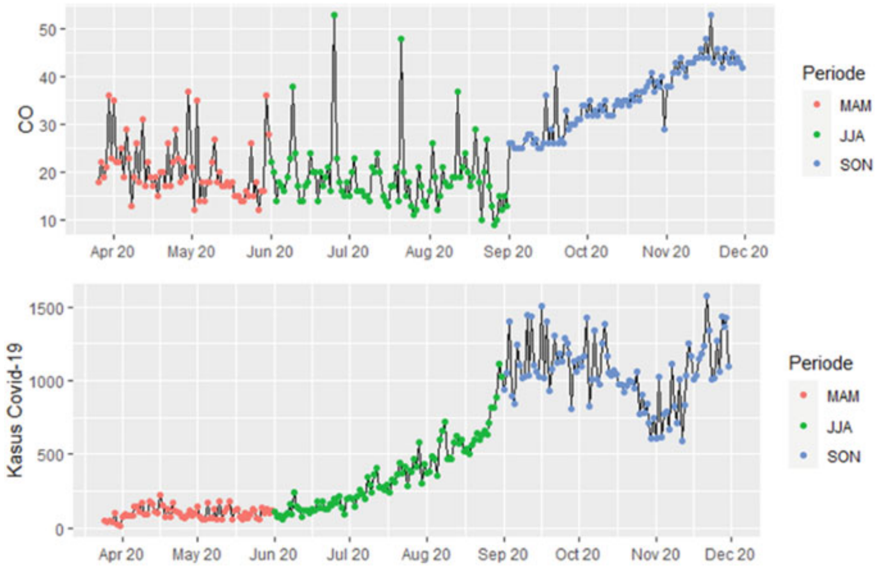


Fig. 41.12 (continued)

with limited movement should be encouraged as well. In addition, the government should accelerate the programme to improve the people movement facilities, which include the public mass transport system development, road and bridge constructions to control and ease traffic jams, and improve comfort for pedestrians, cyclists and other public transport and road users.

- Accelerate the use of zero or low air pollutant emission vehicles such as electric and natural gas-fuelled vehicles to reduce the volume of air pollutant.
- Conduct a programme to accelerate the replacement of fossil fuel-based energy in industry with the renewable or eco-friendly energy.

Conclusion

The results of the OMI and MERRA-2 Models on the analysis of $PM_{2.5}$, NO_2, SO_2 and O_3 for the COVID-19 pandemic in Jakarta showed a decrease in $PM_{2.5}$ in the pandemic year, although not as good as the conditions in 2016. In Jakarta and Banjarmasin, $PM_{2.5}$, NO_2 and SO_2 decreased in 2021 from 2020, in line with the high incidence of COVID-19 in 2021. This reveals that there was an increase in air quality in the form of healthy days in DKI Jakarta in 2020 more than in 2019. In other words, there was an increase in air quality during the implementation of PSBB in 2020 compared to 2019 before the COVID-19 pandemic.

Besides, based on WRF-Chem model result with $PM_{2.5}$ parameter, the daily distribution of air quality in Jakarta was influenced by local circulation such as land-sea breeze. The results comprehensively show an increase in air quality during the COVID-19 pandemic during PSBB to the previous years. This research is believed to provide credible and valuable results and insights for the scientific community and policymakers on the PSBB impact on air quality. Furthermore, this research provides a roadmap to improve the air quality of Jakarta in particular and Indonesia in general in the future.

Acknowledgements We extend our gratitude to Director of Research Center for Climate and Atmosphere for all the support and encouragement during the fieldwork in Bandung.

References

Bar-On YM, Flamholz A, Phillips P et al (2020) Science forum: SARS-CoV-2 (COVID-19) by the numbers eLife 9:e57309. https://doi.org/10.7554/eLife.57309

Bdou T, Drikakis D (2020) Weather impact on airborne coronavirus survival. Phys Fluid 32:093312. https://doi.org/10.1063/5.0024272

Berman JD (2020) Changes in U.S. air pollution during the COVID-19 pandemic. J Sci Total Environ 739:139864. https://doi.org/10.1016/j.scitotenv.2020.139864

Bouarar IB, Gaubert GP, Brasseur et al (2021) Ozone anomalies in the free troposphere during the COVID-19 pandemic. Geophys Res Lett 48(16). https://doi.org/10.1029/2021GL094204

Chan KH, Peiris JSM, Lam SY et al (2011) The effects of temperature and relative humidity on the viability of the SARS coronavirus. Adv Virol 2011:1–7. https://doi.org/10.1155/2011/734690

Chin AWH, Chu JTS, Perera MRA, Peiris M, Poon LLM et al (2020) Stability of SARS-CoV-2 in different environmental conditions. Lancet Microbe 1:e10. https://doi.org/10.1016/S2666-5247(20)30003-3

Coll I et al (2006) On the determining role of CO in local ozone production. Geophys Res Abstr 8:10025

Fredericks B (2020) Top DHS scientists says heat, humidity slow coronavirus. Accessed on 5 May 2020 from https://nypost.com/2020/04/23/top-dhs-scientists-says-heat-humidity-slow-coronavirus/. New York Post, 23 Apr 2020

Gusnita D, Cholianawati N (2019) Pola konsentrasi dan trayektori polutan PM2.5 serta faktor meteo di kota Jakarta (Pollutant concentration and trajectory patterns of PM2.5 including Meteo factors in Jakarta City). J Kimia dan pendidikan kimia, Program Studi Pendidikan Kimia Universitas Sebelas Maret 4(3) https://doi.org/10.20961/jkpk.v4i3.35028

He G et al (2020) The short-term impacts of COVID-19 lockdown on urban air pollution in China. Nat Sustain. https://doi.org/10.1038/s41893-020-0581-y

Hemmes JH, Winkler KC, Kool SM (1962) Virus survival as a seasonal factor in influenza and poliomyelitis. Antonie Leeuwenhoek 28:221–233. https://doi.org/10.1007/bf02538737

Herdiana D (2020) Implementasi Kebijakan Pembatasan Sosial Berskala Besar (PSBB) Sebagai Upaya Penanggulangan Corona Virus Disease 2019 (COVID-19) (Implementation of large-scale social restrictions (PSBB) policies as an effort to overcome Corona Virus Disease 2019 (COVID-19)). Jurnal Administrasi Publik 2(2):1–14. https://doi.org/10.23969/decision.v2i2.2978

Jayaweera MH, Parera B, Gunawadhana JM (2020) Transmission of COVID-19 virus and aerosol: a critical review on unresolved dichotomy. Environ Res 188. https://doi.org/10.1016/j.envres.2020.109819

Jiang J, Luo L (2020) Influence of population mobility on the novel coronavirus disease (COVID-19) epidemic: based on panel data from Hubei, China. Global Health Res Policy 5:30. https://doi.org/10.1186/s41256-020-00151-6

Lastovicka J, Svec P, Paluba D, Kobliuk N, Svoboda J, Hladky R, Stych P (2020) Sentinel-2 data in an evaluation of the impact of the disturbances on forest vegetation. Remote Sensing 12(12). https://doi.org/10.3390/rs12121914

Langematz U (2019) Stratospheric ozone: down and up through the Anthropocene. In: ChemTexts. Springer, Heidelberg https://doi.org/10.1007/s40828-019-0082-7

Malienemi V, Tyssoy HN, Smith-Johnsen C, Arsenovic P, Marsh DR (2021) Effect of enhanced downwelling of NOx on antartic upper-stratospheric ozone in 21st century. Atmos Chem Phys 21:11041–11052

Martorell-Marugán J et al (2021) DatAC: a visual analytics platform to explore climate and air quality indicators associated with the COVID-19 pandemic in Spain. Sci Total Environ 750:141–424. https://doi.org/10.1016/j.scitotenv.2020.141424

McDuffie EE et al (2020) A global anthropogenic emission inventory of atmospheric pollutants from sector- and fuel-specific sources (1970–2017): an application of the Community Emissions Data System (CEDS). Earth Syst Sci Data 12:3413–3442

McMichael AJ (2008) International study of temperature, heat and urban mortality: the "ISOTHU'M' project. Int J Epidemiol 37:1121–1131. https://doi.org/10.1093/ije/dyn086

Mehmood KS, Mushtaq Y, Bao S et al (2022) The impact of COVID-19 pandemic on air pollution: a global research framework, challenges, and future perspective. Environ Sci Pollution Res. https://doi.org/10.1007/s11356-022-19484-5

Miyazaki K, Bowman K, Sekiya T, Takigawa M, Neu JL, Sudo K, Eskes H (2021) Global tropospheric ozone responses to reduces NOx emissions linked to the COVID-19 worldwide lockdown. Sci Adv 7:24. https://doi.org/10.1126/sciadv.abf7460

Nasruddin R, Haq I (2020) Pembatasan Sosial Berskala Besar (PSBB) dan Masyarakat Berpenghasilan Rendah (Large-scale social restrictions (PSBB) and low-income communities). Jurnal Sosial & Budaya Syar-I 7(7):639–648. https://doi.org/10.15408/sjsbs.v7i7.15569

NicePNG (2018) Printable map of Indonesia wallpaper. https://www.nicepng.com/ourpic/u2w7i1q8r5a9a9r5_printable-map-of-indonesia-wallpaper-map-of-indonesia/

Pramana S (2020) Air pollution changes of Jakarta Banten, and West Java, Indonesia during the first month of COVID-19 pandemic. J Bus Econ Environ Stud 10(4):15–19. https://doi.org/10.13106/jbees.2020.vol10.no4.15

Ranga U (2021) SARC-Co-2 aerosol and droplets: an overview. VirusDis 32(2):190–197. https://doi.org/10.1007/s13337-021-00660-z

Rachmawati et al (2021) The use of ICT-based applications to support the implementation of smart cities during the covid-19 pandemic in Indonesia. Infrastructures 6(9). https://doi.org/10.3390/infrastructures6090119

Rakhim R, Pattipeilohy WJ (2021) Dampak Pelaksanaan Pembatasan Sosial Berskala Besar (PSBB) Terhadap Konsentrasi PM10 di Pekanbaru (Impact of large-scale social restrictions (PSBB) on PM10 concentration in Pekanbaru). ECOLAB 15(1):13–22

Rizi UF, Suradi S, Agus A (2019) Analisis dampak diterapkannya kebijakan working from home saat pandemi Covid-19 terhadap kondisi kualitas udara di Jakarta. Jurnal Meteorologi Klimatologi dan Geofisika (Analysis of the impact of the implementation of the working from home policy during the Covid-19 pandemic on air quality conditions in Jakarta). J Meteorol Climatol Geophys 6(3):6–14

Saputra YA, Susanna D, Saki VY (2021) Impact of climate variables on covid-19 pandemic in Asia: a systematic review. Kesmas, Universitas Indonesia, Faculty of Public Health. https://doi.org/10.21109/kesmas.v0i0.5211

Schoeman D, Fielding BC (2019) Coronavirus envelope protein: current knowledge. Virol J 16:69. https://doi.org/10.1186/s12985-019-1182-0

Suhaimi NF et al (2020) Demystifying a possible relationship between COVID-19 air quality and meteorological factors: evidence from Kuala Lumpur, Malaysia. Aerosol Air Qual Res 20:1520–1529. https://doi.org/10.4209/aaqr.2020.05.0218

Tan J et al (2005) An initial investigation of the association between the SARS outbreak and weather: with the view of the environmental temperature and its variation. J Epidemiol Community Health 59:186–192. https://doi.org/10.1136/jech.2004.020180

Triplett M (2020) Evidence that higher temperatures are associated with lower incidence of COVID-19 in pandemic state, cumulative cases reported up to March 27. https://doi.org/10.1101/2020.04.02.20051524

Wang J et al (2020a) High temperature and high humidity reduce the transmission of COVID-19. SSRN Electron J. https://doi.org/10.2139/ssrn.3551767

Wang M et al (2020b) Temperature significantly change COVID-19 transmission in 429 cities. medRxiv preprint. https://doi.org/10.1101/2020.02.22.20025791

Chapter 42
Assessing the Impact of COVID-19 on Urban Socio-economic Vulnerability and Wellbeing for Integrated Planning: A Quantitative Enquiry in the Katwa Municipality, West Bengal

Tanmoy Basu, Biraj Kanti Mondal, and Rima Das

Abstract The present study focuses on the quantitative investigation of economic vulnerability and assesses the perception survey carried out among 75 residents of Katwa Municipality, an up-growing urban area in Purba Barddhaman District, West Bengal. To estimate the socio-economic vulnerability during the lockdown, standardised factor scores have been calculated in the analysis of principal components and GIS-based mapping has been employed also. Among the total working population of the surveyed household, about 20% have changed their occupation, wages have been reduced by 35 and 35% have lost their occupation during the lockdown period. The highly socio-economic vulnerability has been observed in the wards where households and population are also high. The regression coefficient shows that the increasing trend of marginal other workers has the significantly ($p < 0.1$) highest marginal effect on the socio-economic vulnerability. The Likert scale measuring perception indicated that the majority of the respondents agreed with their socio-economic vulnerabilities caused by lockdown during the pandemic situation. The significant outcome of the study indicates the initiation of diversified income generation opportunities and deliberates its contribution to the formation of location-specific planning for the socio-economic development and integrative management of the study area.

Keywords Vulnerability · Perception · COVID-19 · Lockdown · Quantitative · GIS

T. Basu
Department of Geography, Katwa College, Purba Barddhaman, West Bengal 713130, India

B. K. Mondal (✉)
Department of Geography, Netaji Subhas Open University, Kolkata 700064, India
e-mail: birajmondal.kolkata@gmail.com

R. Das
Department of Geography, Bhangar Mahavidyalaya, South 24 Parganas, West Bengal 743502, India

U. Chatterjee et al. (eds.), *Urban Commons, Future Smart Cities and Sustainability*, Springer Geography, https://doi.org/10.1007/978-3-031-24767-5_42

Introduction

COVID-19 (novel coronavirus disease) is one of the severe pandemics of the present century. It started to spread globally as acute respiratory syndrome from January to March 2020. The lockdown period had been started in March 2020 in several countries of the world after the declaration of the World Health Organisation about COVID-19 as the first pandemic globally spread in the twenty-first century (Onyeaka et al. 2021). India faced an extensive lockdown situation during the outbreak of COVID 19 which tremendously impact the national–regional economy of this developing country. According to The Lancet (2020), 18,985 active COVID cases and 603 death reports had been declared in the 31 states and union territories on 30 January 2020. The first lockdown period was extended up to April 2020 with restrictions on public activities within the territory and transportation to and from other countries. The common people of Indian rural and urban areas are affected by the restrictions of lockdown in their social and economic activities. The urban residents and migratory labours engaged in specialising economic activities faced a problematic situation with deducing from their occupation during the entire lockdown period (Jesline et al. 2021; Allain-Dupré et al. 2020). The impact of lockdown on the urban common people is here exemplified in global, national and regional-level scenarios. There were opposite scenarios among the people engaged in businesses and services about their worry about the uncertainty of their occupation in Khulna City Corporation of Bangladesh (Haque et al. 2020). COVID-19 lockdown devastatingly impacted the global urban economy as the misappropriation of women in the informal sectors globally and in the 'hardest hit sectors' like the tourism industry, hospitality management and other services (United Nations 2020). In South Asian countries including India, the pandemic situation of COVID-19 and associated lockdown devastated many migrant workers who had been migrating within the territory of a country (Rasul et al. 2021). They have mainly belonged to informal sectors of the economy that had lost their occupation and were hindered by the restrictions of transport and public movement during lockdown to return to their home (Rasul et al. 2021). Gupta et al. (2021) observed that about 65% of the sample household consisting one migrant person who was engaged in agriculture or non-agricultural labour in an Indian urban area. Gupta et al. (2021) also postulated that the average weekly income of the local household of Indian Sundarbans was not so much originated from local sources. Khan et al. (2022) noted that near about 68.3% of the households were vulnerable to their economic conditions in absence of a steady and secure income from their occupation in Bangladesh. Moreover, about 59.9% of a household consisting of single-income-generation persons were also vulnerable to economic conditions as their average monthly income was reduced during COVID-19 (Khan et al. 2022). Nicola et al. (2020) found that the COVID-19 pandemic has impacted the global communication systems, business and organisational activities which have affected unwittingly on the financial markets and economic conditions worldwide. The lockdown situation also deranged the commodity and service 'supply chains' by creating the incoordination of governmental responses and activities (Nicola et al. 2020).

Martin et al. (2020) opined that the lowest income population was mostly affected by the COVID-19 crisis in the San Francisco Bay Area. The mean recovery period for the affected persons is double (14.3 months) for the lowest income quintile in comparison to the highest income quintile whose mean recovery period is 7.2 months (Martin et al. 2020). Gururaja and Ranjitha (2022) postulated that the impact of COVID-19 and its associated lockdown on employment is in the lower-income countries of the world like India. During COVID-19, 62% of informal employment was inadequately impacted in the world. The significant factors which predicted the risks of COVID 19 in the States and Union Territories of India were ageing, interstate migration, international migration, literate, casual labour in non-agriculture. Moreover, joint or extended family, drinking water outside premises, population density and proportion of the urban population also significantly determined the risks of COVID 19 (Pathak et al. 2020). The non-significant factors were the Scheduled Caste or the Scheduled Tribe population, the Muslim population, casual labour in agriculture, poverty, the proportion of the slum population, and health expenditure (Pathak et al. 2020). Tamrakar et al. (2021) resulted out that the percent of the 15–59 aged population, percent of marginal workers and population density were significantly associated with the infection rate of COVID-19 in India. Socio-economic variables, such as the literate population, ST population, urban population and the average person sleeping in a room significantly, predicted the infection rate of COVID-19 (Tamrakar et al. 2021). According to the analysis by Tamrakar et al. (2021), the Indian districts which have a good infrastructure at the household level have higher feasibility of the rate of infection of COVID-19. Aneja and Ahuja (2021) mentioned in their study that a significant number of 'fiscal' and monetary policies had been measured by the respective authority to combat the impact of lockdown during COVID-19. Aneja and Ahuja (2021) also suggested measuring special attention to the vulnerable sections of India. Attention is needed on the poverty-driven people, small- and medium-scale industries and the non-indispensable commodities sector which has the worst thrash in the demand contraction during the COVID-19 pandemic situation (Aneja and Ahuja 2021). Lahiri and Sinha (2021) studied that household-level individuals have been negatively affected by the lockdown situation regarding loss of their job, deduction of wages or salaries and other related problems around the world including in India. The spread of COVID-19 in India among the proportions of overcrowding households was significantly higher in the rural areas (51%) among the poverty-stricken, socio-economically improvised and depreciated communities. Chaudhary et al. (2020) postulated that COVID-19 had impacted the fiscal and monetary policy of India. The authors opined that the COVID-19 pandemic originated a lesson to the Indian planners and policymakers for dispensing a great impulsion to the sectors in an extensive way (Chaudhary et al. 2020). The sectors could make a superior allocation of resources and diminish the inequality and disparity situations of income generation in India (Chaudhary et al. 2020).

In West Bengal, the 1st case of COVID-19 was observed on 17 March 2020 (Konar et al. 2020). Mondal et al. (2021) identified seven districts consisting of a large number of urban populations included in the high affectivity zone of COVID-19 in West Bengal, those were Howrah, Kolkata, and northern Jalpaiguri. Nadia, Hooghly, Purba Bardhaman and Paschim Bardhaman districts were belonging to low or moderate affectivity zone (Mondal et al. 2021). The rest of the districts of West Bengal were included in the safe zone (Mondal et al. 2021). Choudhury et al. (2022) proved in their study that there was no significant difference in the household income, expenditure and savings of the studied groups in the pre-COVID situation in Hooghly district of West Bengal. Besides, there was no significant difference in household expenditure also during the COVID situation Choudhury et al. (2022). Choudhury et al. (2022) also identified that there was a significant difference in household income and savings during the COVID situation in Hooghly district of West Bengal. Nath et al. (2021) mentioned the situation of COVID cases based on Government records that Kolkata is one of the vulnerable cities in India where the total COVID-19 infection cases were more than 37,000 and the total numbers of deaths were 1200. In Kolkata city, the urban sprawling and congested areas were mostly affected by COVID 19 and about 30% of the slum population to the total population who are deprived and driven by poverty were mostly affected (Ghosh 2013). In this context, the present study attempts to identify the socio-economic vulnerability of COVID-19 in the selected urban unit area and assess the perception of the residents about their wellbeing situation during COVID-19 in 2020–2021.

Objectives

The objectives of the present study are

1. To identify the socio-economic situation of the residents of Katwa Municipality during COVID-19 lockdown period (2020–2021).
2. To formulate the socio-economic vulnerability index in the study area during the lockdown.
3. To analyse the relationship among the socio-economic indicators and the marginal effect of the indicators on the vulnerability index.
4. To access the perception of the respondents on the lockdown situation and suggest major policy measures to sustain the development of the urban dwellers in Katwa Municipality.

Materials and Methods

Study Area

Katwa Municipality is selected as the study area of the present study. It is situated between 23° 37 min north to 23° 39 min north latitude and 88° 6 min east to 88° 8 min east longitude in Purba Bardhaman district of the state of West Bengal, India. It is situated at the confluence of Ajay and Bhagirathi rivers in Gangetic West Bengal where the climate is tropical monsoon. The city is a statutory town of Purba Barddhaman district (former Barddhaman district) with geographical and historical value consisting of a total of 81,615 population and 19,382 households in 2011 (Census of India 2011). The decadal growth rate of population and households are 12.28% and 21.26% from 2001 to 2011, respectively, in Katwa Municipality (Census of India 2001, 2011). The male and female literacy rates are 90.25 and 83.94% in 2011 (Census of India 2011). The municipality area consists of 19 wards (Census of India 2011), and presently, ward number-12 is divided into two wards, those are ward number-12 and ward number-20. The facilities of the residents of this municipality area are well connected with Burdwan city, the district capital by bus and train, and with Kolkata, the state capital by train route. The surrounding areas of Katwa Municipality of Katwa Subdivision of Purba Bardhaman district are mainly rural. Agriculture is the primary economic activity alongside the bank of river Bhagirathi, whereas the municipal area has functioned as multiple economic activities. There was 0.98% of cultivators and 1.94% of agricultural labourers and 5.25% of household industry workers and 91.79% other workers in the total workers, respectively, in Katwa municipality (Census of India 2011). During COVID-19, the Katwa Subdivisional Hospital was a significant and primal health-facilitate centre of the municipality and surrounding areas (Fig. 42.1).

Katwa municipality is selected as the study area of the present study as one case of death occurred due to comorbidity in the primer phase of COVID-19 in the surrounding areas of Katwa. The present study focuses on the socio-economic conditions at the household level and socio-economic vulnerability in the wards of Katwa Municipality during the lockdown in 2020–2021. As the town is one of the significant urban growth centres of Purba Bardhaman district of West Bengal as well as subdivisional, the urban socio-economic situation could be correlated with the working profile, COVID vulnerability and residential perception of their wellbeing. Besides, some migratory labours of West Bengal were returned to their native Katwa and surroundings during the lockdown. Regarding this, socio-economic conditions and vulnerabilities with perceptual wellbeing are under consideration as the objective of the present study conducted in Katwa Municipality.

Data Sources

The present study has been conducted using both secondary data and a primary field survey. Relevant secondary data have been collected from Census of India (2011). A primary field survey has been done in December 2021 by selecting 75 households using simple and purposive random sampling techniques. The households are characteristically consisting of varied socio-economic and infrastructural conditions.

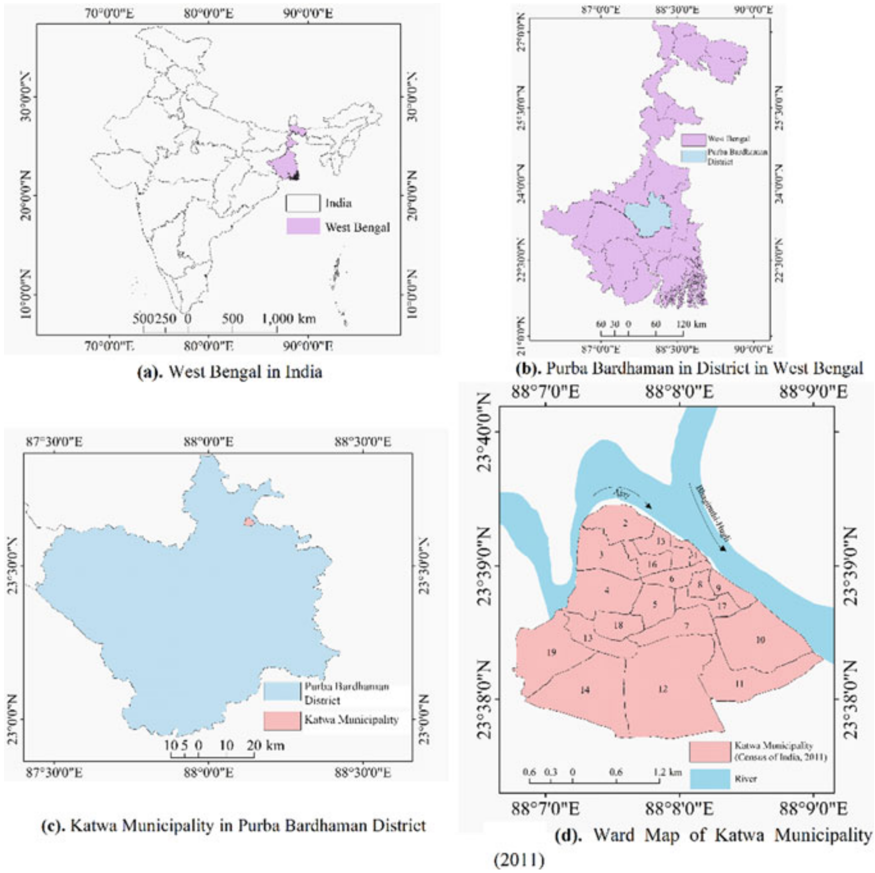


Fig. 42.1 a–d Location map of the study area

Methods and Techniques

Socio-economic Vulnerability Analysis

In the COVID-19 context of India, vulnerability has been measured in different ways. Bhattacharya and Banerjee (2021) measured the Health Vulnerability Index (HVI) and Economic Vulnerability Index (EVI) of COVID-19 in the major twenty-two states of India. Health vulnerability and economic vulnerability have been measured by ranking the states based on health-related and economic indicators (Bhattacharya and Banerjee 2021). Mishra et al. (2020) measured the urban COVID Vulnerability Index using the social distancing, lockdown and direct health variable-related indicators in India. Mishra et al. (2020) constructed a pairwise comparison matrix to measure the vulnerability index in the Analytical Hierarchy Process. Sahu and Mishra (2021) applied the statistical methods of max–min normalisation and multiple indicators combination to construct the COVID-19 Vulnerability Index (VI) in Indian states and UTs. Sahu and Mishra (2021) formulated an equation of Vulnerability Index that Vulnerability Index is the difference between Exposure and Adaptive Capacity multiplied by Sensitivity. Based on the selected indicators of exposure, adaptive capacity and sensitivity, the vulnerability index ranges from −1 to +1 (Sahu and Mishra 2021). Sarkar and Chouhan (2021) used the statistical methods of Z-score data normalisation, principal component analysis (PCA) and aggregating indicators to build up the Socio-Economic Vulnerability Index (SoEVI) of COVID 19 in Indian districts. The construction of the index is based on the selected socio-economic indicators, and it ranges from 1 to 100 (after normalisation of the index). Here, a higher index value represents greater vulnerability (Sarkar and Chouhan 2021). Zhang et al. (2014) postulated that regional environmental vulnerability assessment is based on the information entropy, the extension of the evaluation index number field in normalisation. The method has been modified for the assessment of the proposed regional eco-environmental vulnerability with an improved entropy weight model (Zhang et al. 2014). Li et al. (2022) also used the entropy weight method with positive index calculation and negative index calculation formula to measure the economic system vulnerability.

In the present study, vulnerability assessment is based on the extracted factor scores of principal component analysis (PCA). Primarily data standardisation has been made to avoid internal inconsistency. The composite indices method has been implemented through Factor analysis of PCA on each of the pre-defined criteria to bring out the significant factors of socio-economic conditions and vulnerability of the respondents. For the composite factor analysis, the following formula (PCA, Pearson 1901) has been used:

$$P_1 = \Sigma a_{j1} X Z_j \text{ or } P_1 = a_{11}.Z_1 + a_{21}.Z_2 a_{11}. + \ldots + a_{n1}.Z_n \quad \text{(i)}$$

where P_1 denotes the composite index of development of a unit study as the first factor denotes the factor loading of the 'j'th variable and 1 indicates the factor number that is the first factor-vector of factor loadings.

While the Z_j denotes the standardised value of the 'j'th variable, which is expressed as

$$Z_j = \frac{X_j - X_m}{\delta_j} \quad \text{(ii)}$$

where X_j denotes the original value of 'j'th variable, X_m denotes the mean (simple arithmetic mean) of 'j'th variable, and δ_j denotes the standard deviation of 'j'th variable.

In this aspect, the mean and standard deviation are calculated by using the following formula:

$$\text{Mean} = \frac{\Sigma x}{n} \quad \text{(iii)}$$

$$\text{Standard Deviation (SD, } \sigma) = \sqrt{\left(\frac{x - \overline{x}}{n}\right)} \tag{iv}$$

where $\overline{x}$ is the arithmetic mean; x is the individual value of items; n is the number of terms in the distribution.

Standard error mean has been estimated following the formula of Carlin and Doyle (2000). According to Carlin and Doyle (2000), the SEM must itself be estimated by using the sample SD (s) in place of the unknown σ, the formula is

$$\text{SEM} = \frac{s}{\sqrt{n}}$$

Finally, mean composite factor scores have been calculated using the standardised factor scores extracted from PCA.

$$\text{Mean Composite Factor Scores} = \frac{\text{Factor}_1 + \text{Factor}_2 + \text{Factor}_3 + \ldots + \text{Factor}_n}{\text{Total number of extracted factors}} \tag{v}$$

where, n is the factor.

Correlation and Regression Analysis

To find out the correlations, the following Pearson's formula of r (Pearson 1896) has been used:

$$r = \frac{n\Sigma xy - \Sigma x.\Sigma y}{\sqrt{n\Sigma x^2 - (\Sigma x)^2}\sqrt{n\Sigma y^2 - (\Sigma y)^2}} \tag{vi}$$

where r = Correlation coefficient; x = Independent variable; y = Dependent variable and n = No. of observations.

The multiple linear regression model has been used to identify the relationship between mean composite factor scores and their determinants. The formula of the multivariate regression model (Uyanık and Güler 2013) is

$$Y = \beta_0 + \beta_1 X_1 + \ldots + \beta_n X_n + e_t \tag{vii}$$

where

Y is the dependent variable (here, mean composite factor scores)
X_1 is the independent variable
β_1 is parameter
e_t is error.

The standardised predicted values and standardised residuals are derived from the analysis of the multiple linear regression model.

In the post-estimation analysis of the regression model, the marginal effect of the population mean has been estimated using the following formula adopted by Leeper (2017),

$$\text{Marginal effect concerning } X_1 = \frac{\mathrm{d}Y}{\mathrm{d}X_1} = \beta_1 + \beta_3 X_2 \qquad \text{(viii)}$$

where

d is the change
Y is the dependent variable
X is the independent variable
β_1 is parameter.

In this study, the coefficient value indicates the marginal effects of the statistical population mean of the determinants on the dependent variable. The linear regression model has been performed with a degree of freedom of $n - 1$ (Rawlings et al. 1998) and a confidence coefficient of 0.95 and 0.99.

The test of significance (Fisher 1925 following Student 1908) analysis has been adopted using the following formula,

$$t = r\sqrt{\frac{n-2}{1-r^2}} \qquad \text{(ix)}$$

where t = Value of significance; r = Correlation coefficient; r^2 = Coefficient of determinants and n = No. of observation. In the study, the degree of freedom is ($n - 1$) and confidence intervals are 95 and 99%.

Perception Analysis

To assess the perceptual wellbeing of the respondents during the COVID-19 lockdown in 2020–2021, the rating scale based on a five-point Likert scale (Likert 1932) has been formulated. Based on their perception of agreement, the rating scale has been structured as Table 42.1.

The perceptual responses have been categorised based on the rating scale, and the percentage of the respondents of each response has been calculated using the following formula,

$$\begin{aligned}&\text{Percentage of respondents of individual responses in each category of respondents}\\&= \frac{\text{Number of respondents of an individual responses in each category}}{\text{Total respondents in each category}} \times 100\end{aligned} \qquad \text{(x)}$$

Table 42.1 Perception analysis (Likert scale)

Scale point	Description
1	Strongly disagree
2	Disagree
3	Neutral/undecided
4	Agree
5	Strongly agree

Source Likert (1932)

Results

Socio-economic Situations of the Respondents During the Lockdown

The participants' observation and municipal database show that COVID cases were less than 10% in Katwa and its surroundings compared to the other areas. The phases of lockdown from 2020 and 2021 hindered the socio-economic upliftment of the municipality from diverse perspectives. The primary field survey reports that 53% of the male and 47% female population were more or less affected by the barrier situation of COVID-19 lockdown. The affected population is mostly Hindu and Muslim in Katwa Municipality and surrounding areas. Out of the total surveyed population, 59% were belonging to the general caste, 16% were Scheduled Castes (SCs) and 25% were Other Backward Classes (OBCs). During COVID 19 the literacy education system collapsed and become online-depended. But most of the poverty-driven students were deprived by this system of the lack of e-resources and proper access to electronic gadgets and the internet. During COVID 19, 0.5% of the total surveyed population were illiterate. The percentage of the working population was 42% engaged in various economic activities. But, unfortunately, the percentage of the non-working population is high (85%) who lost their job due to lockdown situations mainly in informal sectors. The various working population categories were 6% of labour, 11% self-employed, 6% of household industry workers (and shopkeepers or marketers); 2% were engaged in the transport sector, 41% were servicemen, and 23% were businessmen; only 2% workers were engaged in agriculture and allied activities, rest of the working population were engaged in other activities in this municipality area. Most of the residents have an income ranging from rupees 10,000 to 50,000 (60%). 26.67% had their income below rupees 10,000 and 13.33% above rupees 50,000. The overall expenditure and health expenditure were changed during the COVID-19 lockdown. The highest percentage of respondents' households were belonging to the lowest total health expenditure (< rupees 20,000 for 80%, and < rupees 5000 for 73.33%, respectively). The income, expenditure, savings and credit profile have been represented in Figs. 42.22, 42.23, 42.24, 42.25 and 42.26. Most of the working population (60%) were aged between 25 and 50 years including COVID warriors in Katwa. The health conditions of the COVID victims deteriorated during the 2nd and 3rd phases of COVID-19. Health expenditure was below rupees 5000 for 73.33% of respondents' households; rupees 5000–10,000 for 20%, and above rupees 10,000 for 6.67% of respondents' households. Out of the total affected population by the lockdown situation, 32% were belonging to below the poverty level (BPL). There was 25% of the respondents who are above 50 years most vulnerable to health issues during the pandemic. Out of the total affected population by the lockdown situation, 32% were belonging to below the poverty level (BPL). Household conditions of the respondents were kuccha in the case of 5%, pucca (87%) and mixed (8%). The lockdown phases also vulnerably affected the lives and livelihoods of the city-dwellers. Twenty percent of the total respondents changed their occupation during and after lockdown. Twenty-one percent had lost their jobs during the lockdown. Twenty percent of the respondents were engaged in a new job or occupation after lockdown. Salary or wages were reduced, and income had been changed in the case of 35% and 30%, respectively, of the respondents. Health expenditure increased in the case of 85% of the total respondents. There were 10% of migratory labours who lost their job and returned to their native areas in Katwa and surroundings from the other states of India and were quarantined. After initiatives of mass vaccination by the respective governmental authority, cent percent of the total respondents were vaccinated from 2021 to 2022. To sustain their economy, 61% had to get financial or non-financial assistance from others, and 39% of the total respondents helped others during the socio-economic and health-related vulnerable situations during COVID-19 lockdown (Figs. 42.2, 42.3, 42.4, 42.5, 42.6, 42.7, 42.8, 42.9, 42.10 and 42.11).

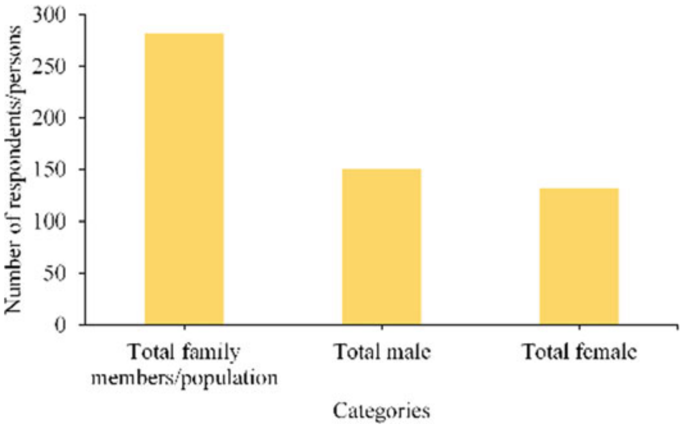


Fig. 42.2 Socio-economic profile-I of the respondents: total surveyed family members, male and female population

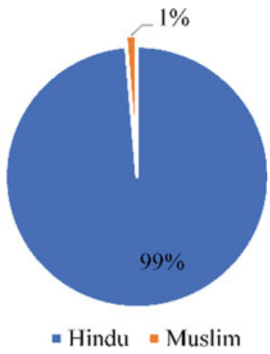


Fig. 42.3 Socio-economic profile-I of the respondents: religious categories of the respondents

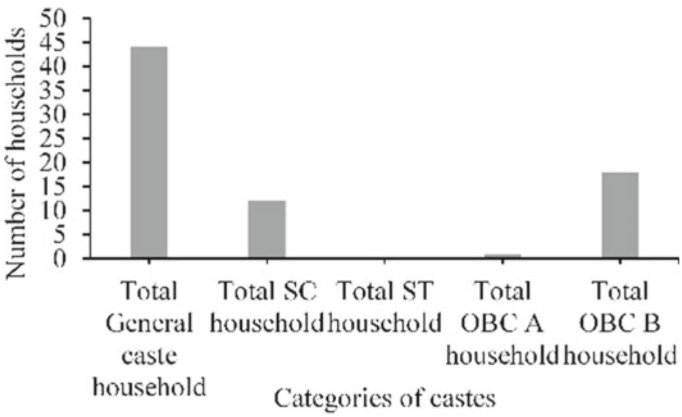


Fig. 42.4 Socio-economic profile-I of the respondents: caste-wise categories of the respondents

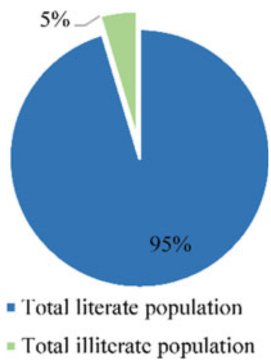


Fig. 42.5 Socio-economic profile-I of the respondents: literacy profile of the respondents

Fig. 42.6 Socio-economic profile-I of the respondents: total workers and non-workers

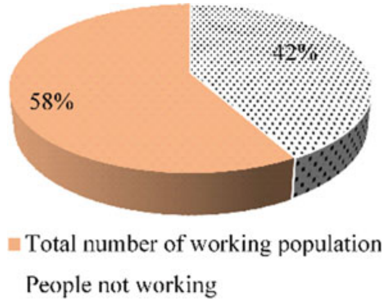


Fig. 42.7 Socio-economic profile-I of the respondents: age profile of the respondents

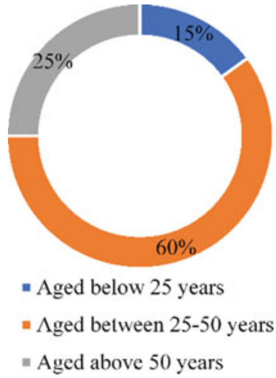
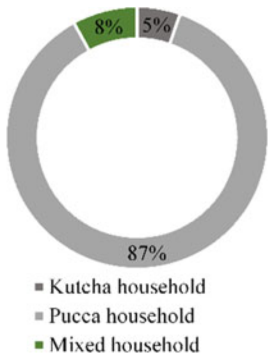


Fig. 42.8 Socio-economic profile-II of the respondents: household conditions of the respondents



Assessment of the Socio-economic Indicators

Various indicators have been selected to access the socio-economic vulnerability of the COVID-19 lockdown situation in Katwa Municipality. Regarding this, a total of 15 indicators based on ward-wise socio-economic indicators have been chosen (S1). S2 shows the descriptive statistics (mean, standard deviation and standard error of

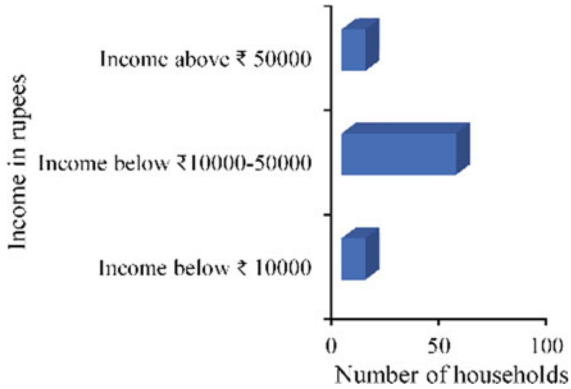


Fig. 42.9 Socio-economic profile-II of the respondents: income situations of the respondents

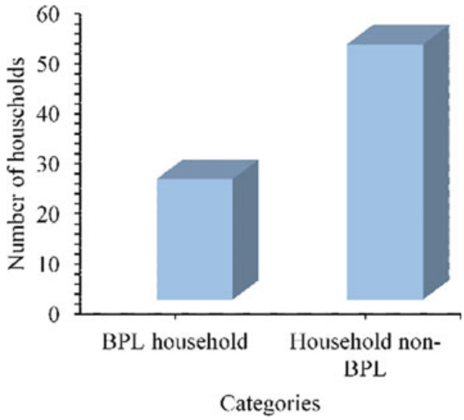


Fig. 42.10 Socio-economic profile-II of the respondents: total BPL and non-BPL households

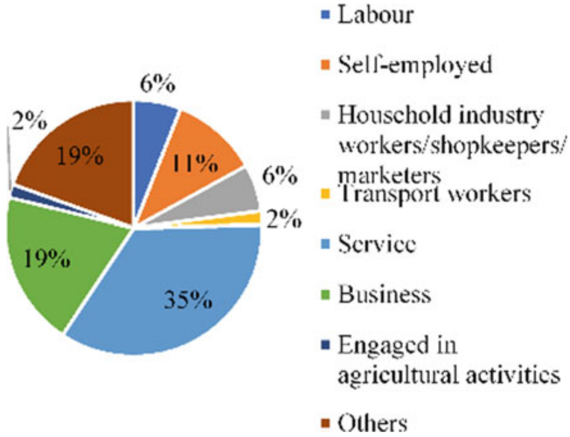


Fig. 42.11 Socio-economic profile-II of the respondents: occupational structure of the respondents

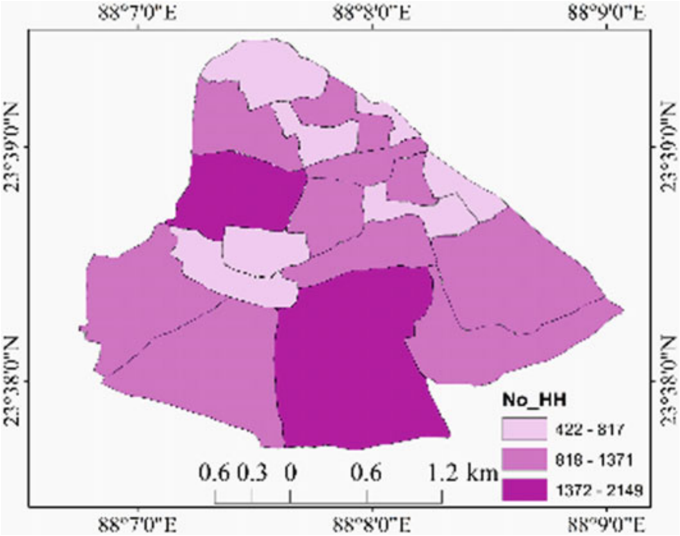


Fig. 42.12 Ward-wise distribution of selected socio-economic status of the respondents: distribution of total numbers of households

mean or SEM) of the selected indicators—a total number of households, male population, female population, population below 0–6 years, SC population, ST population, total literacy rate, the total number of main cultivators, agricultural labourers, household industry workers and other workers and marginal cultivators, agricultural labourers, household industry workers and other workers. The indicator, marginal household industry workers have the lowest difference of standard deviation value from the mean (SEM = 8.07), and the total literacy rate has the highest difference of standard deviation from the mean (SEM = 304.62). The household distribution is high in wards 4 and 12, and the population is also high in those wards including ward number 19. SC and ST populations are also congested in ward number 19. The distribution of households is low in ward numbers 1, 2, 9, 13, 16, 17 and 18. The total population is low in wards 1, 2, 5, 6, 8, 9, 13, 16, 17 and 18. The total literacy rate and total working population are low also in the wards numbers 1, 2, 13, 16 and 18. Figures 42.12, 42.13, 42.14, 42.15, 42.16, 42.17 and 42.18 show the ward-wise distribution of various socio-economic indicators of Katwa Municipality.

Urban Socio-economic Vulnerability Analysis During COVID 19 Lockdown

During COVID 19, urban vulnerability has increased in health and socio-economic conditions of the urban residents. To analyse the urban socio-economic vulnerability, 15 indicators have been composited with extracting the three factors (or components, Table 42.2). The 1st component, the 2nd component and the 3rd component explain

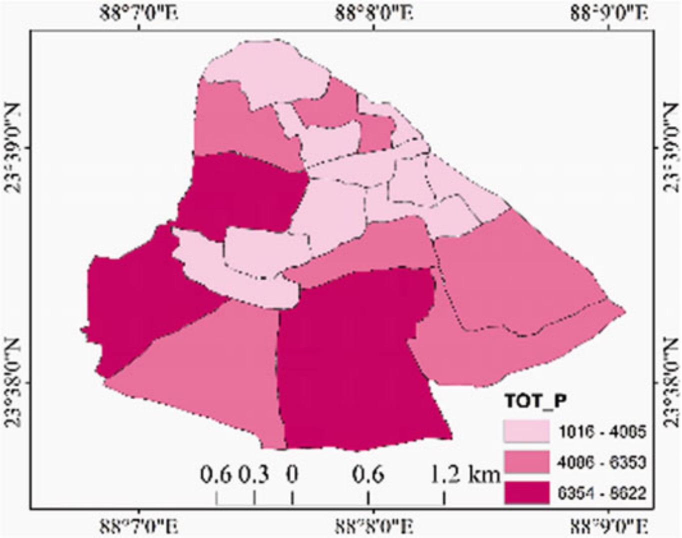


Fig. 42.13 Ward-wise distribution of selected socio-economic status of the respondents: distribution of total population

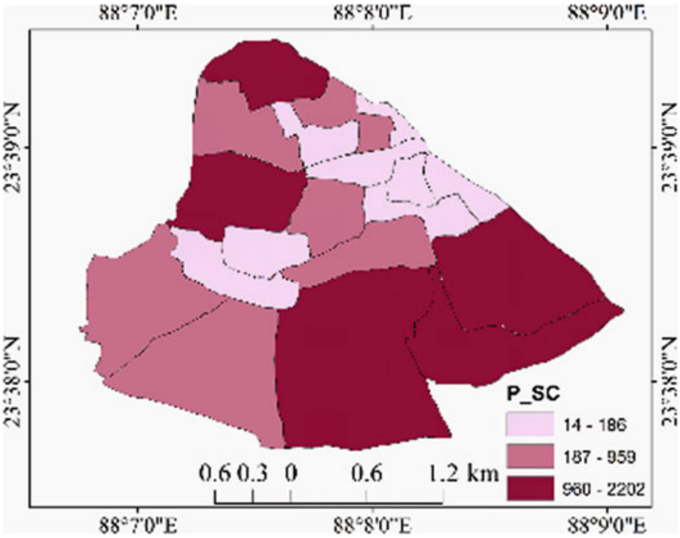


Fig. 42.14 Ward-wise distribution of selected socio-economic status of the respondents: distribution of SC population

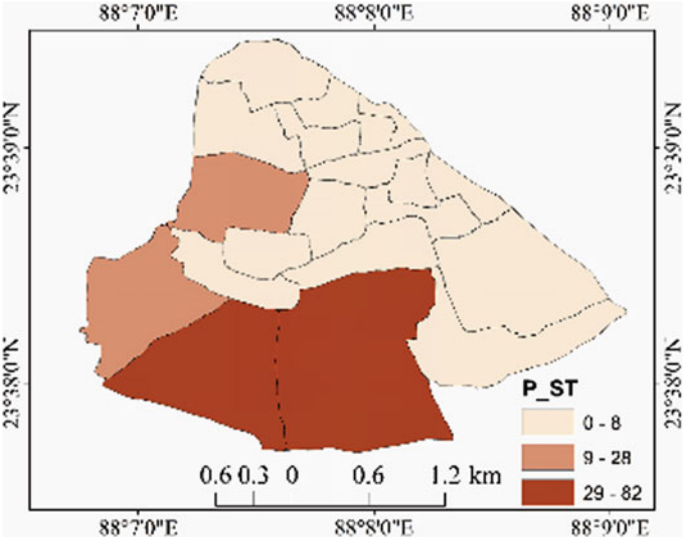


Fig. 42.15 Ward-wise distribution of selected socio-economic status of the respondents: distribution of ST population

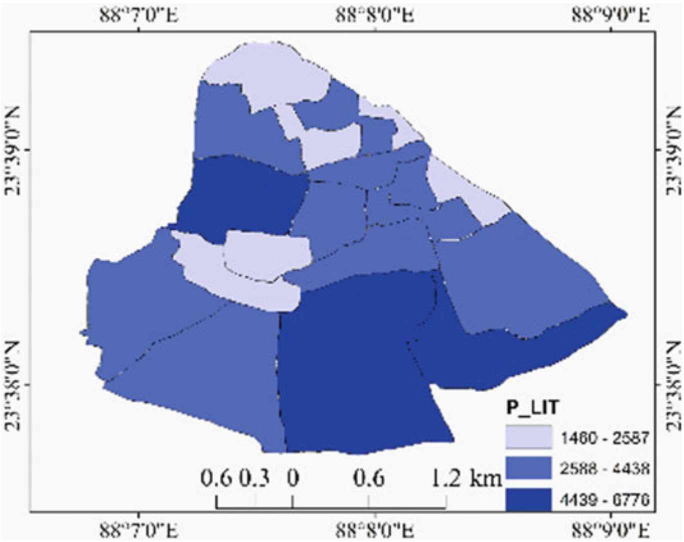


Fig. 42.16 Ward-wise distribution of selected socio-economic status of the respondents: distribution of total literacy rate

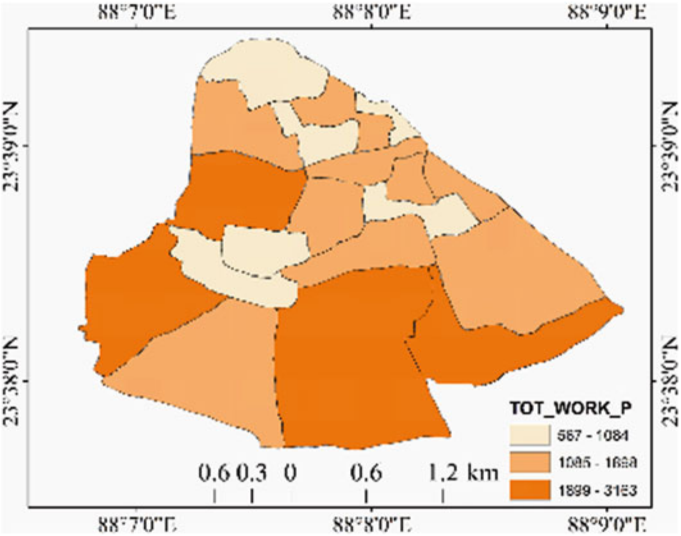


Fig. 42.17 Ward-wise distribution of selected socio-economic status of the respondents: distribution of total workers

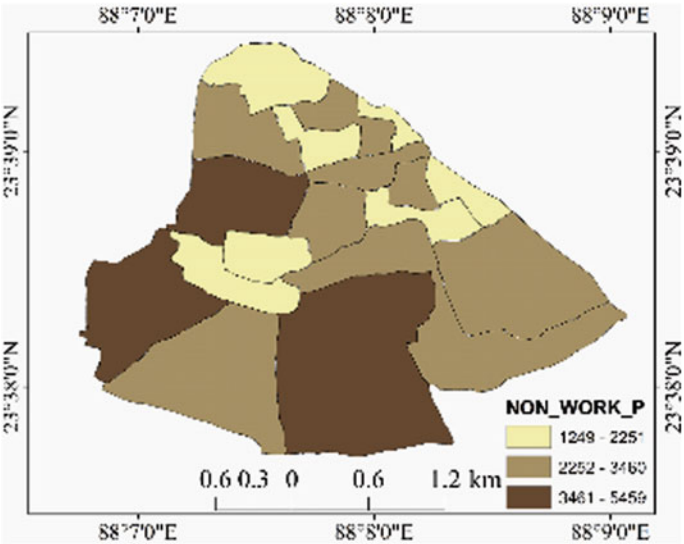


Fig. 42.18 Ward-wise distribution of selected socio-economic status of the respondents: distribution of non-workers

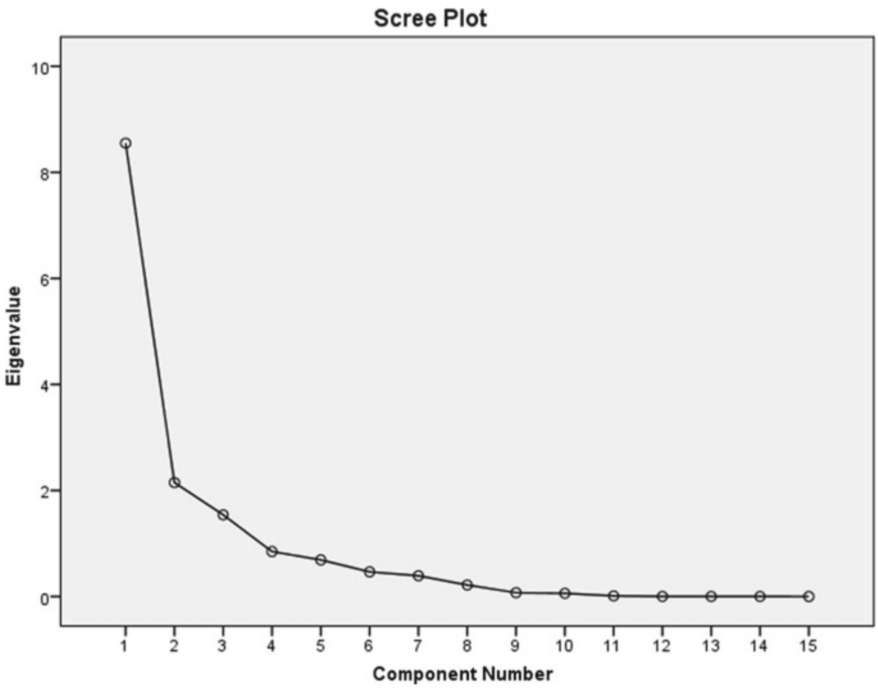


Fig. 42.19 Scree plot of factor analysis

all the indicators 48.172%, 69.288% and 81.597% cumulatively. Based on the mean composite indicators, the socio-economic vulnerability index zones have been represented in Fig. 42.21. A very low vulnerability index (−0.69 to −0.58) has been found in wards 6, 8 and 17; a low vulnerability index (−0.57 to −0.39) has been found in the wards 1, 13, 16 and 18; moderate vulnerability index (−0.38 to −0.0047) has been found in the wards 5, 7, 9, 14 and 15; high vulnerability index (−0.006 to 0.41) has been found in the wards 3, 4 and 10, and very high vulnerability index (0.42–1.0) has been found in the wards 2, 11, 12 and 19. The wards 4, 12 and 19 consist a large population, and wards 4 and 12 consist a large number of households that had a very high socio-economic vulnerability during the lockdown period. Besides, the wards 6 and 18 consist a low population and a low to a moderate number of households that had very low vulnerability during the lockdown period.

Impact of the Indicators on Socio-economic Vulnerability

The selected indicators have marginal effects on the constructed socio-economic vulnerability of the COVID 19 lockdown in Katwa Municipality. S3 represents the correlation among the selected indicators. A very high and significant correlation

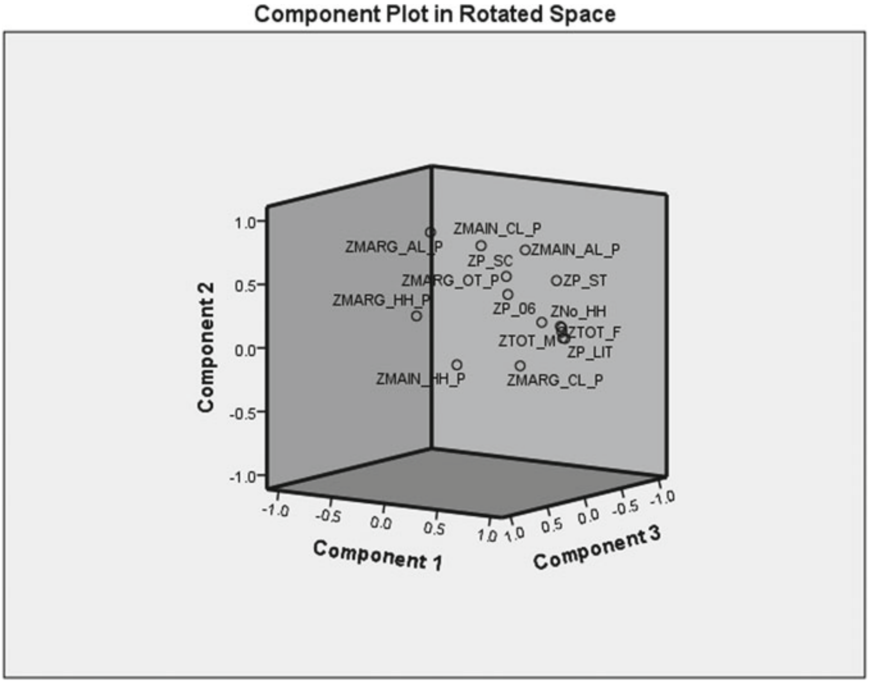


Fig. 42.20 Component plot of factor analysis

($r < 0.90$, $p < 0.01$, $p < 0.005$) value has been found in the case of the indicators-total household and total male, total female population, total literacy, main other workers; total male population, total household, total child population (0–6 years), total literate population; total female population and total household, total male population, total literate population; total child population and total male population; total literate persons and total household, total male population, total female population, main other workers; main other workers and the total number of household, total male population, total female population, total literate population. Unstandardised coefficient values have been extracted in the marginal effect analysis (dy/dx) of the multiple linear regression model (S4). A total of 14 indicators have predicted the mean composite socio-economic vulnerability index (mean composite factor score). In this analysis, the correlation coefficient value is 0.999 (significant at 0.0001 significant level). The Durbin–Watson statistic shows that there is no collinearity among the 14 predictors (DW statistic = 2.013). The variable total child population (0–6 years) has been excluded in the partial correlation method because collinearity exists with this variable. The partial correlation value is -1.00 ($p < 0.0001$). S4 shows that the significant predictors are total literacy rate, main agricultural labourers, marginal cultivators, marginal agricultural labourers and marginal other workers. The highest marginal effect has been identified in the case of marginal other workers as 1 unit increase of marginal other workers increase 1412.40 unit of the dependent variable

Table 42.2 Extracted factor scores of PCA and mean composite scores of vulnerability index

Wards	Factor-1 (FAC1)	Factor-2 (FAC2)	Factor-3 (FAC3)	Composite factor scores	Mean composite factor scores
1	−0.96	−0.52	−0.28	−1.76	−0.59
2	−1.69	2.59	1.28	2.19	0.73
3	−0.62	1.46	−0.33	0.52	0.17
4	1.43	−0.54	0.24	1.12	0.37
5	0.14	−0.99	0.05	−0.79	−0.26
6	−0.27	−0.69	−0.45	−1.42	−0.47
7	0.63	−0.29	−0.35	−0.01	0.00
8	−0.06	−0.72	−0.39	−1.17	−0.39
9	−0.37	−0.61	0.41	−0.57	−0.19
10	0.41	−0.27	1.10	1.24	0.41
11	0.52	−0.34	2.84	3.02	1.01
12	2.27	1.72	−0.95	3.04	1.01
13	−1.47	0.19	−0.48	−1.76	−0.59
14	0.47	0.82	−1.93	−0.64	−0.21
15	0.27	−0.76	0.15	−0.34	−0.11
16	−0.79	−0.44	−0.51	−1.75	−0.58
17	−0.21	−0.85	−0.43	−1.49	−0.50
18	−0.95	−0.49	−0.65	−2.08	−0.69
19	1.25	0.73	0.68	2.66	0.89

Source Authors' Calculation

(significant, $p < 0.1$). Besides, the lowest marginal impact has been identified in the case of the indicator total Scheduled Tribe population. 1 unit increase of ST population increases 7% of the predicted variable (not significant, $p > 0.1$). Figures 42.27, 42.28, 42.29 and 42.30 represent the relationship between the dependent variables and regression standardised predicted values, spatial variation of the regression standardised predicted values, the relationship between the dependent variables and regression standardised residuals and spatial variation of the regression standardised residuals regarding the analysis in the study area. The prediction is that the highly vulnerable areas of Katwa Municipality are more or less the same as the zonation of the socio-economic vulnerability index of COVID-19 lockdown.

Respondents' Perception of the Impact of Lockdown

The respondents responded with their perception of the impact of the lockdown in Katwa Municipality and its surroundings. Based on the 5-point ratings of the Likert scale in the structured questionnaire, their responses on the degree of agreement

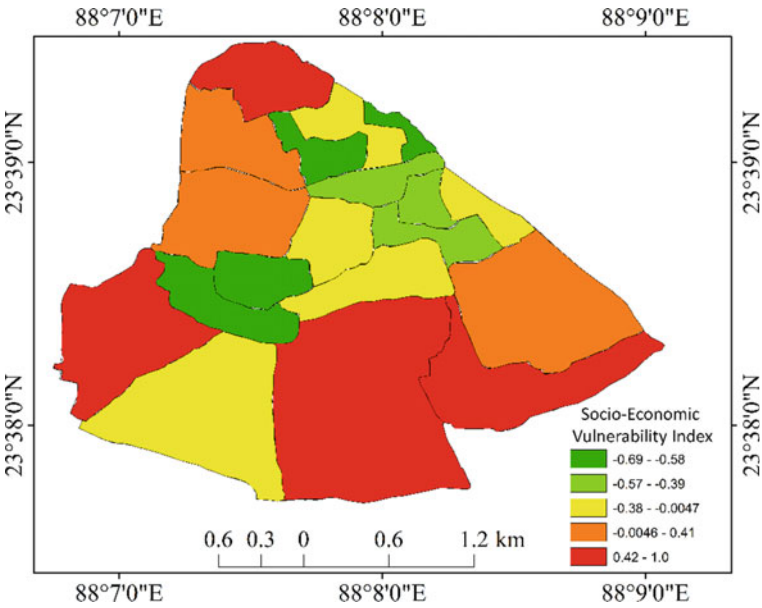


Fig. 42.21 Socio-economic vulnerability index in Katwa Municipality

Fig. 42.22 Respondents' categorisation based on economic conditions during lockdown: percentage of respondents according to income ranges

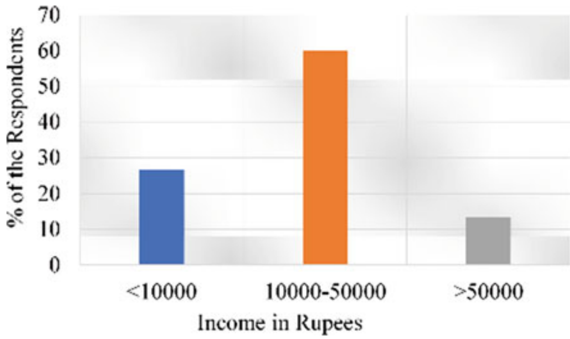
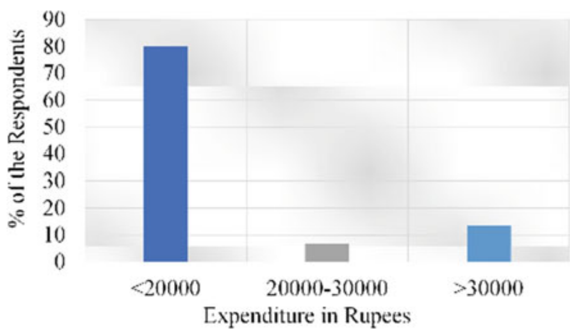


Fig. 42.23 Respondents' categorisation based on economic conditions during lockdown: percentage of respondents according to expenditure ranges



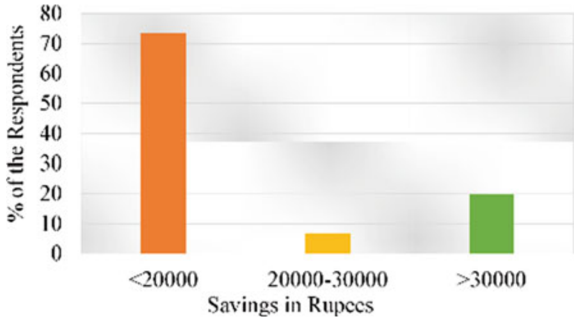


Fig. 42.24 Respondents' categorisation based on economic conditions during lockdown: percentage of respondents according to savings ranges

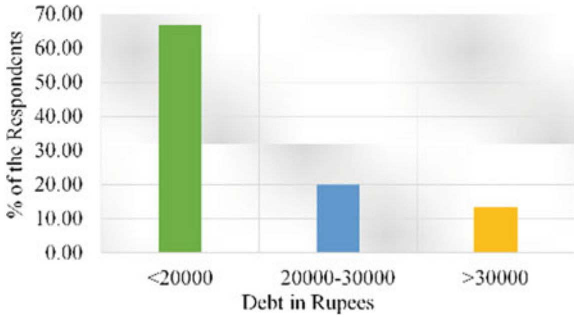


Fig. 42.25 Respondents' categorisation based on economic conditions during lockdown: percentage of respondents according to debt ranges

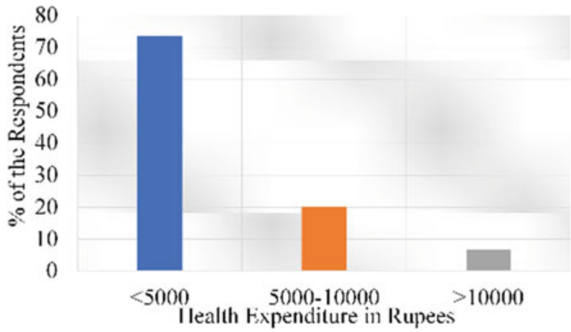


Fig. 42.26 Respondents' categorisation based on economic conditions during lockdown: percentage of respondents according to health expenditure ranges

have been recorded. Table 42.3 shows the respondents' perceptions of COVID-19 lockdown situations. In this analysis, 53.33% of respondents strongly agree with the statement that lockdown had the worst impact on families' economy. About 53.33% of the respondents strongly agree with the statement that they were conscious of the impact of lockdown on families' economy. Forty percent of the respondents agree with the statement that household expenditure was reduced during the lockdown. 33.33% of the respondents strongly disagree with the statement that they had wanted to engage in a new occupation after lockdown. About 33.33% of the respondents strongly disagree with the statement that they want to return to the previous

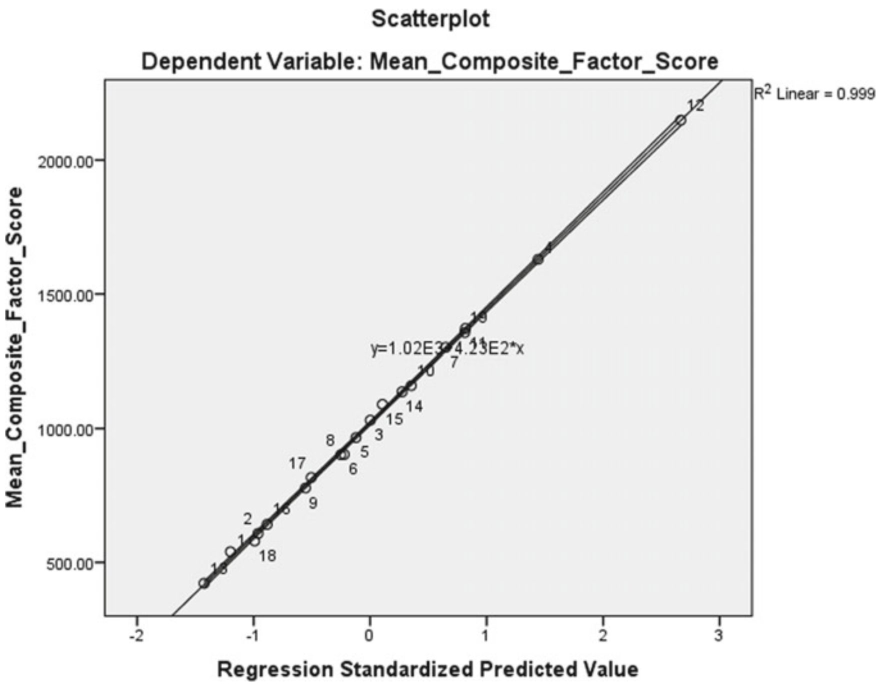


Fig. 42.27 Relationship between the dependent variable and ZPR

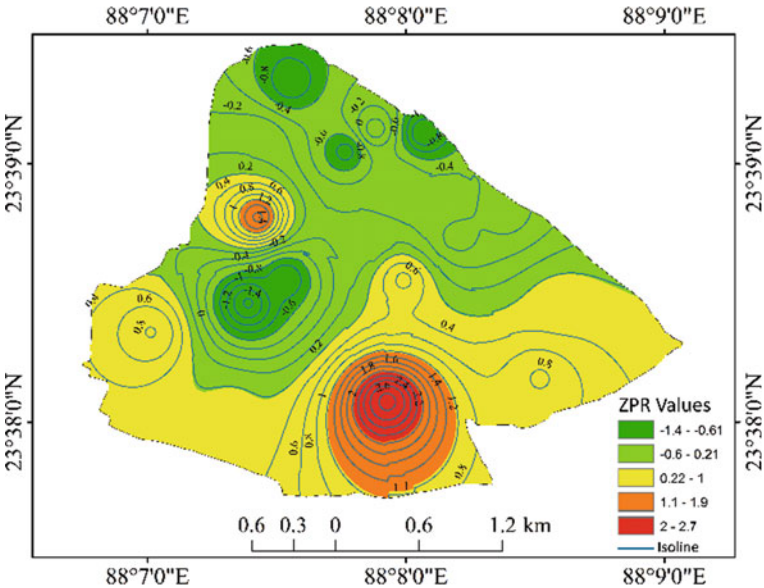


Fig. 42.28 Distribution of regression standardised predicted values

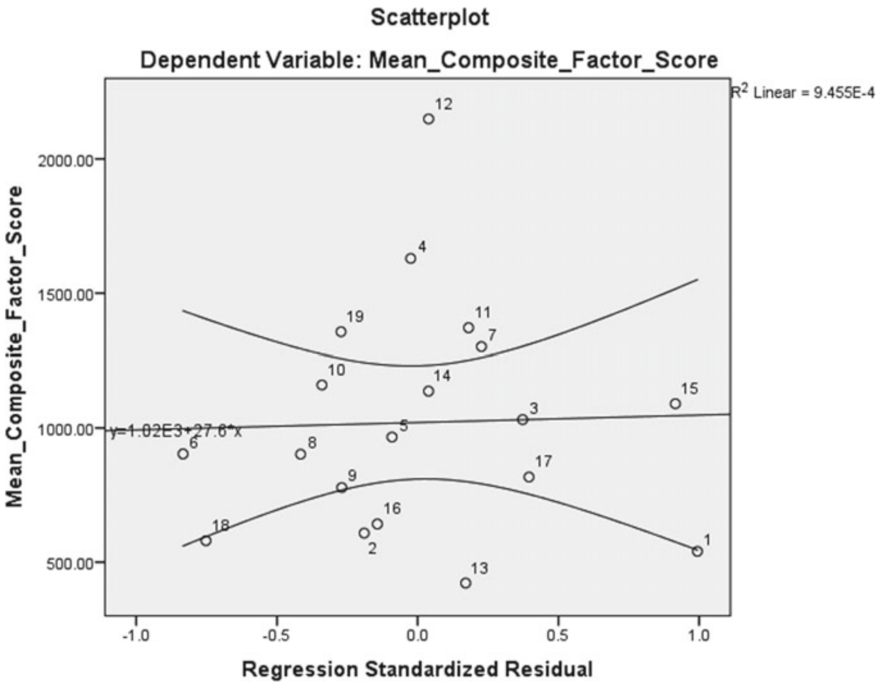


Fig. 42.29 Relationship between the dependent variable and ZRE

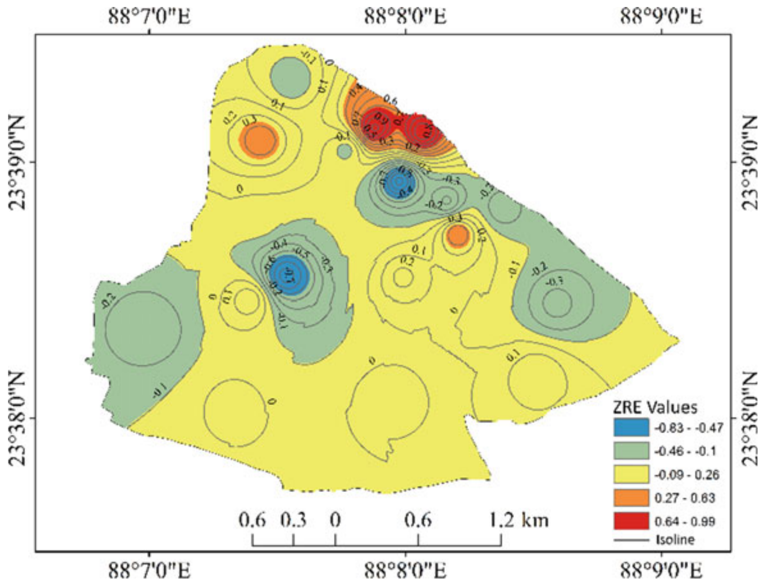


Fig. 42.30 Distribution of regression standardised residuals

occupation that they had lost. About 53.33% of the respondents strongly agree with the statement that lockdown had the worst impact on education. About 60% of the respondents strongly agree with the statement that lockdown had the worst impact on health.

Discussion and Policy Suggestions

Based on the analysis of data and respondents' perceptions, it is identified that the severity of COVID-19 and the influence of lockdown depended on the socio-economic conditions of the residents of Katwa Municipality area. A large number of residents were engaged in activities other than agriculture. They were engaged with either household industry sectors or the transport sector. Moreover, the residents were engaged with services and businesses. A mentionable number of residents are daily wage labour in Katwa Municipality. During the COVID-19 lockdown in 2020–2021, the migratory labours returned to Katwa, their hometown from the other states of India. They had either lost their jobs or their salary or wages had been reduced. A significant number of respondents among the total surveyed population disclosed that they don't want to return to their previous job. For the respondents who were still employed their income had been reduced during the lockdown. They also respond that they want to stay within the active job or occupation by reducing their expenditure on household consumption, repairing or leisure. During COVID-19, no significant amount of income had been increased for the labour class residents of Katwa Municipality. Persons engaged with services still could sustain their economic conditions, but the profits in business and agricultural activities were significantly reduced during the lockdown in 2020–2021. To sustain the economic conditions of their household debts or credits had been taken by the respondents with income below rupees 10,000. As the health expenditure increased, the total household expenditure also increased which created a disbalance of the income, expenditure, savings and debt pattern of the respondents in Katwa. The ward-wise scenarios of socio-economic vulnerability show that highly populated and settlement congested areas are more vulnerable than the others and vice versa. In this case, population increases due to returning of migratory labours, and the preliminary unconsciousness of common people in the market areas extensively influenced the socio-economic and health vulnerability of COVID-19 and associated lockdown. The wards of the municipal area were socio-economically vulnerable with varying degrees from very high to high, moderate and low to very low. The wards adjoined with the surrounding areas were more vulnerable than the wards situated in the central portion of this municipality. Besides, some of the wards with high SC and ST populations were more vulnerable. The respondents, socio-economically deprived and driven by poverty were more vulnerable than the others. There was no deviation of the total main cultivators, low deviation of main agricultural labourers and main household industry workers, and high deviation in the case of main other workers in this Municipality. In the case of the marginal work-force population, all four categories have low deviations. The main workers who had

Table 42.3 Respondents' perceptions of COVID 19 lockdown situations

Perception	No. of respondents	Percentage value
1. Lockdown had the worst impact on families' economies		
Strongly agree	40	53.33
Agree	15	20.00
Neutral/undecided	10	13.33
Disagree	10	13.33
Strongly disagree	0	0.00
2. Conscious about the impact of lockdown on families' economy		
Strongly agree	40	53.33
Agree	30	40.00
Neutral/undecided	0	0.00
Disagree	5	6.67
Strongly disagree	0	0.00
3. Household expenditure was reduced		
Strongly agree	0	0.00
Agree	30	40.00
Neutral/undecided	20	26.67
Disagree	15	20.00
Strongly disagree	10	13.33
4. Want to engage in a new occupation		
Strongly agree	15	20.00
Agree	0	0.00
Neutral/undecided	15	20.00
Disagree	20	26.67
Strongly disagree	25	33.33
5. Want to return to the previous occupation		
Strongly agree	5	6.67
Agree	15	20.00
Neutral/undecided	10	13.33
Disagree	20	26.67
Strongly disagree	25	33.33
6. Lockdown had the worst impact on education?		
Strongly agree	40	53.33
Agree	30	40.00
Neutral/undecided	0	0.00
Disagree	0	0.00
Strongly disagree	5	6.67

(continued)

Table 42.3 (continued)

Perception	No. of respondents	Percentage value
7. Lockdown had the worst impact on health		
Strongly agree	45	60.00
Agree	10	13.33
Neutral/undecided	0	0.00
Disagree	20	26.67
Strongly disagree	0	0.00

Source Authors' Calculation based on primary field survey, 2021

lost their occupation have highly deviated in number. The high and significant value of correlation between the mean composite factor scores of the socio-economic vulnerability index and its predictors shows that socio-economic conditions were strongly dependent on the vulnerability during the lockdown. The increase in the number of marginal other workers highly influenced the increase of vulnerability because of the addition of more people in socio-economic activities. The respondents of Katwa Municipality highly agreed that lockdown had the worst impact on the economy, education and health of the members of their family or household. They were also conscious of that and wanted to reduce household expenditure to sustain their financial conditions. To eradicate the socio-economic vulnerability, the study suggests some measures with personal experience and participants' observation during 2020–2021, such as,

1. Eradication of poverty with the generation of occupational facilities and scope of diversification of occupation of the marginalised people in Katwa Municipality.
2. Continuation of the previously commenced National Urban Health Mission and Universalised COVID vaccination scheme (at present booster dose).
3. Ward-wise distribution of population to decrease the risk and vulnerability of congestion of households as like the ward number 12 has been divided into two separate wards—ward number 12 and 20.
4. The education system needs to be started in a blended mode with proper access to all students and teachers with restrictions and maintenance of COVID protocols.
5. Socio-economic public activities in the city are also being started with prolonged COVID guidelines.
6. Public consciousness and active assistance with COVID warriors need to be preferred with helping underprivileged people by public and private initiatives in Katwa Municipality.

Conclusion

The present study has highlighted the socio-economic situation of the residents of Katwa Municipality during the COVID-19 lockdown period in 2020–2021 using the datasets of secondary and primary field surveys. The urban residents are mainly dependent on multiple economic activities varying from agriculture to service. Most of the people were engaged in other activities than cultivators, agricultural labourers and household industry workers. In this context, the lockdown situation had heterogeneously impacted the respondents of Katwa city. As the data shows that a significant number of working populations lost their job during the lockdown, about 13.33% of workers had migrated from other states to Katwa and its surroundings during the lockdown. Income had been changed also in case of a significant number of the occupants. The composition of the selected indicators shows that wards number 2, 11, 12 and 19 were very highly vulnerable in the context of the socio-economic conditions of the residents of the Katwa Municipality. Most of the wards with congested households and high population show a very high to high and moderate socio-economic vulnerability during COVID-19 lockdown. The indicators—total literacy rate, main agricultural labourers, marginal cultivators, marginal agricultural labourers and marginal other workers—significantly predicted the extracted factor scores. Marginal other workers show the highest marginal effect on the predicted variable that increase of marginal other workers including daily labour and migratory labours had increased the vulnerability in case of their deprived socio-economic conditions during the lockdown situation. To sustain the overall socio-economic development of Katwa Municipality, integrated urban-regional developmental planning needs to be implemented.

Acknowledgements We acknowledge the students of Semester-V (General) of the Department of Geography of Katwa College, Katwa, Purba Bardhaman in West Bengal to actively participate in the primary survey of the present study.

Supplementary Materials

S1. Socio-economic Indicators

Socio-economic variables	Census code
Total number of household	No_HH
Total population	TOT_P
Total male population	TOT_M
Total female population	TOT_F
Child population (0–6 years)	P_06
Male child population (0–6 Years)	M_06
Female child population (0–6 Years)	F_06
Scheduled caste population	P_SC
Scheduled tribe population	P_ST

(continued)

(continued)

Socio-economic variables	Census code
Total literacy rate	P_LIT
Male literacy rate	M_LIT
Female literacy rate	F_LIT
Total workers	TOT_WORK_P
Total male workers	TOT_WORK_M
Total female workers	TOT_WORK_F
Main workers	MAINWORK_P
Main cultivators	MAIN_CL_P
Main agricultural labourers	MAIN_AL_P
Main household industry workers	MAIN_HH_P
Main other workers	MAIN_OT_P
Marginal workers	MARGWORK_P
Marginal cultivators	MARG_CL_P
Marginal agricultural labourers	MARG_AL_P
Marginal household industry workers	MARG_HH_P
Marginal other workers	MARG_OT_P
Non-workers	NON_WORK_P
Non-workers (male)	NON_WORK_M
Non-workers (female)	NON_WORK_F

Source Census of India (2011)

S2. Descriptive Statistics of the Selected Indicators

Indicators	Mean		Std. deviation
	Statistic	Std. error	Statistic
No_HH	1020.11	97.08	423.18
TOT_P	4295.53	407.45	1776.02
TOT_M	2176.32	209.08	911.36
TOT_F	2119.21	198.71	866.14
P_06	357.84	43.78	190.81
M_06	184.16	21.96	95.72
F_06	173.68	22.05	96.12
P_SC	641.53	139.72	609.01
P_ST	11.00	4.91	21.42

(continued)

(continued)

Indicators	Mean		Std. deviation
	Statistic	Std. error	Statistic
P_LIT	3430.89	304.62	1327.82
M_LIT	1797.84	163.19	711.32
F_LIT	1633.05	142.46	620.98
TOT_WORK_P	1511.47	153.19	667.76
TOT_WORK_M	1248.74	119.85	522.43
TOT_WORK_F	262.74	36.66	159.80
MAINWORK_P	1330.68	132.26	576.52
MAIN_CL_P	9.32	2.14	9.32
MAIN_AL_P	18.89	6.45	28.11
MAIN_HH_P	55.68	11.90	51.87
MAIN_OT_P	1246.79	122.52	534.07
MARGWORK_P	180.79	30.12	131.29
MARG_CL_P	5.47	1.12	4.88
MARG_AL_P	10.47	3.38	14.72
MARG_HH_P	23.63	8.07	35.17
MARG_OT_P	141.21	22.52	98.16
NON_WORK_P	2784.05	256.85	1119.59
NON_WORK_M	927.58	91.18	397.46
NON_WORK_F	1856.47	166.83	727.20
Valid N (listwise) = 19			

Source Authors' Calculation

S3. Correlation Matrix of the Selected Indicators

Correlations

		No_HH	TOT_M	TOT_F	P_06	P_SC	P_ST	P_LIT	MAIN_CL_P
No_HH	Pearson correlation	1	0.980**	0.982**	0.803**	0.769**	0.504*	0.985**	0.295
	Sig. (2-tailed)		0.000	0.000	0.000	0.000	0.028	0.000	0.221
TOT_M	Pearson correlation	0.980**	1	0.997**	0.900**	0.739**	0.534*	0.949**	0.359
	Sig. (2-tailed)	0.000		0.000	0.000	0.000	0.019	0.000	0.131
TOT_F	Pearson correlation	0.982**	0.997**	1	0.890**	0.724**	0.498*	0.953**	0.329
	Sig. (2-tailed)	0.000	0.000		0.000	0.000	0.030	0.000	0.168
P_06	Pearson correlation	0.803**	0.900**	0.890**	1	0.623**	0.493*	0.723**	0.462*
	Sig. (2-tailed)	0.000	0.000	0.000		0.004	0.032	0.000	0.047
P_SC	Pearson correlation	0.769**	0.739**	0.724**	0.623**	1	0.403	0.701**	0.466*
	Sig. (2-tailed)	0.000	0.000	0.000	0.004		0.087	0.001	0.044
P_ST	Pearson correlation	0.504*	0.534*	0.498*	0.493*	0.403	1	0.485*	0.365
	Sig. (2-tailed)	0.028	0.019	0.030	0.032	0.087		0.035	0.125
P_LIT	Pearson correlation	0.985**	0.949**	0.953**	0.723**	0.701**	0.485*	1	0.203
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.001	0.035		0.404
MAIN_CL_P	Pearson correlation	0.295	0.359	0.329	0.462*	0.466*	0.365	0.203	1
	Sig. (2-tailed)	0.221	0.131	0.168	0.047	0.044	0.125	0.404	
MAIN_AL_P	Pearson correlation	0.629**	0.613**	0.589**	0.552*	0.804**	0.591**	0.548*	0.590**
	Sig. (2-tailed)	0.004	0.005	0.008	0.014	0.000	0.008	0.015	0.008
MAIN_HH_P	Pearson correlation	0.384	0.444	0.439	0.562*	0.445	-0.054	0.331	0.154
	Sig. (2-tailed)	0.105	0.057	0.060	0.012	0.056	0.825	0.166	0.529
MAIN_OT_P	Pearson correlation	0.981**	0.986**	0.991**	0.857**	0.678**	0.481*	0.964**	0.255

(continued)

(continued)

Correlations

		No_HH	TOT_M	TOT_F	P_06	P_SC	P_ST	P_LIT	MAIN_CL_P
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.001	0.037	0.000	0.291
MARG_CL_P	Pearson correlation	0.538*	0.556*	0.581**	0.511*	0.420	0.084	0.506*	0.111
	Sig. (2-tailed)	0.018	0.013	0.009	0.025	0.074	0.733	0.027	0.650
MARG_AL_P	Pearson correlation	0.046	0.057	0.025	0.099	0.541*	0.109	-0.033	0.584**
	Sig. (2-tailed)	0.853	0.816	0.920	0.686	0.017	0.656	0.893	0.009
MARG_HH_P	Pearson correlation	0.261	0.278	0.243	0.260	0.502*	-0.067	0.256	0.240
	Sig. (2-tailed)	0.281	0.249	0.315	0.282	0.028	0.784	0.289	0.322
MARG_OT_P	Pearson correlation	0.748**	0.786**	0.773**	0.782**	0.858**	0.432	0.681**	0.422
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000	0.064	0.001	0.072

Correlations

		MAIN_AL_P	MAIN_HH_P	MAIN_OT_P	MARG_CL_P	MARG_AL_P	MARG_HH_P	MARG_OT_P
No_HH	Pearson correlation	0.629**	0.384	0.981**	0.538*	0.046	0.261	0.748**
	Sig. (2-tailed)	0.004	0.105	0.000	0.018	0.853	0.281	0.000
TOT_M	Pearson correlation	0.613**	0.444	0.986**	0.556*	0.057	0.278	0.786**
	Sig. (2-tailed)	0.005	0.057	0.000	0.013	0.816	0.249	0.000
TOT_F	Pearson correlation	0.589**	0.439	0.991**	0.581**	0.025	0.243	0.773**
	Sig. (2-tailed)	0.008	0.060	0.000	0.009	0.920	0.315	0.000
P_06	Pearson correlation	0.552*	0.562*	0.857**	0.511*	0.099	0.260	0.782**
	Sig. (2-tailed)	0.014	0.012	0.000	0.025	0.686	0.282	0.000
P_SC	Pearson correlation	0.804**	0.445	0.678**	0.420	0.541*	0.502*	0.858**
	Sig. (2-tailed)	0.000	0.056	0.001	0.074	0.017	0.028	0.000
P_ST	Pearson correlation	0.591**	-0.054	0.481*	0.084	0.109	-0.067	0.432
	Sig. (2-tailed)	0.008	0.825	0.037	0.733	0.656	0.784	0.064
P_LIT	Pearson correlation	0.548*	0.331	0.964**	0.506*	-0.033	0.256	0.681**
	Sig. (2-tailed)	0.015	0.166	0.000	0.027	0.893	0.289	0.001
MAIN_CL_P	Pearson correlation	0.590**	0.154	0.255	0.111	0.584**	0.240	0.422
	Sig. (2-tailed)	0.008	0.529	0.291	0.650	0.009	0.322	0.072
MAIN_AL_P	Pearson correlation	1	0.215	0.573*	0.104	0.506*	0.156	0.576**
	Sig. (2-tailed)		0.376	0.010	0.670	0.027	0.524	0.010
MAIN_HH_P	Pearson correlation	0.215	1	0.411	0.237	-0.069	0.515*	0.441
	Sig. (2-tailed)	0.376		0.081	0.329	0.780	0.024	0.059
MAIN_OT_P	Pearson correlation	0.573*	0.411	1	0.532*	-0.032	0.212	0.712**

(continued)

(continued)

Correlations

		MAIN_AL_P	MAIN_HH_P	MAIN_OT_P	MARG_CL_P	MARG_AL_P	MARG_HH_P	MARG_OT_P
	Sig. (2-tailed)	0.010	0.081		0.019	0.897	0.383	0.001
MARG_CL_P	Pearson correlation	0.104	0.237	0.532*	1	-0.006	0.011	0.523*
	Sig. (2-tailed)	0.670	0.329	0.019		0.979	0.964	0.022
MARG_AL_P	Pearson correlation	0.506*	-0.069	-0.032	-0.006	1	0.412	0.453
	Sig. (2-tailed)	0.027	0.780	0.897	0.979		0.080	0.052
MARG_HH_P	Pearson correlation	0.156	0.515*	0.212	0.011	0.412	1	0.563*
	Sig. (2-tailed)	0.524	0.024	0.383	0.964	0.080		0.012
MARG_OT_P	Pearson correlation	0.576**	0.441	0.712**	0.523*	0.453	0.563*	1
	Sig. (2-tailed)	0.010	0.059	0.001	0.022	0.052	0.012	

*Correlation is significant at the 0.05 level (2-tailed)
**Correlation is significant at the 0.01 level (2-tailed)
Source Authors' Calculation

S4. Regression Coefficients

Coefficients[a]							
Model		Unstandardised coefficients		*t*	Sig.	95.0% confidence interval for B	
		B	Std. error			Lower bound	Upper bound
1	(Constant)	1456.57	602.45	2.42	0.07	−216.10	3129.25
	No_HH	−0.09	0.36	−0.25	0.81	−1.08	0.90
	TOT_M	0.12	0.24	0.52	0.63	−0.54	0.79
	TOT_F	−0.28	0.58	−0.48	0.66	−1.89	1.34
	P_SC	2.83	1.64	1.73	0.16	−1.71	7.37
	P_ST	0.07	0.10	0.70	0.52	−0.21	0.35
	P_LIT	−8.06	3.67	−2.19	0.09*	−18.25	2.14
	MAIN_CL_P	−2.89	1.82	−1.59	0.19	−7.93	2.16
	MAIN_AL_P	−3.52	1.54	−2.28	0.09*	−7.80	0.77
	MAIN_HH_P	0.16	0.24	0.67	0.54	−0.51	0.84
	MAIN_OT_P	−6.93	3.44	−2.02	0.11	−16.48	2.62
	MARG_CL_P	−11.72	4.65	−2.52	0.07*	−24.62	1.19
	MARG_AL_P	−5.95	2.41	−2.47	0.07*	−12.63	0.73
	MARG_HH_P	−1.79	0.93	−1.92	0.13	−4.36	0.79
	MARG_OT_P	1412.40	582.76	2.42	0.07*	−205.60	3030.40

[a]Dependent variable: Mean_Composite_Factor_Score
R square: 0.999
$F > 0.0001$
Durbin–Watson Statistic: 2.013
*$P < 0.1$

Excluded variables[a]								
Model		Beta In	*t*	Sig.	Partial correlation	Collinearity statistics		
						Tolerance	VIF	Minimum tolerance
1	P_06	−3.703[b]	−3099.913	0.000	−1.000	6.896E−5	14,500.416	2.270E−6

[a]Dependent variable: Mean_Composite_Factor_Score
[b]Predictors in the model: (Constant), MARG_OT_P, P_SC, MAIN_OT_P, MARG_CL_P, P_LIT, MAIN_CL_P, MAIN_AL_P, TOT_F, P_ST, MARG_AL_P, MARG_HH_P, MAIN_HH_P, TOT_M, No_HH
Source Authors' Calculation

References

Allain-Dupré D, Chatry I, Michalun V, Moisio A (2020) The territorial impact of COVID-19: managing the crisis across levels of government. In: OECD Policy Responses to Coronavirus (COVID-19), vol 10, pp 1–94. 1620846020-909698535

Aneja R, Ahuja V (2021) An assessment of socioeconomic impact of COVID-19 pandemic in India. J Public Aff 21(2):1–7. https://doi.org/10.1002/pa.2266

Bhattacharya M, Banerjee P (2021) COVID-19: indices of economic and health vulnerability for the Indian states. Soc Sci Humanities Open 4(1):1–6. https://doi.org/10.1016/j.ssaho.2021.100157

Carlin JB, Doyle LW (2000) 3: basic concepts of statistical reasoning: standard errors and confidence intervals. J Paediatr Child Health 36(5):502–505. https://doi.org/10.1046/j.1440-1754.2000.00588.x

Census of India (2001) District Census Handbook Barddhaman, Village and Town Wise Primary Census Abstract (PCA). Directorate of Census Operations, West Bengal, Series-20, Part-A and B

Census of India (2011) District Census Handbook Barddhaman, Village and Town Wise Primary Census Abstract (PCA). Directorate of Census Operations, West Bengal, Series-20, Part XII-B, 1-464

Chaudhary M, Sodani PR, Das S (2020) Effect of COVID-19 on economy in India: some reflections for policy and programme. J Health Manag 22(2):169–180. https://doi.org/10.1177/0972063420935541

Choudhury T, Souman Samanta PKP, Maiti A (2022) Impact of COVID-19 pandemic on households in West Bengal: a study in Hooghly District. Sch J Arts Humanit Soc Sci 1:24–31. https://doi.org/10.36347/sjahss.2022.v10i01.004

Fisher RA (1925) Theory of statistical estimation. Proc Camb Philos Soc 22(5):700–725. https://doi.org/10.1017/S0305004100009580

Ghosh S (2013) Regional disparities of slums, 2013—an overview with special emphasis to Kolkata. Int J Humanit Soc Sci Invention 2(3):48–54

Gupta A, Zhu H, Doan MK, Michuda A, Majumder B (2021) Economic impacts of the COVID-19 lockdown in a remittance-dependent region. Am J Agr Econ 103(2):466–485. https://doi.org/10.1111/ajae.12178

Gururaja BL, Ranjitha N (2022) Socio-economic impact of COVID-19 on the informal sector in India. Contemp Soc Sci 17(2):173–190. https://doi.org/10.1080/21582041.2021.1975809

Haque MN, Ansar SB, Biswas G, Islam MR, Al Mamun A (2020) The impact of COVID-19 on socio economic condition of city people: lessons from the selected KCC area. J Eng Sci 11(2):117–126. https://doi.org/10.3329/jes.v11i2.50903

Jesline J, Romate J, Rajkumar E, George AJ (2021) The plight of migrants during COVID-19 and the impact of circular migration in India: a systematic review. Humanit Soc Sci Commun 8(1):1–12. https://doi.org/10.1057/s41599-021-00915-6

Khan M, Kabir KH, Hasan K, Sultana R, Hoque F, Imran SA, Karmokar S (2022) Households' socioeconomic vulnerability assessment due to COVID-19 outbreak: a web-based survey in Bangladesh. Electron J Gener Med 19(3):1–12. https://doi.org/10.29333/ejgm/11797

Konar A, Banerjee T, Roy A (2020) Detailed study of Covid-19 outbreak in India and West Bengal. Int J Multidisc 05(05):39–49. https://doi.org/10.31305/rrijm.2020.v05.i05.010

Lahiri S, Sinha M (2021) A study of the socio-economic implications of the COVID-19 pandemic. Australas Acc Bus Financ J 15(1):51–69. https://doi.org/10.14453/aabfj.v15i1.5

Lancet (2020) India under COVID-19 lockdown. Lancet (London, England) 395(10233):1315. https://doi.org/10.1016/S0140-6736(20)30938-7

Leeper TJ (2017) Interpreting regression results using average marginal effects with R's margins. In: The comprehensive R archive network. Reference Manual, pp 1–31. Retrieved from https://cloud.r-project.org/web/packages/margins/vignettes/TechnicalDetails.pdf

Li Z, Wu J, Cui X, Mi Z, Peng L (2022) Assessment and influencing factors analysis of economic system vulnerability of the Belt and Road Initiative countries. Plos One 17(1):1–17. https://doi.org/10.1371/journal.pone.0262611

Likert R (1932) A technique for the measurement of attitudes. Arch Psychol

Martin A, Markhvida M, Hallegatte S, Walsh B (2020) Socio-economic impacts of COVID-19 on household consumption and poverty. Econ Disasters Clim Change 4(3):453–479. https://doi.org/10.1007/s41885-020-00070-3

Mishra SV, Gayen A, Haque SM (2020) COVID-19 and urban vulnerability in India. Habitat Int 103:1–11. https://doi.org/10.1016/j.habitatint.2020.102230

Mondal BK, Sahoo S, Paria P, Chakraborty S, Alamri AM (2021) Multi-sectoral impact assessment during the 1st wave of COVID-19 pandemic in West Bengal (India) for sustainable planning and management. Arab J Geosci 14(23):1–26. https://doi.org/10.1007/s12517-021-08836-z

Nath B, Majumder S, Sen J, Rahman MM (2021) Risk analysis of COVID-19 infections in Kolkata Metropolitan city: a GIS-based study and policy implications. GeoHealth 5(4):1–17. https://doi.org/10.1029/2020GH000368

Nicola M, Alsafi Z, Sohrabi C, Kerwan A, Al-Jabir A, Iosifidis C et al (2020) The socio-economic implications of the coronavirus pandemic (COVID-19): a review. Int J Surg 78:185–193. https://doi.org/10.1016/j.ijsu.2020.04.018

Onyeaka H, Anumudu CK, Al-Sharify ZT, Egele-Godswill E, Mbaegbu P (2021) COVID-19 pandemic: a review of the global lockdown and its far-reaching effects. Sci Prog 104(2):1–18. https://doi.org/10.1177/00368504211019854

Pathak PK, Singh Y, Mahapatro SR, Tripathi N, Jee J (2020) Assessing socioeconomic vulnerabilities related to COVID-19 risk in India: a state-level analysis. Disaster Med Public Health Preparedness 1–14. https://doi.org/10.1017/dmp.2020.348

Pearson K (1896) Mathematical contributions to the theory of evolution. III. Regression, heredity and panmixia. Philos Trans R Soc Lond 187:253–318. https://doi.org/10.1098/rsta.1896.0007

Pearson K (1901) On lines and planes of closest fit to system of points in space. Phil Mag 6(2):559–572. https://doi.org/10.1080/14786440109462720

Rasul G, Nepal AK, Hussain A, Maharjan A, Joshi S, Lama A et al (2021) Socio-economic implications of COVID-19 pandemic in South Asia: emerging risks and growing challenges. Frontiers Sociol 6:1–14. https://doi.org/10.3389/fsoc.2021.629693

Rawlings JO, Pantula SG, Dickey DA (eds) (1998) Applied regression analysis. Springer texts in statistics, p 25. https://doi.org/10.1007/b98890

Sahu N, Mishra MM (2021) Assessing the vulnerability index of COVID-19 pandemic in India. Geogr Environ Sustain 14(4):131–139. https://doi.org/10.24057/2071-9388-2021-059

Sarkar A, Chouhan P (2021) COVID-19: district level vulnerability assessment in India. Clin Epidemiol Global Health 9:204–215. https://doi.org/10.1016/j.cegh.2020.08.017

Singh SK, Aditi, Mondal S (2020) Socio-economic vulnerabilities to COVID-19 in India: swimming against the tide. Glob J Med Res 20(4):6–16

Student (1908) The probable error of a mean. Biometrika 6(1):1–25. https://doi.org/10.2307/2331554

Tamrakar V, Srivastava A, Saikia N, Parmar MC, Shukla SK, Shabnam S et al (2021) District level correlates of COVID-19 pandemic in India during March–October 2020. PloS One 16(9):1–17. https://doi.org/10.1371/journal.pone.0257533

United Nations (2020) COVID-19 in an urban world. United Nations, New York, NY, USA, pp 1–30

Uyanık GK, Güler N (2013) A study on multiple linear regression analysis. Procedia-Soc Behav Sci 106:234–240. https://doi.org/10.1016/j.sbspro.2013.12.027

Zhang X, Wang C, Li E, Xu C (2014) Assessment model of eco-environmental vulnerability based on improved entropy weight method. Sci World J 797814:1–7. https://doi.org/10.1155/2014/797814

Chapter 43
Post-pandemic Urban World: Rethinking Urban Policies for Selected Indian Cities

Parama Raychaudhuri Bannerji

Abstract With ninety percent of COVID-19 reported cases from urban areas, the urban world became an epicenter of the pandemic. A technology-driven approach was followed by Chinese cities had managed to keep the transmission in control. However, in Western countries, a human-driven approach was followed to combat the pandemic. The cities of global south were relatively more challenged in terms of technology as well as human-driven approaches. Likewise Indian cities too faced additional problems like inadequate infrastructure facilities. The pandemic aftermath did lay bare the disparities among different population groups, particularly the vulnerable ones who had been dually hit by low income as well as weak social and economic coverage. Though a multitude of research has been done on the general impact of pandemic, a limited number of research outpourings were observed on the impact of pandemic on the 'third space'. As a critical component of social distancing all the 'communal hangout spots' like park, local markets and gyms were forced to shut down during a pandemic which critically altered the social infrastructure. The study aimed to understand of the impact of pandemics on urban life, with a focus on the 'third spaces', in the selected Indian cities. The methodology was integrated research review which included research output from popularly used database of scientific articles as well as government reports, documents, etc. This chapter questions how these spaces are perceived and how the perception changed during the outbreak.

Keywords Pandemic · Urban policies · Resilience · Global south · Post-pandemic cities · Smart cities

Introduction

Societal developments do manifest in urban spaces and are reflected in the characteristics of urban areas. One such development was the COVID-19 crisis. Even if

P. R. Bannerji (✉)
Department of Geography, Naba Barrackpore Prafulla Chandra Mahavidyalaya, Kolkata, India
e-mail: paramabannerji3@gmail.com

U. Chatterjee et al. (eds.), *Urban Commons, Future Smart Cities and Sustainability*, Springer Geography, https://doi.org/10.1007/978-3-031-24767-5_43

the concrete urban spaces did not change their physical characteristics, their pattern, use and need to be changed following lockdown and other restrictions. Fear of the spread of Contagion made every city impose complete to partial lockdown (Tosepu et al. 2020). Globally, cities had been the epicentres of the COVID-19 pandemic. For the cities of the Global South, pandemic-related lockdown exposed the existing fault lines including wide economic disparity or inadequate access to affordable housing, and inequitable access to core public services. Physical (or as it was called social) distancing was followed and restrictions were imposed on access to urban public spaces to reduce the transmission of COVID-19 (Honey-Rosés et al. 2021). Unfortunately amid the COVID-19 crisis, citizens lost their familiar, vibrant, social and lively public places (Honey-Rosés et al. 2021).

The objective of this article is to focus on the questions that arise at the interface of COVID-19 and planning of urban centres. People form attachments to their neighborhood and are emotionally connected which is described as a 'sense of place' (Tuan 2001). Social isolation policies had called for partial or complete restriction of such activities and hence these places did not offer the vibrancy as Street vendors, tea stalls, parks, gyms were shut down. This study endeavours to summarise preliminary research questions about how the COVID-19 pandemic crisis might change the habits of usage of public space by the citizens. The study takes a case-based approach and focuses on the impact of pandemic-related Indian government's restrictive policies on Indian cities, to make the study more specific. This article also tries to explore beyond the current measures of pandemic-related policies for the city, to consider which changes are likely going to stay with them once the pandemic takes a backseat.

The methodology of this study was to understand what the relevant literature like newspaper articles, research papers, government reports say browsing the popularly used database of scientific articles. The study uses the case of Indian Cities as Indian cities present a complex hub of the population in terms of income, class, religion or caste and where the impact had been profoundly different for different segments of the population.

Objectives

The broad aim of this study is to explore how citizens experienced, navigated and acted upon their changing spaces during the pandemic-related lockdown, specifically in Indian Cities.

The specific objectives of the study are as follows

- To understand how the spaces of social interaction for the citizens transformed with the pandemic-related social isolation policies
- To explore the scope of newer third spaces in the post-pandemic city
- To understand how the relationship with public space can change in the post-pandemic cities in terms of social behaviours, emotional connectedness to that place

- The study also tries to understand if this change would be transformational or short term.

Methodology

The methodology of this study was to comprehend what the relevant literature say browsing the broadly used database of scientific articles. Typically, the review was conducted to examine a certain issue or research problem, namely the 'impact of pandemic on third spaces' in urban areas of 'global south'. The study chooses the case of Indian cities. The case of Indian cities was selected for the study because the initial literature review revealed that Indian cities had followed 'stringent' lockdown policies radically altering the lifestyle and the usage of living space. Google search engine (Google Scholar) was used with keywords like 'urban third space', 'Covid 19 impact' resulting in surfacing of 117,000 reports. The study follows a meta-synthesis of a review of literature, reports and newspaper articles. The technique integrates, evaluates and interprets findings of multiple qualitative research studies following an inductive research approach. The study uses the case of Indian Cities as Indian cities present a complex hub of the population in terms of income, class, religion or caste where the impact had been profoundly different for different segments of the population.

Review of Literature

Spaces are planned with a vision of public life. Geographer Yi-Fu-Tuan (2001) analysed how people 'feel' about space. He also discussed how they form attachments to the neighborhood and the way by which 'space' and 'place' are affected by the sense of time. The concept of space has been developed by several scholars (Soja 1996; Lefebvre 1974). Relevant to this study is the concept of 'third space' and how it transformed due to social isolation policies during the Pandemic. Third space in its original conception emerged as a tool of political resistance and appeared in Bhabha's (1994) analysis of cultural identity and colonisation. He introduced the third space theory to open up the possibilities of hybrid cultures in less hierarchical ways. While discussing third space, one has to refer to the work of Edward Soja who had contributed in the field of cultural geography. He used the work of French Marxist urban sociologist Henri Lefebvre (1901–1991), author of *The Production of Space* (1974).

Soja (1996) in his theory of third space discusses three urban spaces: first space, second space and third space. The first space is the physical built environment, which can be mapped. The second space is conceptual space. It is that space which is constructed in the minds of the people who inhabit it. It is influenced by economic goals of as well as social norms. The third space is 'imagined' space or the lived space. It is the way that people live in and experience that urban space. Based on this idea, in 1989, sociologist Ray Oldenberg used a phrase for a social hangout, which was not workplace, nor home-place, but a third place. He described it as a neutral place for leisure and for connecting with friends and the local community.

Thus, the third space is that space frequented by an individual which is neither for work nor home and plays a role in social fostering or community association. However, with the pandemic-induced lockdowns of COVID-19, policies of social isolations changed the morphology of the third space. Severe acute respiratory syndrome coronavirus-2 (SARS-CoV-2), was declared a pandemic by the World Health Organisation (WHO) on the 11th of March 2020, leading to some form of lockdown across almost all countries of the world (Onyeaka et al. 2021).

Covid-19 pandemic emergency changed the habits and use of people in places and cities (Sepe 2021). The first reported case in India was from the state of Kerala in January 2020. India's lockdown was an example of the dominant global policy response to the COVID-19 pandemic. It entailed the observance of physical distancing and social isolation to control transmission (Ray and Subramanian 2020). A population of 1.3 billion people had been restricted to their homes and transport services, schools, factories and business establishments were closed.

According to the news article, *Covid Ruined Our Hangout Spots. Here's How They Come Back* (Bloomberg.com), *globally,* as a critical component of social distancing all the 'communal hangout spots' like a park, local markets and gyms were forced to shut down during a pandemic. However, it critically altered the social infrastructure, and living without third places may have social consequences.

There have been several studies on third places in urban areas in general. However, the lockdown policies altered these 'third places', and not many studies were observed in this area. For, the developing countries, particularly in the Global South with a complex urban population diversity, the need for research is particularly more intense as it is important to know how different the impact for each of the population group-the high income-low income groups, migrant-non migrant workforce groups, gendered groups, geriatric-pediatric age group and so on. Mobility data from Google published on April 11, 2021, showed that in India, compared to the baseline, there had been a 52% drop in visits to parks, plazas and public gardens in India, and a 69% decrease in visits to public transport hubs such as bus and train stations. In this backdrop, the study has the potential to address the much-needed focus on 'third space'.

Pandemic and Third Places in Indian Cities

While urban areas have always been vulnerable to disease outbreaks, global south cities like Indian cities faced additional problems like inadequate housing and infrastructure facilities, and inequitable access to education and health facilities. For these cities, the pandemic aftermath did lay bare the disparities among different population groups, particularly the vulnerable ones who had been dually hit by low income as well as weak social and economic coverage.

According to Maniktala and Jain (2021), India had quickly responded to the pandemic imposed a very strict lockdown. University of Oxford had prepared a stringency index to measure government response to COVID-19. As per the index, India had been rated as 100 on a 0–100 scale (from 31st March to 19 April 2020). Saha et al. (2020) prepared a report of *Lockdown for COVID-19 and its impact on community mobility in India: An Analysis of the COVID-19 Community Mobility Reports, 2020*. The report informed that in India, retail and recreation dropped by 73.4%, grocery and pharmacy dropped by 51.2% while visits to parks by 46.3%. However, visits to residential places mobility increased by 23.8%. This was because people mostly stayed home during the lockdown.

With effects on community mobility, the morphology of 'Third Places' in Indian Cities changed. In an interview, noted architect L. P. Rajendran (April 2021) pointed out that these third spaces have always taken a backspace in Indian city planning and even the Smart City Mission does not focus on it. However, author Oldenberg (1999) gave the criteria for third space in his book. These spaces should be free or inexpensive, food nearby, highly accessible, people can congregate there, neutral ground, low profile, playful mood and conversation is the main activity. Based on these criteria, the study selects a few urban spaces from Indian Cities and how these spaces were affected by the lockdown-informal arrangement on sidewalks, tea stalls, local markets, shopping malls and parks.

Findings on the Impact of Social Distancing Policies on Some of the Third Spaces in Indian Cities

Historically, the Third Place was a place where people could vent their steam, rejuvenate and socialise. And so, in the past few years, we have seen various combinations of the 'Places' as they evolved. For example, a combination of first and second places is now called coliving, a combination of second and third places is called coworking and a combination of first and third places is called comingling places.

Informal Arrangement on Sidewalks

In India, the trend is that of rapid urbanisation. However, without adequate employment opportunities in the organised sector, there has been an emergence of informal spatial units on the sidewalk. One can observe that the formal and informal economies both emerged side by side on distinct spatial terms.

Informal street trading here defined as the temporary and insecure street occupancy (Bhowmik 2016), provides a living for many of India's city dwellers while supplying the population with essential day-to-day services. Partha Chatterjee, in his work 'Politics of the Governed' (2004) had explained this phenomenon. The population belonging to the urban informal sector comes under the protection of the organised political unit as 'survival politics of the poor'. In contemporary Indian cities, there is a dynamic relationship between abstract formal cities and informal city bazaars shaped by local politics. Sometimes it's antagonistic while sometimes it's cooperative. Street vending is an age-old profession and is the livelihood of a large proportion of India's population. According to Deore and Lathvi (2019), street vendors make street life 'vibrant" through the diversity of activity and merchandise, footfall, and canopy cover.

According to Bhowmik (2016), street vendors in urban areas have low-level skills and have migrated to the urban areas from rural areas or small towns in search of employment. They take up street vending when they do not find other means of livelihood. In India, the National Policy of 2009 introduced three zonal categories, namely, 'Restriction-free Vending Zones,' 'Restricted Vending Zones,' and 'No-Vending Zones'. This was done so that a clear demarcation could be established between the usage of space by vendors and the space needed traffic, public health and environment (Balbuena and Skinner 2020).

During Lockdown

According to Diego, 2022, since 24 March 2020, lockdown came down heavily on the informal sectors of the economy. Empty city meant an immediate loss of their source of income. Some vendors (fruit and vegetable sellers) began venturing out after a few days without explicit permission and immediately faced police harassment. However, a few weeks later, the government eased restrictions and essential vendors were being permitted to vend partly because of the advocacy of vendor organisations and activist networks. But the interim loss was deeper. According to an article in BBC by Apeksha Bhateja (2020), daily wage-workers such as street vendors, most of whom migrated from rural areas of India found that their jobs in the cities were not there. Many were forced to travel several hundred kilometres on foot to get to their hometowns as there was no public transport and some died on the way.

Tea Stalls

According to Islam and Sharif (2021), tea stalls are vibrant places for friendly hang-outs for students and employers alike and are highly preferred for 'adda'—the Bengali term for leisurely, after-work hangouts. Tea stalls are small structures which are found scattered about throughout Indian cities and even rural areas that sell tea and snacks.

Tea is a popular drink that has gone beyond its functional aspects and has become a daily ritual. People enjoy a cup of tea indoors, outdoors, while waiting or talking to friends, during serious discussions, debates and meetings.

According to an article published in BBC by Apeksha Bhateja (2020), on 24 March 2020, India went into a three-month nationwide lockdown as a response to curb the spread of the pandemic. Similar to other countries, workplaces closed down and working from home became the norm. Because of this, the tea shops and stalls pulled down their shutter. The article also quoted a few interviews where the employees discussed how their informal chats outside of work would happen here. They also admitted that they discussed stress and our bad experiences with our bosses and learn about someone's personal life. The pandemic lockdown had detrimental impact on India's street vendors. While apparently, it may look like being a loss of everyday 'chai break', the loss was deeper. The tea stall owners like other street vendors suffered livelihood losses. According to an interview of a certain Kishore Chaudhary, a 'chai' seller in Gurugram, the tea stalls were not allowed to open during the lockdowns. This was the reason that most of his fellow shop owners went back to their villages. He was unable to sustain his business too as before the lockdown, and he used to get an influx of around 500 customers a day. However when the first phase of lifting lockdown began, there were only two or three customers.

Local Market

According to Mohanty (2007), the scene of the Bazaar as a public space added a new dimension to the European perception of natives. Congested shabby shops, sellers selling products of various colours, fruits, vegetables, stray animals, etc. offered a new visual dimension to the Europeans in Colonial India. Bazaars since history have offered a critical public encounter domain for cultural intermingling.

During Lockdown

The city dwellers had limited public transport and spent much of their time in their homes. This led them use the shopping facilities of essential needs from the neighborhood. This convenience and greater sense of security were encouraged buying in local stores.

Shopping Mall

The Collins Cobuild English Language Dictionary defines shopping as 'the activity of going to shops and buying things'. In doing the shopping activity, shoppers interact with the elements surrounding them which affect their degree of entertainment shopping experience. Thus in simple terms, the shopping mall is a large retail complex containing a variety of stores including restaurants and other business establishments housed in a series of connected or adjacent buildings or a single large building. Shopping malls with their infrastructure like parking, ambiance, security, hygiene, avenues for entertainment, food and shopping all fit into the 'third place' definition.

During Lockdown

The impact of COVID-19 on shopping malls was negative. They opened in restricted timings, and there were restrictions on restaurants, entertainment services, etc.

Coupled with this was the fear of contagion. The COVID-19 pandemic had detrimentally impacted trade and leisure. It had also changed the behaviour of city dwellers. According to a news article in Hindustan Times (8 July 2020), the malls in Kolkata received a 'mixed reaction' when the facilities reopened after being closed for 45 days. In an interview, the manager of Acropolis Mall 'about 90 percent of the stores opened and 'vibes' were positive but footfall was not very high due to lack of public transport. South City mall management said they received a better response'.

Park

As integral parts of city life, park is known to attract a diverse community. As an entity, the park contains elements of Ray Oldenburg's idea of a third place (Oldenberg 1999). A public park is defined as an area of land, usually in a mostly natural state, for the enjoyment of the public. The shortage of 'for-mal' public spaces makes neighborhood parks such as this vital for the community's social, mental and physical wellbeing. Public parks have always served a critical function as free recreational spaces.

During Lockdown

Saha et al. (2020) had published a report *Lockdown for COVID-19 and its impact on community mobility in India: An analysis of the COVID-19 Community Mobility Reports, 2020.* Across India, the visits to park dropped by 46.3% (up to 30th April). The states which had the highest drop (up to 30th April) were Chandigarh (− 90.3%) and Delhi (− 80.3). Some of the states which had the lowest drop were Manipur (− 17.3%), Arunachal Pradesh (17.3%), Lakshadweep (− 7.7%). This may be due to stringent lockdown measures as well as the general fear of transmission of the disease.

Revisiting Theories

For Moje et al. (2011), the third space has three objectives—to build bridges between marginalised and dominants, to enable members to navigate across different discourses and to create conversational spaces. The above section had taken up specific third spaces of Indian cities and how they were used in the pre-lockdown and lockdown phases. However, the question arises if they are transformed forever or if these changing uses are temporary phases. This section in general tends to summarise how the relationship with these spaces in the cities changed and how will these changes impact the post-pandemic utilisation of the third space. For these, the following points are discussed.

- **Changes in the use and perceptions of third spaces in the post Covid era**

Studies on public life often count people in streets or parks to evaluate how the site functions (Gehl 2013). As discussed above, for Indian cities the pattern had already changed. However, a class differential was observed as a majority of the population using public spaces belonged to the low-income group like the vendors, delivery boys and wage labourers who did not have the facility of working from home like the higher income group belonging to the skilled group like IT sectors, banking or teaching.

- **Will the changes be transformational?**

The two main activities of public space include shopping and socialising. With the advent of Covid 19, there had been a drop in pedestrian traffic. This drop pedestrian traffic affected the commercial activities like the street vendors and tea stalls. Further, the habit of online shopping may also transform shopping malls. But there may be another argument. COVID-19 had prompted the Indian Municipal authorities to restrict access to large shopping areas and malls. This in turn can force a change in consumption habits, and high-income group may now venture into local markets.

Urban designers create city spaces that are comfortable, safe and welcome table. The stay-at-home restrictions may change how both children and youth would develop a sense of emotional attachment or connectedness with public places like parks, clubs, gyms, etc. As a result of the prolonged absences, they might grow accustomed to online isolation.

- **Infringements in civil liberty by lockdown measures**

Complete or partial lockdown,work from home options, night curfews, etc. were strategies that allowed governments to slow down the outbreak (WHO 2020). These strategies had been implemented via control measures such as restricted entries, barricades, police checks, permit systems, etc. The Government of India, under the Disaster Management Act 2005, declared a countrywide lockdown, to pause the spread of COVID-19 which was a blow to the livelihood of the daily labourers and street vendors under the right to life conferred by Article 21 under Indian Constitution. Janta Curfew and later Night curfew restricted mobility. Restricting movement may have been a strategy to reduce COVID-19 transmission, but it could also have been used to deny mass gatherings and suppress political opposition.

- **Need for a new typology of urban space**

The pandemic could force urban planners to create a new typology to describe places in terms of social density, distances, and crowding. Options of better maintenance of public spaces-temporary green spaces, temporary hospitals where clubhouses and schools were overnight transformed into COVID centres have prompted out-of-box thinking for post-pandemic city designs.

Limitation of the Study

Constraint of time was the main limitation of the study followed by lack of previous published research material.

Conclusion

The change in perception and usage of spaces, particularly third spaces during and after the Covid-19 outbreak in Indian cities, was chosen as the study area. The findings were related to the effects of the pandemic process on the perception of these spaces which were used for fostering social association. In the analyses made, how these spaces are perceived and how the perception changed during the outbreak were questioned. It was concluded that the pandemic did transform the spaces of social interaction for the citizens with the pandemic-related social isolation policies, This prompts the need to explore the scope of newer third spaces in the post-pandemic city. These newer third spaces may also take the shape of virtual places. As discussed above, public space can change in post-pandemic cities in terms of social behavior and emotional connectedness to that place. But whether the change would be transformational or short-term is yet under the scanner.

References

Balbuena P, Skinner C (2020) For world's street vendors, life may never be the same after COVID-19. WIEGO. https://www.wiego.org/blog/worlds-street-vendors-life-may-never-be-same-after-covid-19

Bhabha H (1994) The location of culture. Routledge, London

Bhateja A (2020) Will coronavirus end India's Tapri Chai Culture. Accessed at https://www.bbc.co.uk/Worklife/article/20200626

Bhowmik (2016) Hawkers and the urban informal sector: a study of street vending in seven cities. Accessed from https://www.wiego.org/sites/default/files/publications/files/Bhowmik-Hawkers-URBAN-INFORMAL-SECTOR.pdf

Chatterjee P (2004) The politics of the governed. Columbia University Press, New York

Chatterjee T (2016) From margin to mainstream: informal street vendor and local politics in Kolkata, India. Online J Polit Geogr Geopolit 26(2)

Deore P, Lathvi S (2019) Streets as public spaces. Lesson from street vending in Ahmedabad, India. Urban Plann 4(2)

Gehl J (2013) Cities for people. Island Press, Washington, DC

Google Mobility Report. Accessed from https://www.gstatic.com/covid19/mobility/2020-04-11_IN_Mobility_Report_en.pdf

Honey-Rosés J, Anguelovski I, Chireh VK, Daher C, Konijnendijk C, van den Bosch JS, Litt VM, McCall MK, Orellana A, Oscilowicz E, Sánchez U, Senbel M, Tan X, Villagomez E, Zapata O, Nieuwenhuijsen MJ (2021) The impact of COVID-19 on public space: an early review of the emerging questions—design, perceptions and inequities. Cities Health 5(sup1):S263–S279. https://doi.org/10.1080/23748834.2020.1780074

Interview of L.P. Rajendran. https://theconversation.com/in-indias-cities-life-is-lived-on-the-streets-how-coronavirus-changed-that-135232

Islam M, Sharif S (2021) Assessing the role of tea stalls as third places in Rajshahi, Bangladesh. Available from: https://www.researchgate.net/publication/356492781_ASSESSING_THE_ROLE_OF_TEA_STALLS_AS_THIRD_PLACES_IN_RAJSHAHI_BANGLADESH. Accessed 04 July 2022

Lefebvre H (1974) The production of space (English trans 1991 by D Nicholson-Smith). Basil Blackwell, Oxford

Maniktala N, Jain T (2021) State of street vendors in India: pre and post COVID-19 analysis. Int J Policy Sci Law 1(2). Accessed on https://ijpsl.in/wp-content/uploads/2021/01/State-of-Street-Vendors-in-India-Pre-and-Post-COVID-19-Analysis_Nitya-Maniktala-Tanisha-Jain.pdf

Mohanty PKr (2007) Bazar as a contesting public space: its differing perceptions and usage at colonial Cuttack. Proc Indian Hist Congr 68:1029–1040. http://www.jstor.org/stable/44147908

Moje EB, Ciechanowski KM, Kramer K, Ellis L, Carillo R, Collazo T (2011) Working toward third space in content literacy: an examination of everyday funds of knowledge and discourse. Read Res Q 39(1):38–70. https://doi.org/10.1598/rrq.39.1.4

Oldenberg R (1999) The great good place: cafes, coffee shops, bookstores, bars, hair salons, and other hangouts at the heart of a community. Da Capo Press

Onyeaka H, Anumudu CK, Al-Sharify ZT, Egele-Godswill E, Mbaegbu P (2021) COVID-19 pandemic: a review of the global lockdown and its far-reaching effects. Science Progr 104(2)

Ray D, Subramanian S (2020) India's lockdown: an interim report. Indian Econ Rev 55(suppl 1):1–49. https://doi.org/10.1007/s41775-020-00094-2. Epub ahead of print. PMID: 32836357; PMCID: PMC7435223. https://www.bloomberg.com/news/articles/2021-04-06/the-death-and-post-covid-rebirth-of-third-places

Saha J, Barman B, Chouhan P (2020) Lockdown for COVID-19 and its impact on community mobility in India: an analysis of the COVID-19 Community Mobility Reports 2020. Child Youth Serv Rev 116:105160. https://doi.org/10.1016/j.childyouth.2020.105160

Sepe M (2021) Covid-19 pandemic and public spaces: improving quality and flexibility for healthier places. Urban Des Int 26:159–173. https://doi.org/10.1057/s41289-021-00153-x

Soja EW (1996) Thirdspace. Blackwell, Malden, MA, p 57

Tosepu R, Gunawan J, Effendy SD, Ahmad AI, Lestari H, Bahar H et al (2020) Correlation between weather and Covid-19 pandemic in Jakarta, Indonesia. Sci Total Environ 725:138436. https://doi.org/10.1016/j.scitotenv.2020.138436

Tuan Y-F (2001) Space and place: the perspective of experience

WHO (2020) Global surveillance for human infection with coronavirus disease (COVID-19). Interim Guidance. Available at: https://www.who.int/publications-detail/global-surveillance-for-human-infection-with-novel-coronavirus-(2019-ncov)

Index

U. Chatterjee et al. (eds.), *Urban Commons, Future Smart Cities and Sustainability*, Springer Geography, https://doi.org/10.1007/978-3-031-24767-5

U