Shalini Dhyani
Mrittika Basu
Harini Santhanam
Rajarshi Dasgupta *Editors*

Blue-Green Infrastructure Across Asian Countries

Improving Urban Resilience and Sustainability

Springer

Blue-Green Infrastructure Across Asian Countries

Shalini Dhyani • Mrittika Basu •
Harini Santhanam • Rajarshi Dasgupta
Editors

Blue-Green Infrastructure Across Asian Countries

Improving Urban Resilience and Sustainability

Springer

Editors
Shalini Dhyani
National Environmental Engineering Research Institute, NM
Council Scientific and Industrial Research
Nagpur, Maharashtra, India

Mrittika Basu
Laboratory of Sustainable Rural Development
Kyoto University
Kyoto, Japan

Harini Santhanam
National Institute of Advanced Studies
Bangalore, India

Rajarshi Dasgupta
Institute for Global Environmental Strategies
Kanagawa, Japan

ISBN 978-981-16-7127-2 ISBN 978-981-16-7128-9 (eBook)
https://doi.org/10.1007/978-981-16-7128-9

This Springer imprint is published by the registered company Springer Nature Singapore Pte Ltd.
The registered company address is: 152 Beach Road, #21-01/04 Gateway East, Singapore 189721, Singapore

Foreword

Cities are expanding and so are the number of people inhabiting these cities. Following the current trend, the global urban population is expected to be 70% or 6.3 billion by 2050, nearly doubling up from the urban population in 2010, i.e. 3.5 billion. This increase will not only be concentrated in megacities, but also across small- and medium-sized cities across the world. Pressure on the urban resources is anticipated to increase manifold including, but not limited to, depleting green and blue spaces, water scarcity, air pollution, urban heat islands, increasing disaster risks, noise pollution, waste dumping, etc. Maintaining a healthy and habitable urban life is one of the major challenges facing the *Anthropocene*.

There have been quite a few studies on urban infrastructural facilities like transportation systems, wastewater treatment, solid waste disposal, water supply, electricity supply and urban settlements. On the other hand, urban ecological infrastructures like open spaces, parks, waterbodies, urban wetlands, etc., collectively referred to as 'Blue-Green Infrastructure' (BGI), are the first prey to urban expansion and, yet they fail to get ample attention. Though much has been written about the benefits provided by urban ecosystems, development of new blue-green infrastructures and their mainstreaming in urban policy planning is yet to be realized, especially in the Global South. This book *Blue-Green Infrastructure Across Asian Countries—Improving Urban Resilience and Sustainability* fills up this gap impeccably. The book clearly exemplifies the importance of the Blue-Green Infrastructures through various case studies across different Asian countries and suggests convincing ways to mainstream this infrastructure in urban policy planning.

This book not only explores the benefits and challenges of Blue-Green Infrastructures, but also explores the different advances that can be adopted like citizen science initiatives, spatial planning and socio-ecological technological approaches to monitor and implement them. Different environmental designs are proposed for the inclusion of Blue-Green Infrastructures in urban settings. For example, home gardens of Sri Lanka delineate the multifunctional role of ecological infrastructures and present a unique design where both blue- and green-infrastructures can be designed together at a relatively smaller space. The different environmental designs presented in this book provide an opportunity to replicate them to include in other urban areas with some modifications, if needed.

Blue infrastructures in urban areas find a special place in this book. Very little information on urbanization impacts on blue infrastructures is available except for spatial maps that show the shrinkage in urban waterbodies. Starting from the ancient waterbodies in India to nature-based solutions for marine and coastal ecosystems to alleviating the impacts of disasters like flood, the role of blue infrastructures is explored in detail and their implementation discussed. The book opens up new avenues of research on the roles of blue infrastructure that will ameliorate the quality of life of urban dwellers. Likewise, case studies on the importance of EcoDRR demonstrate the role of Blue-Green Infrastructure in urban resilience building and disaster risk mitigation.

Considering the urban complexities and uncertainties, it is timely and important to explore alternative interventions for a sustainable urban future, as detailed in this book. The book not only quantifies and explores the importance of Blue-Green Infrastructure, but also suggests on mainstreaming it in the urban policy planning process which will eventually help in implementing the ecological infrastructures. Academicians, policy planners, city planners, local communities and both local government and non-governmental agencies will find this book helpful as the book delivers an integrated knowledge on Blue-Green Infrastructure and makes a valuable contribution towards building a sustainable and resilient urban future.

I congratulate the authors for presenting diverse concepts, cases and novel approaches on the subject that are relevant for diverse stakeholders including urban planners and policy makers. I also warmly congratulate the editors: Shalini Dhyani, Mrittika Basu, Harini Santhanam and Rajarshi Dasgupta—for their timely efforts to produce this insightful volume of concepts, innovations and case studies. This book is an important and timely contribution to the knowledge pool of urban ecosystems, nature-based solutions, disaster risk reduction and climate change adaptations. Readers will be highly benefited from the insightful chapter content and analysis presented in this book. I wish the editors and authors all success in their endeavour.

Resilience to Disasters and Conflicts
Support Branch, UNEP
Geneva, Switzerland

Muralee Thummarukudy

Acknowledgements

Putting together a book on a relatively futuristic topic of *Blue-Green Infrastructure Across Asian Countries: Improving Urban Resilience and Sustainability* would not have been possible without the constant support, contributions, perseverance and dedication of expert authors. We are enormously grateful to many subject experts, scientists and researchers who volunteered their precious and busy time out of their heavily engaged academic involvements and helped to critically review the book chapters. We truly appreciate their cooperation and good understanding in meeting our rather strict paper submissions and review deadlines. Many of our supporters deserve special appreciation. We sincerely thank the Director CSIR-NEERI, Nagpur, for the valuable support during the preparation of this book. We are grateful to many of our very hard working and supportive research scholars without whose critical support our efforts alone would not have been enough to bring out this book in time. We specially thank Ms. Sunidhi Singh for her keeping record of all the email communications and attachments and Ms. Kavita Bramhanwade for her help in overseeing formatting and language correction to avoid major mistakes. Finally, the production team members of Springer deserve special appreciation for guiding us through the process of publishing this work. Despite our best efforts to avoid any mistake, it is, however, possible that a very few errors, may be grammatical in nature, remain owing to the fast pace of production and strict timelines we had to adhere to. Each individual chapter included in this book was finalized with the primary responsibility of author and co-authors. The editors have gone through all the chapters included and reviewed them personally as well, with careful scrutiny following international standards including ethics of publication. We shall be immensely grateful to receive constructive comments and suggestions from readers of this book for further improvement of our publications in future. Any errors found in this book are the collective responsibility of the chapter authors and of the editors. Last but not least, we thank our family members, especially our parents, spouses and children, for their understanding, adjustments, patience and encouragement to continue and complete this mammoth task well in time.

In closing, we express our gratitude to Dr. Muralee Thummarukudy, Chief, UNEP, for writing the foreword for this book.

Contents

About the Editors

Shalini Dhyani is a Senior Scientist in the Critical Zone Research Group of the Water Technology and Management Division at CSIR-NEERI, India. She is South Asia regional chair for IUCN-CEM (Commission on Ecosystems Management) and also serves as the lead author for IPBES Sustainable Use of Wild Species Assessment (2018–2021). She is a skilled ecologist with more than 17 years of strong experience in environmental impact assessment, ecosystem health assessment, climate change impact on natural ecosystems and species, nature-based solutions, climate-sensitive restoration and sustainability projects. She has extensively worked on the interlinkages between ecological, human and social systems through sustainability science approaches. Her research interest focuses on science-policy integration for better biodiversity and ecosystem-inclusive decision-making for impact assessment, sustainable development and disaster risk reduction. In the last few years, she has also contributed to assess the importance, threats and opportunities in fast expanding urban areas and mainstreaming blue-green infrastructure for ensuring urban resilience and sustainability. She has been involved in the gender task force of IUCN and has also helped to develop governance pathways for intergenerational partnerships in conservation. She was awarded first "IUCN-CEM Chair Young Professional Award" at the IUCN World Parks Congress 2014 in Sydney, Australia, for her excellent research and publications on forests of the Himalayan region. She is recipient of various national as well as international financial grants, viz. Indo-Italian joint bilateral research grant, Indo-Japan multilateral grant from APN, UNEP, GIZ, FAO, IUCN, UNU, European Union-LEANES, Rufford SGP and DST. She has more than 60 peer-reviewed national and international publications with many popular articles to her credit.

Mrittika Basu is an Assistant Professor in the Laboratory of Sustainable Rural Development, Graduate School of Global Environmental Studies (GSGES), Kyoto University, Japan. Prior to this position, she was a UNU-JSPS postdoctoral fellow in the United Nations University Institute for the Advanced Study of Sustainability (UNU-IAS), Tokyo. Her research mainly focused on understanding the change in ecosystem services, relational values and well-being among peri-urban communities affected by rapid urbanization and industrial development. She has also been a contributing author (CA) in the IPBES Global Assessment Report (2015–2018).

Currently, she is leading a project on migration decision-making in salinity-affected areas of Bangladesh and India (2020–2022), funded by Asia Pacific Network (APN) for Global Change Research. Apart from this, she is working on assessing nature connectedness and biophilia assessment among school children in India and Japan. Her research interests include, but not limited to, water ecosystem services, water resources management, ecosystem values and services and human–nature relations. She has published several peer-reviewed scientific papers in international journals.

Harini Santhanam is an Assistant Professor with the National Institute of Advanced Studies, Bangalore, India, studying multiple aspects of natural lake systems such as biogeochemistry, hydro-geological processes and land-water-human nexus from an ecosystem perspective. She has been a long-term researcher with IISc Bangalore, working in multidisciplinary teams with a focus on analytical and modelling techniques, with implications towards influencing management measures for the resource base. Recently, she led an investigation of the hydrochemistry of Pulicat Lake in detail, as the principal investigator of a DST-funded Women Scientists project (2015–2018) at IISc. She was awarded the National Doctoral Fellowship from AICTE, India (2004–2008). Her research interests are largely multidisciplinary, bringing together the insights from aquatic biogeochemistry (especially on themes like trophic status and ecosystem indices), geomatics-based integrative modelling, paleo-ecological reconstructions and investigating the anthropogenic influence on the recycling of nutrients through the aquatic food web, among others. Her work also encompasses the development and application of novel environmental proxies and indices. Further, she investigates the challenges towards sustainable development of urban lake environments and models the lake–land interactions from the perspective of urban blue-green infrastructure development and adopting nature-based solutions for enhancing urban resilience. She has more than 20 publications in national and international journals and conferences.

Rajarshi Dasgupta is a Senior Researcher in the domain of natural resource and ecosystem services at the Institute for Global Environmental Strategies (IGES), Kanagawa, Japan. He holds diverse research interests in the field of landscape ecology and planning, which include Ecosystem-based Disaster Risk Reduction (Eco-DRR), spatial quantification of ecosystem services, land change simulation, development of socio-ecological scenarios, participatory conservation and social forestry. Earlier, he has worked extensively with mangrove communities in India, Bangladesh and Myanmar. Prior to joining IGES, he was working with the University of Tokyo as the Japan Society for the Promotion of Science (JSPS) postdoctoral fellow in the Graduate School of Agriculture and Life Sciences. Previously, he has worked in multiple technical and administrative capacities, including government, NGO and academia, and also served as a lead author (LA) for IPBES Asia-Pacific Regional Assessment Report. He is currently serving as the lead author for IPBES Sustainable Use of Wild Species Assessment (2018–2021), as chapter scientist/contributing author of IPCC AR-6 (WG-II) and as a visiting associate professor in the Institute for Future Initiatives, University of Tokyo.

Abbreviations

ABC	Active, Beautiful, Clean Waters
ACB	ASEAN Centre for Biodiversity
ACCCRN	Asian Cities Climate Change Resilience Network
ADB	Asian Development Bank
AIIMS	All India Institute of Medical Sciences
ALI	Advanced Land Imager
ALOS- PALSAR	Advanced Land Observing Satellite- Phased Array type L-band Synthetic Aperture Radar
AMRUT	Atal Mission for Rejuvenation and Urban Transformation
AMS	Accelerator Mass Spectrometry
ANOVA	Analysis of Variance
AQI	Air Quality Index
AQMS	Air Quality Management System
ASDMA	Assam State Disaster Management Authority
ASTER	Advanced Spaceborne Thermal Emission and Reflector Radiometer
ATLAS	Advanced Topographic Laser Altimeter System
AZN	Currency of Azerbaijan: Azerbaijani Manat
B	Balancing loop
BAU	Business As Usual
BBA	Blue to Built-up Area
BDA	Bengaluru Development Authority
BGI	Blue-Green Infrastructure
BMCs	Biodiversity Management Committees
BMPs	Best Management Practices
BOD	Biological Oxygen Demand
C	Carbon
CALABARZON	Cavite, Laguna, Batangas, Rizal, Quezon
CAS	Climate Adaptation Summit
CBA	Community-Based Adaptation
CBD	Convention on Biodiversity
CBI	City Biodiversity Index
CCA	Climate Change Adaptation

CCBA	Climate Community and Biodiversity Alliance
CCC	Chittagong City Corporation
CDA	Chittagong Development Authority
CDD	Cooling Degree Days
CER-GI-CON	Ceramic-Galvanized Iron-Concrete
CER-GI-WD	Ceramic-Galvanized Iron-Wood
CER-LS-MXD	Ceramic-Long Span-Mixed Materials
CER-TEG-CON	Ceramic-Tegula-Concrete
CFD	Computational Fluid Dynamics
C-HED	Centre for Heritage, Environment and Development
CICES	Common International Classification of Ecosystem Services
CIS	Coupled Infrastructure System
Cl	Chlorine
CLD	Causal Loop Diagrams
CO_2	Carbon Dioxide
COD	Chemical Oxygen Demand
CON-GI-CON	Concrete-Galvanized Iron-Concrete
CON-GI-WD	Concrete-Galvanized Iron-Wood
CON-TEG-BR	Concrete-Tegula-Brick
CON-TEG-CON	Concrete-Tegula-Concrete
COP	Conference of the Parties
CPCB	Central Pollution Control Board
CSO	Combined Sewer Overflow
CSO	Civil Society Organisation
CV	Contingent Valuation
CWs	Constructed Wetlands
DADP	Detailed Area Development Planning
DAP	Detailed Area Plan
DEM	Digital Elevation Model
DMDP	Dhaka Metropolitan Development Plan
DN	Digital Numbers
DO	Dissolved Oxygen
DPSIR	Driver Pressure State Impact Response Framework
DRM	Disaster Risk Management
DRR	Disaster Risk Reduction
DSM	Digital Surface Models
DSP	Dolphin Space Programme
EAF	Ecosystem Approach to Fisheries
EbDRR	Ecosystem-based Disaster Risk Reduction approaches
EBM	Ecosystem-Based Management
EMR	Electro Magnetic Radiation
EnMAP	Environmental Mapping and Analysis Program
ENPHO	Environmental Public Health Organization
ERI	Ecological Risk Index
ESS	Ecosystem Services

ESZ	Eco-Sensitive Zone
ETM	Enhanced Thematic Mapper
EV	Egyptian Vultures
EWS	Early Warning System
FAO	Food and Agricultural Organization
FD	Forest Department
FDPP	Full Depth Permeable Pavement
FEMA	Federal Emergency Management Agency
FGD	Focus Group Discussions
FPI	Fabry-Pérot Interferometer
GBA	Greater Baku Area
GBR	Green-to-Blue Ratio
GCDA	Greater Cochin Development Authority
GCF	Green Climate Fund
GDP	Gross Domestic Product
GE	Google Earth
GEDI	Global Ecosystem Dynamics Investigation
GEE	Google Earth Engine
GGF	Green Growth Framework
GHGs	Greenhouse Gases
GI	Green Infrastructure
GIM	National Mission for Green India
GIS	Geographical Information Systems
GLAS	Geoscience Laser Altimeter System
GMC	Guwahati Municipal Corporation
GMDA	Guwahati Metropolitan Development Authority
GPS	Global Positioning Systems
GR-GI-BAM	Ground-Galvanized Iron-Bamboo
GR-GI-MXD	Ground-Galvanized Iron-Mixed Materials
GR-GI-WD	Ground-Galvanized Iron-Wood
GR-NIP-MXD	Ground-Nipa-Mixed Materials
GR-NP-BAM	Ground-Nipa-Bamboo
GR-NP-WD	Ground-Nipa-Wood
GS	Guwahati-Shillong
HAC	Hoi An City
HDD	Heating Degree Days
HHMI	Hard Human-Made Infrastructure
HI	Human Infrastructure
HRIDAY	Heritage City Development and Augmentation Yojana
HySIS	Hyper Spectral Imaging Satellite
ICAP	India Cooling Action Plan
ICCC	Integrated Command and Control Center
ICELI KCC	ICLEI Kaohsiung Capacity Center
ICZM	Integrated Coastal Zone Management
IFM	Integrated Flood Management

IISD	International Institute for Sustainable Development
IMFFS	Integrated Mangroves Fisheries Farming System
INCOIS	Indian National Centre for Ocean Information Services
IPBES	Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services
IPCC	Intergovernmental Panel on Climate Change
IPZ	Island Protection Zone
IRS LISS	Indian Remote Sensing Satellite Linear Imaging Self Scanning Sensor
ISA	Percentage Impervious Surface Area
ISRO	Indian Space Research Organisation
IUCN	International Union for Conservation of Nature
IUWM	Integrated Urban Water Management
JNNURM	Jawaharlal Nehru National Urban Renewal Mission
KDA	Khulna Development Authority
KHGs	Kandyan Homegardens
KSDMA	Kerala State Disaster Management Authority
KUIDFC	Karnataka Urban Infrastructure Development Finance Corporation
LAI	Leaf Area Index
LaP	Local Area Planning Authority
LBSAP	Local Biodiversity Strategy Action Plan
LBV	Long-Billed Vultures
LCS	Low-Carbon Society
LID	Low-Impact Development
LiDAR	Light Detection and Ranging
LLDA	Laguna Lake Development Authority
LPG	Liberalisation-Privatisation-Globalisation
LST	Land Surface Temperature
LULC	Land Use Land Cover
MFAs	Marine Fishery Advisories
MFF	Mangroves for the Future
MIMAROPA	Mindoro, Marinduque, Romblon, Palawan
MIMES	Multiscale Integrated Model of Ecosystem Services
MLC	Maximum Likelihood Classifier
MLIT	Ministry of Land, Infrastructure, Transport and Tourism, Japan
MNDWI	Modified Normalized Difference Water Index
MODIS	Moderate Resolution Imaging Spectroradiometer
MoE	Ministry of the Environment, Japan
MoEFCC	Ministry of Environment, Forest and Climate Change
MoES	Ministry of Earth Sciences
MONRE	Ministry of Natural Resources and Environment
MoUD	Ministry of Urban Development
MS	Multi Spectral
MSS	Multispectral Scanner System

MSWM	Municipal Solid Waste Management
MXD-GI-MXD	Mixed Materials-Galvanized Iron-Mixed Materials
MXD-TEG-BR	Mixed Materials-Tegula-Brick
N	Nitrogen
NAPCA	National Association for the Promotion of Community Universities, Taiwan
NAPCC	National Action Plan on Climate Change
NASA	National Aeronautics and Space Administration
NAT	NbS Assisting Technologies
NBA	National Biodiversity Act
NBS	Nature-Based Solutions
NCAER	National Council of Applied Economic Research
NCR	National Capital Region
NDC	Nationally Determined Contributions
NDMA	National Disaster Management Agency
NDRRMC	National Disaster Risk Reduction and Management Council
NDRRMP	National Disaster Risk Reduction and Management Plan
NDVI	Normalized Difference Vegetation Index
NDWI	Normalized Difference Water Index
NE	North East
NFCP	Natural Forest Conservation Program
NFPP	Natural Forest Protection Program
NGOs	Non-Governmental Organisations
NI	Natural Infrastructure
NIR	Near Infrared
NMEEE	National Mission of Enhanced Energy efficiency
NO_3	Nitrate
NRC	National Research Council
NRM	Natural Resources Management
NSCB	National Statistics Coordination Board
NSSL	National Severe Storms Laboratory
NTFP	Non-Timber Forest Products
OLI	Operational Land Imager
OP	Oriented-plan
OSF	Ocean State Forecast
OTH-GI-WD	Others-Galvanized Iron-Wood
OTH-TEG-BAM	Others-Tegula-Bamboo
PA	Protected Areas
PAGASA	Philippine Atmospheric, Geophysical and Astronomical Services Administration
PAN	Panchromatic
PBL	Planetary Boundary Layer
PFZ	Potential Fishing Zone
PHI-2	Push broom Hyperspectral Imaging II
PI	Public Infrastructure

PIP	Public Infrastructure Provider
PM	Particulate Matter
PMCG	Pembrokeshire Marine Code Group
PPP	Public–Private Partnership
PPS	Permeable Pavement Systems
PSA	Philippine Statistics Authority
PUB	Public Utilities Board
PV	Proportion of Vegetation cover
QGIS	Quantum GIS
R	Reinforcing Loop
RADAR	Radio Detection and Ranging
RBP	Reference Behaviour Pattern
RBTS	Reed Bed Treatment System
RCM	RADARSAT Constellation Mission
RDA	Rajshahi Development Authority
RF	Reserve Forest
RMDP	Rajshahi Metropolitan Development Plan
RMP	Revised Master Plan
RPI	River Pollution Index
RS	Remote Sensing
RS	Resource System
RU	Resource User
RVS	Ramadevarabetta Vulture Sanctuary
S	Scenario
S&T	Science and Technology
SAR	Synthetic Aperture Radar
SAVi	Sustainable Asset Valuation
SCC	Sponge City Concept
SCP-Asia	Sustainable Cities Programme-Asia
SDGs	Sustainable Development Goals
SDWF	Shannon Dolphin and Wildlife Foundation
SESs	Social-Ecological Systems
SET	Social-Ecological Technological
SHMI	Soft Human-Made Infrastructure
SIDS	Small Islands Developing States
SMCE	Spatial Multi-Criteria Evaluation
SNC	Second National Communication
SOI	Survey of India
SPC	Sponge City Program
SS	Suspended Solids
SSNN	Self-Adapting Selection of Multiple Artificial Neural Networks
SuDS	Sustainable Urban Drainage Systems
SUNRM	Sustainable Urban Natural Resources Management
SW	Southwest Monsoon
SWIR	Short-Wave Infrared

SWM	Solid Waste Management
TCPO	Town and Country Planning Organisation
TIR	Thermal Infrared
TIRS	Thermal Infrared Sensor
TM	Thematic Mapper
TSS	Total Suspended Solids
UAV	Unmanned Aerial Vehicle
UBGI	Urban Blue-Green Infrastructure
UCCR	Urban Climate Change Resilience
UCI	Urban Cooling Islands
UDA	Urban Development Authority
UESs	Urban Ecosystem Services
UGI	Urban Green Infrastructure
UGS	Urban Green Spaces
UHI	Urban Heat Islands
UN	United Nations
UNDESA	United Nations Department of Economic and Social Affairs
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change
UNFPA	United Nations Fund for Population Activities
UNHABITAT	United Nations Human Settlements Programme
UNICEF	United Nations International Children's Emergency Fund
URR	Urban Risk Resiliency
UT	Union Territories
UV	Ultraviolet
VC	Ventilation Coefficient
VI	Vegetation Index
VNIR	Visible and Near-Infrared
WD-TEG-BAM	Wood-Tegula-Bamboo
WHO	World Health Organization
WI	Water Index
WRF	Weather Research and Forecasting
WSUD	Water Sensitive Urban Design
WTP	Willingness to Pay
WWT	Wastewater Treatment

1 Blue-Green Infrastructure for Addressing Urban Resilience and Sustainability in the Warming World

Shalini Dhyani, Sunidhi Singh, Mrittika Basu, Rajarshi Dasgupta, and Harini Santhanam

Abstract

Urban blue-green infrastructure (UBGI) has been recognized as vital component of urban environment management, disaster risk reduction, and climate change adaptations. There has been growing consensus and advancement in the conceptualization, research, implementation, and mainstreaming of UBGI in urban policy planning to enhance urban resilience to increasing disaster risks and climate change. Despite the growing interest in UBGI, most of the global research on UBGI has been carried out in the Global North, while uncertainty linked with the performance of UBGI in the Global South has resulted in lack of confidence, and public acceptance has limited its adoption and implementation in many developing Asian countries. This edited book volume investigates the issues, gaps, opportunities, and advances related to UBGI from the diverse perspectives of researchers and experiences of professionals from various science and policy disciplines to enhance and enrich the existing knowledge on effective mainstreaming of UBGI across Asia. Case studies highlighting UBGI successes, gaps, opportunities, and threats from different Asian countries are presented in

S. Dhyani (✉) · S. Singh
CSIR-National Environmental Engineering Research Institute (CSIR-NEERI), Nagpur, Maharashtra, India
e-mail: s_dhyani@neeri.res.in

M. Basu
Laboratory of Sustainable Rural Development, Graduate School of Global Environmental Studies, Kyoto University, Kyoto, Japan

R. Dasgupta
Institute for Global Environmental Strategies, Kanagawa, Japan

H. Santhanam
National Institute of Advanced Studies, Bengaluru, India

S. Dhyani et al. (eds.), *Blue-Green Infrastructure Across Asian Countries*,
https://doi.org/10.1007/978-981-16-7128-9_1

this volume. However, all the cases discussed in the book stress on identifying and managing biophysical and sociopolitical threats for enhancing and ensuring the mainstreaming of UBGI as practical and scientifically sound sustainable solutions that involve multi-stakeholder groups. The volume especially highlights the potential of UBGI in providing ecosystem services for addressing emerging urban environmental risks, enhancing climate change adaptation, and urban disaster risk reduction. The thematic and cross-cutting chapters bring in scientific evidence-based innovations to enhance the prospects of UBGI (environmental, economic, and social benefits).

Keywords

Urban ecosystems · Disaster · Climate change · Urban blue-green infrastructure · Resilience · Sustainability

1.1 Introduction

Uncertainty, unpredictability, and transformation are considered crucial features of the Anthropocene. It was observed for the very first time, in the year 2009, that a comparatively lesser number of people were living in rural areas than urban expansions. More than 70% of the population of the world is projected to live in urban areas by the year 2025. Urbanization is rapidly occurring in secondary cities of Africa and Asia, and these secondary cities are projected to be the future urban centers of growth and massive expansion (Cissé et al. 2011). Presently, Anthropocene has entered the urban century having multiple urban sustainability challenges as these urban centers are contributors of more than 70% of global greenhouse gas emissions and 90% of them are close to coastal areas (Elmqvist et al. 2019). Urban areas and urbanization have severely altered the society-environment relationship by disturbing the sustainability and resilience at alarming rates by enhancing the complexities (Romero-Lankao et al. 2016). Larger impacts of climate change, despite being a global problem, are observed locally, and cities are emerging as new hotspots of risks and disasters (Hordijk and Baud 2011; Dhyani and Thummarukuddy 2016; Dhyani et al. 2018). Megacities of the south are extremely susceptible to these ongoing and emerging challenges due to exponential growth in population, poor living conditions due to poverty, and climate change (Wilhelm 2011). Globally, urban population ratio has surpassed 50% in 2007 and is continuously rising following Northam's "S"-curve theory (Shen et al. 2016). Several fast-growing urban areas in the developing and underdeveloped countries of the Global South, due to rampant urbanization and insufficient enforcement of urban planning guidelines, are vulnerable to floods (Drosou et al. 2019). Urbanization through its rapid developmental projects has changed permeable open surfaces to hard impermeable concretized surfaces. These changes on soil surface have drastically affected and changed the hydrological cycle and enhanced flash floods in fast-expanding urban areas (Shafique et al. 2018). Shrinking green and blue spaces and increasing built-up and concretized surfaces has enhanced urban heat islands and reduced groundwater infiltration (Lahoti et al. 2019). Urban areas worldwide are facing drainage issues, enhanced flood incidences, and heat and water stress (Liu et al. 2014; Majidi et al. 2019). Concepts like natural capital, ecosystem services, and nature's contributions (benefits and disbenefits) define the numerous profits people receive from nature. Rapid and often unplanned urbanization across the world has been the key factor behind the deterioration and loss of natural capital universally (Ncube and Arthur 2021). Urban resilience and nature-based solutions (NbS) are globally acknowledged and endorsed in different international agreements and targets (SDGs, Paris COP, CBD, Ramsar Convention, etc.) for their additional co-benefits in disaster risk reduction and climate adaptations (Suárez et al. 2018). Climate change and uncontrolled urban sprawls can bring multiple challenges to urban planning with special reference to water management. In order to counter these challenges, NbS and resilience building need to be promoted as balancing approaches to counter the emerging issues in urban areas of the world (Suárez et al. 2018). The conceptual development of sustainable urban infrastructure has been intensifying ever since the UN proposed the idea of sustainability in the year 1982 (Du et al. 2019). Sustainable urban development is interspersed with eco-action that leads to socio-ecosystems and green infrastructure for building ecological resilience (Vargas-Hernández and Zdunek-Wielgołaska 2021). Urban environmental concerns have their deep roots in ecology as well as urbanism perspectives (Masnavi et al. 2019). In academic and policy discourses, the conception of urban resilience is flourishing (Meerow and Newell 2019). Sustainability and resilience have emerged as important ideas that focus on understanding the essential urban dynamics to address the challenges and ensuring habitable urban futures (Romero-Lankao et al. 2016). Considerable optimism is being attributed to the capacity of resilience building to balance environmental risks in the warming world (Borie et al. 2019). "Resilience" as a concept is relevant in urban planning and practice as it can offer innovative and progressively appropriate concepts and approaches for addressing the complexities of the urbanized world to safeguard communities from diverse emerging risks and hazards (Coaffee and Clarke 2015). Resilience building can also be advantageous when the internal and external system sustainability components are considered while planning suitable nature-based solutions (Dhyani et al. 2021a). Enhancing urban socioeconomic and spatial vulnerabilities and loss of natural environment reflect the growing requirement of resilience thinking in urban planning and development (Masnavi et al. 2019). Urban areas present exceptional challenges as well as opportunities for sustainability and resilience. Urban expansion relates to the socio-ecosystem that is itself a complex human-dominated system having erratic ecological resilience that experiences continuous interaction of physical, structural, engineering, social, psychological, natural, and environmental components that can influence each other for developing resilient city (Vargas-Hernández and Zdunek-Wielgołaska 2021). Understanding, supporting, and promoting diverse knowledge types, stimuli abilities, and aims of diverse members and their networks are considered vital for developing sustainable and resilient cities (Romolini et al. 2016). For transforming existing social-ecological systems, the transformative capability needs to be strengthened by supporting its three pillars, i.e., reconnecting life-support systems, agency, and social interconnections (Ziervogel et al. 2016). However, it is important to note that there is no simple "spatial fix" for overconsumption that is prevalent in growing urban areas. Hence, the crucial role of urban planning in the warming world will be for adaptation and not mitigation (Gleeson 2008). Enhancing and improving education opportunities followed by access to information, improving awareness, endorsing transfer of innovative technologies, strengthening connections and collaborations among organizations, improving convergence, decentralized governance, and reassuring citizen involvement can be advantageous for steering the theoretical complications along with other diverse perspectives of multiple stakeholder groups. A transdisciplinary approach can ensure co-production of key knowledge for resilience building that also connects the science-policy interface (Aldunce et al. 2016). Despite having global endorsement of the concept urban resilience and their need for human well-being, it has not been appropriately addressed in different national contexts especially for the countries in the South. "Resilience thinking" along with the "community-based adaptation" has been endorsed globally, but the scientific evidences of the successes of the approach are confined to regional levels from rural areas for natural resources management (NRM) within social-ecological systems. Still, there exists a major gap in urban resilience praxis to connect the resilience theories with actual implementation. Sustainable urban growth can only be achieved when resilience building is considered in suitable urban planning (Zhang and Li 2018). Climate and increasing pandemic risks have enhanced the need to integrate blue-green infrastructure (BGI) in urban areas as a pressing call for practical and sustainable urban areas of present and futures. The potentials of BGI have already been highlighted in many scientific studies for their diverse ecosystem benefits in ensuring human well-being and urban sustainability (Staddon et al. 2018) especially to solve urban climate and health crises (Pamukcu-Albers et al. 2021). There is growing global demand need to expand and improve BGI, especially for the countries of Global South following an integrative and participatory approach (Fig. 1.1).

Chapters in this book are authored by invited expert professionals, scientists, and practitioners who have decades of research experience related to urban BGI (UBGI). These experts have also contributed novel ideas to improve existing BGI-based solutions to reduce disaster risks and enhance climate adaptations for good quality of life of urban residents. The edited book volume is an effort to showcase the context, concept, issues, cases, relevance, and growing need to mainstream BGI in fast-expanding urban sprawls of Asia. Despite urban areas of Asia facing extreme disaster risks and climate vulnerabilities, the importance and role of ecosystem-based approaches or BGI in addressing climate as well as disaster risks are either ignored or have not received sufficient recognition so far. Under the different subheadings of this opening chapter of the book, we not only bring the concepts of BGI but also showcase ongoing developments and novel approaches for implementing BGI. Chapters in different sections of this book volume provide a broader overview of scientific advances in the field of BGI followed by the key gaps and issues to mainstream and implement them. A dedicated last section of the book

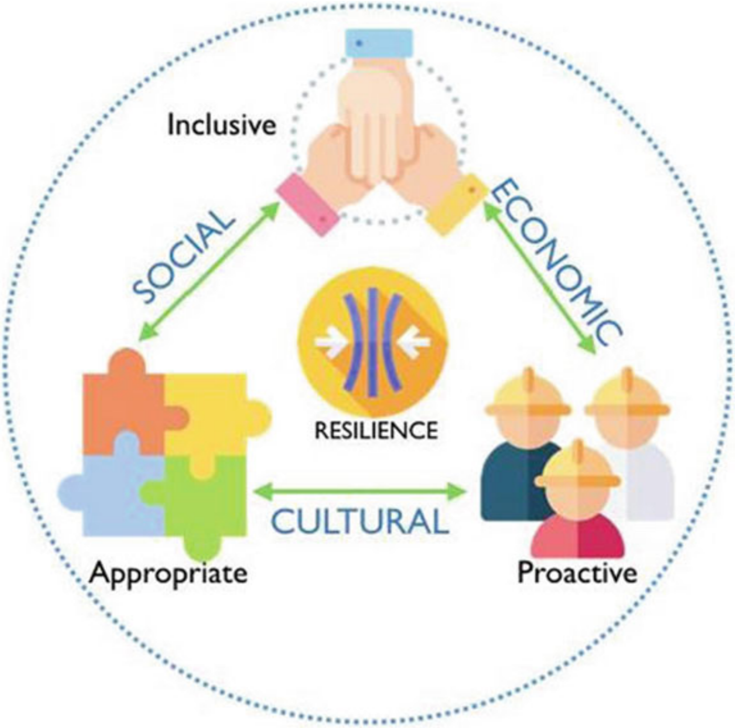


Fig. 1.1 Community-centered approach to enhancing flood resilience with blue-green infrastructure (BGI) *(Adapted from (*Drosou et al. 2019*)*

volume discusses the opportunities and pathways to mainstream BGI in urban policies and urban planning in developing countries of Asia.

1.1.1 Urban Blue-Green Infrastructure—Examples

Rapid urbanization is leading to an exponential rise in population densities in risk-prone zones (Andersson et al. 2017). Habitat loss and modification as a probable environmental impact of urbanization warrant the incorporation of ecologically sensitive strategies into urban planning (Evans et al. 2019). Predictions of rampant urban expansion and increasing water hazards and risks in Asia require substantial investments in NbS, viz., urban green spaces and ecosystem-based engineered systems. Most of the awareness and scientific research on BGI is emerging from the Global North, overseeing the multiplicity of global urban issues and contexts (Hamel and Tan 2021). Adaptation capacity is a vital essential for urban resilience. Considering the establishment of open green spaces that are accessible by the local public can enhance urban resilience (Ni'mah and Lenonb 2017). BGI is a recognized approach to develop resilience to counteract growing urban vulnerabilities because of climate change and disaster risks (Thorne et al. 2018). BGI significantly depends on the ecosystem services of urban green spaces and natural water flows for urban hazards and risks (Lamond and Everett 2019; Dhyani et al. 2020). The multi-functionality of BGI and its several co-benefits can lead to mutual efforts to develop an infrastructure that can help to achieve the strategic goals of both public and private organizations (O'Donnell et al. 2018). Integration of BGI concepts and approaches for developing urban landscapes has the potential to increase flood resilience and offer broader environmental benefits (Drosou et al. 2019). BGI is an ecosystem-based approach that depends on biophysical measures, e.g., confinement, stowage, permeation, and biological uptake of contaminants, to achieve urban floodwater quantity as well as quality. BGI as an innovative approach involves urban water management and green infrastructure to regulate natural water cycles for improving and restoring urban ecology (Drosou et al. 2019). Rain gardens, bioswales, biopores, infiltration wells, retention ponds, sponge gardens and cities, constructed wetlands, permeable pavements, rainwater harvesting, and green roofs are examples of some commonly used BGI infrastructures unlike the gray civil engineering structures intended to take away stormwater (e.g., drainpipes, culverts) (Sidek et al. 2013; Li et al. 2016; Metcalfe et al. 2018; Malaviya et al. 2019; Santhanam and Majumdar 2020; Ekka et al. 2021). BGI is different than single-functioned gray engineering infrastructure, and these landscapes are capable of delivering multiple ecosystem services. BGI also provides other eco-benefits like disaster risk reduction and climate change adaptation and also includes flood risk reduction, improving water quality, and reducing the temperature while conserving and protecting urban ecosystems and biodiversity (Liao et al. 2017) (Fig. 1.2).

Constructed wetlands (CWs) are helpful in sustainably treating urban wastewater. CWs are biological systems that have been globally well studied in the last three decades. The selection of appropriate plant species and their combinations have been proven to significantly enhance the bioremediation potential of the performance of CWs (Licata et al. 2019). Thus, CWs are promising ecosystem-based wastewater treatment systems, having exceptional treatment ability and an eco-friendly appeal; their cost-effectiveness has made them relevant to scientists and urban planners to be explored as sustainable technologies especially for developing countries of the Global South (Stefanakis 2016; Rousseau 2018). Hotels, guest houses, lodges, and resorts worldwide are adopting different CWs that include surface as well as subsurface flow in unconventional ecosystem-based wastewater management systems (Makopondo et al. 2020). Out of many BGI as best management practices (BMPs), rain gardens (also referred to as "bio-retention systems") are widely used to decrease nonpoint source contamination to urban water bodies. Physicochemical and biological characteristic of rain gardens reduce contaminants and help in the storage of runoff water by reducing peak flow. Rain gardens have also improved nutrient cycling and decontamination of heavy metal and are an additional source of recreation (Malaviya et al. 2019). Rain gardens area well-known green technology to ensure stormwater management in Malaysia. Integrated efforts in managing stormwater in fast-expanding urban areas have been well utilized in Malaysia that

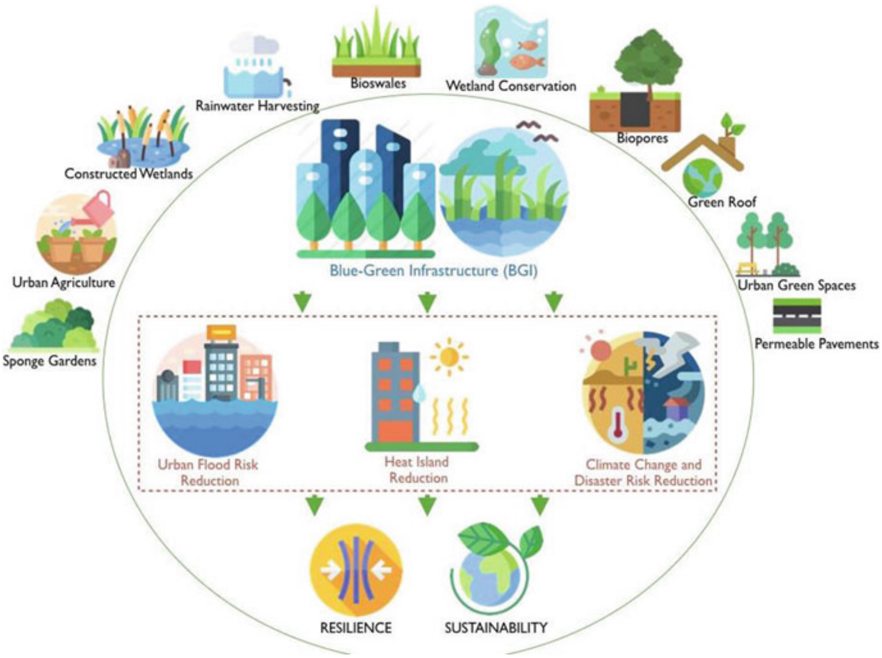


Fig. 1.2 Blue-green infrastructure to mitigate risks and hazards and develop urban resilience and sustainability

ensures reducing peak discharge followed by reducing diverse stormwater pollutants (Sidek et al. 2013).

Swales as one of the oldest green technologies or BGI help in controlling flash floods by treating the roadway runoff. Swales are also evolving into flash flood treatment options and as a vital part of BGI to develop resilient cities (Ekka et al. 2021). Bioswales as a critical constituent of water-sensitive or a low-impact urban design include trees as a novel approach to release the water from flash floods to the atmosphere following the ecophysiological process of transpiration loss. Trees in bioswales lead to 46–72% of water outputs from transpiration that helps in reducing the runoff. Plants with high stomatal conductance contribute the greatest to the bioswale function (Scharenbroch et al. 2016). Bioswales are considered extremely noticeable interventions that demand support from urban locals as well as urban planners to implement and preserve them suitably (Everett et al. 2018).

Biopore infiltration holes are found an effective solution for mitigating flood disasters. Biopores as infiltration holes are used in dense urban areas having marginal water catchment zones, and by enhancing the absorption of groundwater, they reduce the intensity and impact of flooding on urban areas (Khusna et al. 2020). Wet retention ponds can temporarily store as well as slowly release the floodwater to moderate peak flow rates of the flood and also can help to eliminate particulate-bound contaminants. Having sandy underlying soils, wet retention ponds are reported to deliver surplus co-benefits by enhancing the infiltration and recharging the groundwater by supporting the base flow of small streams (Baird et al. 2020). Investigation of infiltration well use indicates that they are capable of reducing flood peaks by up to 50% compared to without wells (Kusumastuti et al. 2017).

Permeable Pavement Systems (PPS) are sustainable drainage systems that can help to improve water security. Substantial research has been carried out on the functions of PPS as sustainable drainage systems for enhancing water quality (Imran et al. 2013). Construction of PPS in urban sidewalks is a low-impact development (LID) to reduce and control the stormwater runoff volume for decreasing the pollutants in urban blue spaces (Kamali et al. 2017; Santhanam and Majumdar 2020). PPS including full depth permeable pavement (FDPP) is expected to be part of the integrated sustainable transportation program (Kayhanian et al. 2019). Evaporation-enhancing PPS are known for their potential to mitigate UHI than conventional permeable pavement (Liu et al. 2018). PPS can function hydraulically to remove particulate pollutants if they are maintained and cleaned annually (Kamali et al. 2017).

Green roofs are another UBGI that can enhance the urban biodiversity and reduce the storm peak to the drainage systems by reducing the runoff quality as well as quantity while also reducing the air pollutants (Li and Yeung 2014). Green roofs address diverse urban environmental and socioeconomic problems and ensure unrestricted flow of ecosystem services by acting as multifunctional and decentralized units. Depending on the specific urban challenges that a city expects, diverse green roof configurations can be considered (Calheiros and Stefanakis 2021; Dhyani et al. 2021a). Covering the external concretized urban built-up surfaces with green vegetation can address many socioeconomic and ecological issues. Urban Green Spaces, especially, significantly improves indoor thermal issues by reducing the temperatures and enhancing comfort (Abass et al. 2020).

1.1.2 Global Recognition and Acceptance of UBGI

To address the growing environmental and human well-being challenges of urban areas, urban policies are gradually shifting their attention from civil engineering interventions to NbS and UBGI (Raymond et al. 2017). Green infrastructure (GI) as a practical physical structure is increasingly been acknowledged as the most profitable approach to adapt and mitigate the social-ecological and climate challenges using multifunctional ecosystem services of urban green spaces (Liu et al. 2020). The emerging importance of BGI in the Global South has a focus on sustainable development in fast-expanding urban areas. This development targets to address concerns of urban vegetation, land use plans, nutritional security, and poverty reduction (Valente de Macedo et al. 2021). While managing urban water woes, BGI has been unanimously appreciated for its co-benefits that can help to improve quality of life and ensure human well-being (O'Donnell et al. 2021). While exploration of urban agriculture dominates in Africa, urban green spaces and parks are more frequently discussed and implemented in Asian, Latin American, and Caribbean countries (Valente de Macedo et al. 2021). The prospects of UBGI that include ecological engineering, natural infrastructure, green infrastructure, urban forests, urban green spaces, urban agriculture, etc. have been widely endorsed and acknowledged by researchers, scientists, academicians, bureaucrats, urban planners, as well as policymakers (Armson et al. 2013; Dhyani and Thummarukuddy 2016; Raymond et al. 2017; Dhyani et al. 2020, 2021a). UBGI have proven air quality (Calfapietra et al. 2015), biodiversity, and ecosystem services (Connop et al. 2016; Tan and Jim 2017; de Oliveira and Mell 2019), mitigate heat island (Makido et al. 2019), reduce urban flash flood risks (Majidi et al. 2019), and provide solutions to many urban sustainability issues and challenges (Perez and Perini 2018) that include public health and human well-being (Bennett et al. 2015).

The "Sponge City Concept" (SCC) has enhanced curiosity and interest in urban planning. Chinese cities, especially, are recognizing the benefits of Sponge Cities technologies. At the national level itself in China, the State Council has set an advanced target to implement SCC initiatives by 2030 (Zevenbergen et al. 2018). Sponge City (SPC) as an urban water management program was projected in 2014 by China to reduce urban flood inundation and water shortage (Li et al. 2016). A total of 16 cities have been selected in 2015 by China as SPC's pilot cities including Wuhan (Zhang et al. 2018).

1.1.3 Opportunities and Challenges

There are examples and proven evidence that BGI is capable of enhancing flood damage control; improving water quality, size of habitats, and carbon sequestration potential; and reducing noise pollution. Using BGI for multiple co-benefits can enable partnerships for the execution of multifunctional BGI (O'Donnell et al. 2018). Exploration and identification of air pollutant-tolerant tree and shrub species in the plantation zones to reduce and control air pollution; spreading bioswales to improve urban connectivity by enhancing green spaces; and using green roofs for noise attenuation and carbon sequestration are some of the important co-benefits and opportunities (Fenner 2017). BGI has progressively been recognized as a vital mechanism and approach for managing urban floods. However, there is a lot of uncertainty about their hydrologic outputs and lack of public acceptance that are important challenges that have so far limited its widespread adoption (Thorne et al. 2018). For example, insufficient knowledge and technical care; off-season low volume discharge; limited land availability; and the approach of urban planners for including CS are few of the major challenges (Makopondo et al. 2020). There is limited field-based practical knowledge to mainstream BGI in urban planning despite the significant amount of research been carried out on the subject. However, greater insights on the performances of existing BGI along with urban gray engineering infrastructure are needed for objective assessments of their capabilities. There is a need for more primary data on the impacts of BGI on hydrology along with societal and environmental impacts (Hamel and Tan 2021). Urban planners, bureaucrats, policymakers, and scientists should mainstream urban resilience and sustainability in decision-making (Zhang and Li 2018). There is clear evidence that urban green spaces along with blue spaces improve the effectiveness of urban risk resiliency (URR). Still mainstreaming and inclusion of urban green spaces (UGS) has been significantly limited in developing and underdeveloped countries. A dearth of integrated approaches, insufficient understanding or expertise in green-engineering designs, lack of regular monitoring, and management are some of the key challenges to mainstream BGI in fast-growing urban areas (Mukherjee and Takara 2018). Determination of the zones facing UGS degradation can help urban planners in proactive planning by efficient allocation of finances for conserving and restoring degraded UGS (Bardhan et al. 2016). The instrument of open green space provision for the growing urban sprawls should be endorsed for developing "urban green commons" as an organized approach for collective participation in land management in urban areas (Ni'mah and Lenonb 2017). However, the valuation of the prospective environmental profits from urban green space is challenging because of the irregularities in management practices and their dissimilar nature (Pudifoot et al. 2021). Performance-based monitoring can be an important approach to improve the effectiveness of UGS to address urban heat and water stress (Mukherjee and Takara 2018). It has also been observed that national and regional statutes do not identify adaptation arrangements for urban areas (García Sánchez et al. 2018). Cities are the most active entities in the implementation of adaptation strategies. The vital need of adapting urban sprawls to climate risks demands robust political and administrative action at the local level. Local adaptive actions can address the explicit requirements and capabilities of local communities and socioeconomics. It is important to understand that climate change adaptations at a local level may initiate new and exceptional challenges for the local administration and this might exceed their existing capacities regarding the risks, understanding, economic requirements, and legal accountability. This case is more observed in developing and underdeveloped countries (Garschagen and Kraas 2011). However, in developed countries like the USA and many European countries, municipal sovereignty helps to regulate and integrate climate change adaptation in their plans and actions. For example, Red Hook in New York and Zorrotzaurre in Bilbao City have taken up the initiatives to outline adaptation plans without even waiting for the state statutory act or policies (García Sánchez et al. 2018). Transformative changes in policy and enforcement concerning strictly multifunctional setup are required to enhance the provisions of numerous BGI profits for fulfilling priorities and strategic aims of respective cities. BGI uptake is expected to improve by enhancing awareness of urban planners and policymakers concerning multifunctional BGI. BGI has global significance for other expanding urban areas that are on the way to ecological and sustainable futures (O'Donnell et al. 2021).

1.1.4 Progress and Developments in UBGI on the Science Front

The urban adaptation issue has largely been a physical one and focuses on protecting the existing infrastructure and urban form of cities. In the last few decades, significant attention has been dedicated to the protection of critical urban infrastructures to safeguard cities from sea-level rise, floods, droughts, increasing temperatures, and other associated impacts of climate change (Tusinski and Balbo 2011). Ongoing urban expansion globally on priority requires integration and establishment of adaptation strategies against climate change (Mathey et al. 2011). It is important to note that BGI has still not been realized as a low-impact advanced plan to address urban risks, excluding in China, where investigators are working on numerous cases of systematic inclusiveness of BGI in urban planning and ecosystem-based disaster risk reduction (EcoDRR; Valente de Macedo et al. 2021). Transitional "hybrid" approaches, which include both blue and green as well as gray approaches, have been most effective in reducing urban hazards and risks (Depietri and McPhearson 2017).

1.1.4.1 Urban Green Spaces for Increasing Resilience

Urban green spaces (UGS) are of great benefit to growing urban areas. UGS can enable and support nutritional security, social connections, human well-being, livelihoods, and many other direct and indirect benefits. UGS has proven potential to ensure resilience and refuge of energy security, health benefits, water security, food and nutrition, ecosystem services, and biodiversity systems (Mukherjee and Takara 2018). Urban green spaces have also been highly endorsed as NbS that can help to alleviate the negative impacts of climate change (Pudifoot et al. 2021). To develop resilience against extreme events, place and composition of urban green spaces are expected to be the key adaptive strategy of fast-expanding urban areas facing climate vulnerabilities (García Sánchez et al. 2018) (Fig. 1.3).

1.1.4.2 UBGI to Manage Urban Heat Islands

Increasing temperature conditions are intensified by climate change that has enhanced urban heat islands having serious implications on human well-being in urban areas. In the last more than a decade, there is growing concern that by following the preventative attitude, urban designs and infrastructure must address the changes in the urban climate to make the urban areas comfortable and habitable for the future (Katzschner 2011). Urban heat island (UHI) is a threat to urban areas and the world over; the ongoing efforts are targeting to solve the issue by integrating UBGI (Liu et al. 2018). Green infrastructure has proven potential to improve urban climate and has a critical role in reducing and mitigating heat islands (Mathey et al. 2011). UGS are complementary substitutes to engineered infrastructures to enhance and enrich the urban quality of life by mitigating urban heat islands (UHI) and urban water management (Mukherjee and Takara 2018). Stand-alone green roofs, as well as hybrid green roof systems as a BGI with other established techniques, are also proven to substantially reduce heat islands (Vijayaraghavan 2016). The extent of water and green zones, leaf area index (LAI) of roads, and hydration degree of green roofs, along with the location of green walls, are essential BGI factors for UHI mitigation (Antoszewski et al. 2020).

A study in Medellin Metropolitan Area, Colombia, projected carbon sink potential and emission offsets by urban green spaces (Reynolds et al. 2017). Considering

Fig. 1.3 Urban blue-green infrastructure for disaster risk reduction, socio-ecological and economic benefits, and human well-being

the available space for plantations, carbon offsets can be even more inexpensive, ensuring an unrestricted supply of co-benefits that can help in the socioeconomic upliftment of urban poor. Nowak, Dhyani, and Zheng have also endorsed the importance of urban green forests in the carbon sequestration of urban and community areas in the USA, India, and China (Zheng et al. 2013; Nowak et al. 2013; Dhyani et al. 2021b). Urban and peri-urban green areas were found to have a profound impact on biomass-based vegetation carbon stocks, and the density of plants enhances these positive impacts (Yao et al. 2017). Similarly, lined parks along the city waterways were observed to improve the well-being and helped developing community resilience (Giannakis et al. 2016). Urban green space design for climate adaptation for urban areas in India also endorses the NbS and UBGI approach for climate adaptations and mitigations (Govindarajulu 2014). Another study from India has also provided sufficient evidence of how depletion of green spaces in urban areas may jeopardize the flow of ecosystem services and associated co-benefits (Padigala 2012; Imam and Banerjee 2016).

A historic analysis of urban green spaces in Tokyo confirmed remarkable resilience, especially the ability to adjust and reconstruct to address consecutive key disturbances. UGS in Tokyo is reported to be flexible, but is an increasingly declining resource across the city. Tokyo case highlights the risks due to reduction of green spaces that are helpful in indirect recovery by accommodating development and short-term resilience (Kumagai et al. 2015). In another study in the city of Kolkata, it was detected that the small green spaces were significantly influenced by the high built-up area around them that reflected that the older Kolkata zone was vulnerable to risks, whereas the zones bordered by wetlands were the firmest having high resilience to urban risks (Bardhan et al. 2016). In another city of Asia, Karachi one of the biggest cities of Pakistan is extremely vulnerable to climate change and extreme weather events. A noteworthy decline in UGS and enhanced infrastructure buildup were reported between 1984 and 2016. Despite this, the study observed that forests around the city are capable of absorbing up to 55.4 million tons of carbon emissions stressing the need of mainstreaming UGS and BGI in urban planning (Arshad et al. 2020).

1.1.4.3 UBGI to Manage Urban Flood Risks

Urban poor settlements close to water bodies (rivulets, ponds, rivers, wetlands, and coastal areas) are getting more prone to flooding due to climate change and increasing frequency of extreme climate events (Cissé et al. 2011). Conventional urban flood management approaches have been of low sustainability; hence, there has been increasing interest and inclusion of nontraditional drainage BGI measures (Alves et al. 2018). Researchers have given enough evidence to showcase the impacts of gray engineering infrastructures that include trenches, channels, catch basins, and concrete drains that are most commonly employed for reducing urban floods. These gray engineering structures are however not effective to provide the co-benefits that are associated with NbS and UBGI (Watkin et al. 2019). In a study on indicating the demand for NbS using IPCC Risk Framework to generate flood risk carried out in Bandung City of Indonesia, it was observed that distribution of UGS in the city is not equally distributed and hence these green space locations are not capable to support resilience against the urban flood protection (Afriyanie et al. 2020). BGI implementation in Ayutthaya, Thailand, stressed the involvement of diverse stakeholders and giving importance to locally required co-benefits along with flood risk reduction (Alves et al. 2018). In another study in Semarang, Indonesia, the adoption of local BGI was found to be facilitated by following the core principles of inclusiveness, appropriateness, and proactiveness as preconditions for augmenting local resilience to urban flooding (Drosou et al. 2019). Liu et al. (2014) endorsed the benefits of UBGI through their community-scale simulation models that projected reduction of urban floods by reducing their volume and peak flow. However, the study stressed that integrated GIs will be required to reduce the intensity of impacts of larger rainstorms as single GI is not sufficient for harnessing the larger benefits (Liu et al. 2014). Identifying and managing biophysical as well as sociopolitical concerns can help to expand applied, scientifically sound, and locally supported application of BGI (Thorne et al. 2018).

1.1.5 Structure of the Book

This book volume has 23 chapters on diverse topics of BGI and is divided into 6 sections. The book volume includes a detailed introductory chapter providing background on mainstreaming of BGI for improving resilience and sustainability in the warming world by Dhyani et al. (Chap. 1). Chapter 1 covers insights on the global recognition of urban BGI followed by opportunities and constraints to implementing them. Chapter 1 also deliberates on the progress and developments on the core themes of UBGI. Part I of the book highlights "opportunities and advances" for mainstreaming BGI under the same title of the section and discusses the opportunities by implementing UBGI under six important chapters (Chaps. 1–6). Thammadi et al. (Chap. 2) present an overview on regional trends in Social-Ecological-Technological (SET) approaches to sustainable urban planning and discuss the SET approaches with an exclusive focus on Asia. Bartlett (Chap. 3) bring in the risk assessment approach in the volume to urban resilience for addressing the risk of planting trees that cannot adapt and continue to provide the services under future conditions that will be more obvious because of the changing climate and increasing urban risks. Murthy and Khalid (Chap. 4) provide an overview and relevance of citizen science initiatives for mainstreaming and promoting BGI in fast-expanding urban areas of India. This is a sought-out area of work that can potentially revolutionize the conservation of existing BGI in urban areas. The chapter by Chien et al. (Chap. 5) addresses the question if ensuring the sustainable implementation of BGI is possible. It brings in the systems thinking approach for considering and acknowledging the urban rivers as socio-ecological systems. Chapter 6 by Francis et al. elaborates on the importance and contribution of remote sensing (RS) and GIS technology and explains the growing interest in spatial maps to map and design the BGI in growing urban areas. Integration of RS and GIS tools is necessary for systematic mapping of urban green spaces and can also help in understanding the loss and gain as a key indicator of urban ecosystem health. Part II of the book under the title "Challenges and Constraints" is comprised of three chapters (Chaps. 7–9). The opening chapter in the section by Bhaskar et al. (Chap. 7) presents a case of a protected area in the peri-urban Bengaluru Metropolitan Region of South India. The chapter highlights the changing people-nature linkages around green infrastructure in rapidly urbanizing landscapes. Chapter 8 by Bhat et al. showcases the need of understanding the urban ecological risks for harnessing the benefits and co-benefits of nature-based solutions. Scandizzo and Abbasov (Chap. 9) throw light on an important question to understand if urban residents appreciate the economic value of water. The chapter presents a case of Baku City from Azerbaijan and how understanding the economic value of urban blue ecosystems and water can help urban communities to conserve them. Part III of the volume considers the importance of "multiscale environmental design for BGI." The section covers four important chapters (Chaps. 10–13), and the opening chapter of this section is by Jayakody and Basu (Chap. 10) that uses the case of home gardens as an important multiscale environmental design which is a sustainable urban agroforestry system. Home gardens of Sri Lanka are highlighted in the chapter as a sustainable urban agroforestry system to promote urban household well-being. Kanchana C.B. in Chap. 11 of this section discusses the need for enhancing tree cover so that urban liveability can be improved and showcases this through a case of fast-expanding city of Kochi on the west coast of India. Misra and Hussain in Chap. 12 conceptualize and elaborate on remodeling urban spaces for integrating and mainstreaming the blue-green infrastructure and use the case of Guwahati a fast-expanding urban area in northeast

India. The concluding chapter of this section is by Gopalan and Radhakrishnan (Chap. 13) that talks of hidden connections between built form and life in cities. This chapter discusses how important biodiversity is for the growing urban sprawls of India and what are hidden socio-ecological connections in concrete jungles. Part IV of the book volume includes the chapters with a focus on "BGI for Sustainable Water Management." This section has four relevant chapters (Chaps. 14–17). Chapter 14 by Kimura in Part IV discusses the potential of nature-based solutions for restoring an urban Abukuma River in Japan. After the typhoon Hagibis, it was important to explore long-term solutions to reinstate the ecological conditions for the river. Santhanam and Kundu in Chap. 15 of this section bring insight into the vulnerability of the coastal area and highlight the need to plan for and use of NbS for coastal regions. In Chap. 16, deLeon and Magcale-Macandog investigate the physical vulnerability of residential houses to flooding through a case study from the coastal area of Sta. Rosa City in Laguna, Philippines. The last chapter of this section (Chap. 17) by Suganya et al. covers the importance of degrading urban ancient water systems and sacred groves that have been a core foundation of healthy ecosystems and biodiversity conservation in these urban landscapes. Urban expansion has taken a toll on these water bodies and the remaining refuge of biodiversity. The second last section of this volume (Part V) is centered around concepts, advances, and case studies on including BGI in urban environmental risk management with the same title of the section. This section has four relevant chapters (Chapters 18–21) to address the issue. The opening chapter (Chap. 18) of the section by Kadaverugu et al. broadly addresses the potential of BGI in air pollution reduction and mitigation in fast-expanding urban sprawls. The chapter draws attention through a case of an urban expansion where BGI can be implemented and mainstreamed in urban planning for urban sustainability and resilience building. Chapter 19 by Parvin et al. covers the role of BGI in disaster risk reduction and resilience building in urban areas of Bangladesh. Das et al. in Chap. 20 stress the importance of assessing ecosystem health in urban sprawls for EcoDRR inclusive urban planning. Authors endorse and discuss the need for mainstreaming the Singapore Index or City Biodiversity Index (CBI) for improving the BGI in urban areas. Waste management and treatment is one of the most neglected areas of work in urban management. The last chapter of the section (Chap. 21) by Pham Phu et al. covers the case of greenhouse gas mitigation by integrating waste treatment systems toward the low-carbon city in Vietnam. The last section of this book volume (Part VI) is "Policy Concerns for BGI" which further comprises two pertinent chapters (Chaps. 22 and 23). Chapter 22 by Chiang et al. addresses the relevance of nongovernmental actors in facilitating the inclusion and mainstreaming of BGI. Citing an example from Taipei City of Taiwan in Northeast Asia, it provides a comparative overview of the community initiatives for mainstreaming BGI. The last and concluding chapter (Chap. 23) by Ramananda et al. addresses the relevance of mainstreaming BGI in urban policy planning to positively contribute to SDG 11 that is mostly missing from developing and underdeveloped countries in Asia. The chapter stresses facilitating new pathways for localizing and achieving SDG 11 that is interconnected with so many other SDGs as a transformative approach in urban sustainability and resilient building. Through this book volume, editors, as well as authors, expect a satisfactory response and if also possible feedback from readers belonging to diverse backgrounds and fields for encouraging productive critiques that facilitates intuitive and foresighted professional discussions for mainstreaming BGI in urban areas and identification of new research issues to fill the existing gaps.

Acknowledgments The authors are grateful to Knowledge Resource Centre (KRC) CSIR-NEERI for extending help for using software iThenticate under the number CSIR-NEERI/KRC/2021/NOV/WTMD/3 for avoiding plagiarism.

Conflict of Interest Statement The authors report no conflict of interest for this publication.

References

Abass F, Ismail LH, Wahab IA, Elgadi AA (2020) A review of green roof: definition, history, evolution and functions. IOP Conf Ser: Mater Sci Eng 713:012048. https://doi.org/10.1088/1757-899X/713/1/012048

Afriyanie D, Julian MM, Riqqi A et al (2020) Re-framing urban green spaces planning for flood protection through socio-ecological resilience in Bandung City, Indonesia. Cities 101:102710. https://doi.org/10.1016/j.cities.2020.102710

Aldunce P, Bórquez R, Adler C et al (2016) Unpacking resilience for adaptation: incorporating practitioners' experiences through a transdisciplinary approach to the case of drought in Chile. Sustainability 8:905. https://doi.org/10.3390/su8090905

Alves A, Patiño Gómez J, Vojinovic Z et al (2018) Combining co-benefits and stakeholders perceptions into green infrastructure selection for flood risk reduction. Environments 5:29. https://doi.org/10.3390/environments5020029

Andersson E, Borgström S, McPhearson T (2017) Double insurance in dealing with extremes: ecological and social factors for making nature-based solutions last. 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 51–64

Antoszewski P, Świerk D, Krzyżaniak M (2020) Statistical review of quality parameters of blue-green infrastructure elements important in mitigating the effect of the urban Heat Island in the temperate climate (C) zone. Int J Environ Res Public Health 17:7093. https://doi.org/10.3390/ijerph17197093

Armson D, Stringer P, Ennos AR (2013) The effect of street trees and amenity grass on urban surface water runoff in Manchester, UK. Urban For Urban Green 12:282–286. https://doi.org/10.1016/j.ufug.2013.04.001

Arshad A, Ashraf M, Sundari RS et al (2020) Vulnerability assessment of urban expansion and modelling green spaces to build heat waves risk resiliency in Karachi. Int J Disaster Risk Reduct 46:101468. https://doi.org/10.1016/j.ijdrr.2019.101468

Baird JB, Winston RJ, Hunt WF (2020) Evaluating the hydrologic and water quality performance of novel infiltrating wet retention ponds. Blue-Green Syst 2:282–299. https://doi.org/10.2166/bgs.2020.010

Bardhan R, Debnath R, Bandopadhyay S (2016) A conceptual model for identifying the risk susceptibility of urban green spaces using geo-spatial techniques. Model Earth Syst Environ 2:144. https://doi.org/10.1007/s40808-016-0202-y

Bennett EM, Cramer W, Begossi A et al (2015) Linking biodiversity, ecosystem services, and human well-being: three challenges for designing research for sustainability. Curr Opin Environ Sustain 14:76–85. https://doi.org/10.1016/j.cosust.2015.03.007

Borie M, Pelling M, Ziervogel G, Hyams K (2019) Mapping narratives of urban resilience in the global south. Glob Environ Chang 54:203–213. https://doi.org/10.1016/j.gloenvcha.2019.01.001

Calfapietra C, Barbati A, Perugini L et al (2015) Carbon mitigation potential of different forest ecosystems under climate change and various managements in Italy. Ecosyst Health Sustain 1:1–9. https://doi.org/10.1890/EHS15-0023

Calheiros CSC, Stefanakis AI (2021) Green roofs towards circular and resilient cities. CircEconSust 1:395–411. https://doi.org/10.1007/s43615-021-00033-0

Cissé G, Koné B, Bâ H et al (2011) Ecohealth and climate change: adaptation to flooding events in riverside secondary cities, West Africa. In: Otto-Zimmermann K (ed) Resilient cities. Springer Netherlands, Dordrecht, pp 55–67

Coaffee J, Clarke J (2015) On securing the generational challenge of urban resilience. Town Plan Rev 86:249–255

Connop S, Vandergert P, Eisenberg B et al (2016) Renaturing cities using a regionally-focused biodiversity-led multifunctional benefits approach to urban green infrastructure. Environ Sci Pol 62:99–111

de Oliveira FL, Mell I (2019) Planning cities with nature: theories, strategies and methods. Springer, Cham, Switzerland

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, Cham, pp 91–109

Dhyani S, Thummarukuddy M (2016) Ecological engineering for disaster risk reduction and climate change adaptation. Environ Sci Pollut Res 23:20049–20052. https://doi.org/10.1007/s11356-016-7517-0

Dhyani S, Lahoti S, Khare S et al (2018) Ecosystem based disaster risk reduction approaches (EbDRR) as a prerequisite for inclusive urban transformation of Nagpur City, India. Int J Disaster Risk Reduct 32:95–105. https://doi.org/10.1016/j.ijdrr.2018.01.018

Dhyani S, Karki M, Gupta AK (2020) Opportunities and advances to mainstream nature-based solutions in disaster risk management and climate strategy. In: Dhyani S, Gupta AK, Karki M (eds) Nature-based solutions for resilient ecosystems and societies. Springer, Singapore, pp 1–26

Dhyani S, Majumdar R, Santhanam H (2021a) Scaling-up nature-based solutions for mainstreaming resilience in Indian cities. In: Mukherjee M, Shaw R (eds) Ecosystem-based disaster and climate resilience: integration of blue-green infrastructure in sustainable development. Springer, Singapore, pp 279–306

Dhyani S, Singh A, Gujre N, Joshi RK (2021b) Quantifying tree carbon stock in historically conserved Seminary Hills urban forest of Nagpur, India. Acta Ecol Sin 41:193–203. https://doi.org/10.1016/j.chnaes.2021.01.006

Drosou N, Soetanto R, Hermawan F et al (2019) Key factors influencing wider adoption of blue–green infrastructure in developing cities. Water 11:1234. https://doi.org/10.3390/w11061234

Du H, Liu D, Lu Z et al (2019) Research development on sustainable urban infrastructure from 1991 to 2017: a bibliometric analysis to inform future innovations. Earth's Future 7:718–733. https://doi.org/10.1029/2018EF001117

Ekka SA, Rujner H, Leonhardt G et al (2021) Next generation swale design for stormwater runoff treatment: a comprehensive approach. J Environ Manag 279:111756. https://doi.org/10.1016/j.jenvman.2020.111756

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

Evans AJ, Firth LB, Hawkins SJ et al (2019) From ocean sprawl to blue-green infrastructure – a UK perspective on an issue of global significance. Environ Sci Pol 91:60–69. https://doi.org/10.1016/j.envsci.2018.09.008
Everett G, Lamond JE, Morzillo AT et al (2018) Delivering green streets: an exploration of changing perceptions and behaviours over time around bioswales in Portland, Oregon. J Flood Risk Manag 11:S973–S985. https://doi.org/10.1111/jfr3.12225
Fenner R (2017) Spatial evaluation of multiple benefits to encourage multi-functional design of sustainable drainage in blue-green cities. Water 9:953. https://doi.org/10.3390/w9120953
García Sánchez F, Solecki WD, Ribalaygua Batalla C (2018) Climate change adaptation in Europe and the United States: a comparative approach to urban green spaces in Bilbao and New York City. Land Use Policy 79:164–173. https://doi.org/10.1016/j.landusepol.2018.08.010
Garschagen M, Kraas F (2011) Urban climate change adaptation in the context of transformation: lessons from Vietnam. In: Otto-Zimmermann K (ed) Resilient cities. Springer Netherlands, Dordrecht, pp 131–139
Giannakis E, Bruggeman A, Poulou D et al (2016) Linear parks along urban rivers: perceptions of thermal comfort and climate change adaptation in cyprus. Sustain For 8:1023. https://doi.org/10.3390/su8101023
Gleeson B (2008) Critical commentary. Waking from the dream: an Australian perspective on urban resilience. Urban Stud 45:2653–2668. https://doi.org/10.1177/0042098008098198
Govindarajulu D (2014) Urban green space planning for climate adaptation in Indian cities. Urban Clim 10. https://doi.org/10.1016/j.uclim.2014.09.006
Hamel P, Tan L (2021) Blue–green infrastructure for flood and water quality management in southeast Asia: evidence and knowledge gaps. Environ Manag. https://doi.org/10.1007/s00267-021-01467-w
Hordijk M, Baud I (2011) Inclusive adaptation: linking participatory learning and knowledge management to urban resilience. In: Otto-Zimmermann K (ed) Resilient cities. Springer Netherlands, Dordrecht, pp 111–121
Imam AUK, Banerjee UK (2016) Urbanisation and greening of Indian cities: problems, practices, and policies. Ambio 45:442–457. https://doi.org/10.1007/s13280-015-0763-4
Imran HM, Akib S, Karim MR (2013) Permeable pavement and stormwater management systems: a review. Environ Technol 34:2649–2656. https://doi.org/10.1080/09593330.2013.782573
Kamali M, Delkash M, Tajrishy M (2017) Evaluation of permeable pavement responses to urban surface runoff. J Environ Manag 187:43–53. https://doi.org/10.1016/j.jenvman.2016.11.027
Katzschner L (2011) Urban climate strategies against future heat stress conditions. In: Otto-Zimmermann K (ed) Resilient cities. Springer Netherlands, Dordrecht, pp 79–89
Kayhanian M, Li H, Harvey JT, Liang X (2019) Application of permeable pavements in highways for stormwater runoff management and pollution prevention: California research experiences. Int J Transp Sci Technol 8:358–372. https://doi.org/10.1016/j.ijtst.2019.01.001
Khusna NI, Amin S, Sekarrini CE (2020) The effect of using biopore on flood reduction in district of Besuki, Tulungagung Regency
Kumagai Y, Gibson RB, Filion P (2015) Evaluating long-term urban resilience through an examination of the history of green spaces in Tokyo. Local Environ 20:1018–1039. https://doi.org/10.1080/13549839.2014.887060
Kusumastuti D, Jokowinarno D, Khotimah S, Dewi C (2017) The use of infiltration wells to reduce the impacts of land use changes on flood peaks: an Indonesian catchment case study. Pertanika J Sci Technol 25:407–424
Lahoti S, Lahoti A, Saito O (2019) Benchmark assessment of recreational public urban green space provisions: a case of typical urbanizing Indian City. ScienceDirect, Nagpur
Lamond J, Everett G (2019) Sustainable blue-green infrastructure: a social practice approach to understanding community preferences and stewardship. Landsc Urban Plan 191:103639. https://doi.org/10.1016/j.landurbplan.2019.103639
Li WC, Yeung KKA (2014) A comprehensive study of green roof performance from environmental perspective. Int J Sustain Built Environ 3:127–134. https://doi.org/10.1016/j.ijsbe.2014.05.001

Li X, Li J, Fang X, et al (2016) Case studies of the sponge city program in China. 295–308. https://doi.org/10.1061/9780784479858.031

Liao K-H, Deng S, Tan PY (2017) Blue-green infrastructure: new frontier for sustainable urban stormwater management. In: Tan PY, Jim CY (eds) Greening cities: forms and functions. Springer, Singapore, pp 203–226

Licata M, Gennaro MC, Tuttolomondo T et al (2019) Research focusing on plant performance in constructed wetlands and agronomic application of treated wastewater – a set of experimental studies in Sicily (Italy). PLoS One 14:e0219445. https://doi.org/10.1371/journal.pone.0219445

Liu W, Chen W, Peng C (2014) Assessing the effectiveness of green infrastructures on urban flooding reduction: a community scale study. Ecol Model 291:6–14. https://doi.org/10.1016/j.ecolmodel.2014.07.012

Liu Y, Li T, Peng H (2018) A new structure of permeable pavement for mitigating urban heat island. Sci Total Environ 634:1119–1125. https://doi.org/10.1016/j.scitotenv.2018.04.041

Liu Z, Xiu C, Ye C (2020) Improving urban resilience through green infrastructure: an integrated approach for connectivity conservation in the Central City of Shenyang, China. Complexity 2020:e1653493. https://doi.org/10.1155/2020/1653493

Majidi AN, Vojinovic Z, Alves A et al (2019) Planning nature-based solutions for urban flood reduction and thermal comfort enhancement. Sustainability 11:6361. https://doi.org/10.3390/su11226361

Makido Y, Hellman D, Shandas V (2019) Nature-based designs to mitigate urban heat: the efficacy of green infrastructure treatments in Portland, Oregon. Atmos 10:282. https://doi.org/10.3390/atmos10050282

Makopondo ROB, Rotich LK, Kamau CG (2020) Potential use and challenges of constructed wetlands for wastewater treatment and conservation in game lodges and resorts in Kenya. Sci World J 2020:e9184192. https://doi.org/10.1155/2020/9184192

Malaviya P, Sharma R, Sharma PK (2019) Rain gardens as Stormwater management tool. In: Shah S, Venkatramanan V, Prasad R (eds) Sustainable green technologies for environmental management. Springer, Singapore, pp 141–166

Masnavi MR, Gharai F, Hajibandeh M (2019) Exploring urban resilience thinking for its application in urban planning: a review of literature. Int J Environ Sci Technol 16:567–582. https://doi.org/10.1007/s13762-018-1860-2

Mathey J, Rößler S, Lehmann I, Bräuer A (2011) Urban green spaces: potentials and constraints for urban adaptation to climate change. In: Otto-Zimmermann K (ed) Resilient cities. Springer Netherlands, Dordrecht, pp 479–485

Meerow S, Newell JP (2019) Urban resilience for whom, what, when, where, and why? Urban Geogr 40:309–329. https://doi.org/10.1080/02723638.2016.1206395

Metcalfe CD, Nagabhatla N, Fitzgerald SK (2018) Multifunctional wetlands: pollution abatement by natural and constructed wetlands. In: Nagabhatla N, Metcalfe CD (eds) Multifunctional wetlands: pollution abatement and other ecological services from natural and constructed wetlands. Springer, Cham, pp 1–14

Mukherjee M, Takara K (2018) Urban green space as a countermeasure to increasing urban risk and the UGS-3CC resilience framework. Int J Disaster Risk Reduct 28:854–861. https://doi.org/10.1016/j.ijdrr.2018.01.027

Ncube S, Arthur S (2021) Influence of blue-green and grey infrastructure combinations on natural and human-derived capital in Urban Drainage Planning. Sustainability 13:2571. https://doi.org/10.3390/su13052571

Ni'mah NM, Lenonb S (2017) Urban greenspace for resilient city in the future: case study of Yogyakarta City. IOP Conf Ser Earth Environ Sci 70:012058. https://doi.org/10.1088/1755-1315/70/1/012058

Nowak DJ, Greenfield EJ, Hoehn RE, Lapoint E (2013) Carbon storage and sequestration by trees in urban and community areas of the United States. Environ Pollut 178:229–236. https://doi.org/10.1016/j.envpol.2013.03.019

O'Donnell EC, Woodhouse R, Thorne CR (2018) Evaluating the multiple benefits of a sustainable drainage scheme in Newcastle, UK. Proc Inst Civ Eng Water Manag 171:191–202. https://doi.org/10.1680/jwama.16.00103

O'Donnell EC, Netusil NR, Chan FKS et al (2021) International perceptions of urban blue-green infrastructure: a comparison across four cities. Water 13:544. https://doi.org/10.3390/w13040544

Padigala B (2012) Urbanization and changing green spaces in Indian cities (Case study – city of Pune). Int J Geol Earth Environ Sci 2:148–156

Pamukcu-Albers P, Ugolini F, La Rosa D et al (2021) Building green infrastructure to enhance urban resilience to climate change and pandemics. Landsc Ecol 36:665–673. https://doi.org/10.1007/s10980-021-01212-y

Perez G, Perini K (2018) Nature based strategies for urban and building sustainability. Butterworth-Heinemann, Oxford

Pudifoot B, Cárdenas ML, Buytaert W et al (2021) When it rains, it pours: integrating citizen science methods to understand resilience of urban green spaces. Front Water 3:33. https://doi.org/10.3389/frwa.2021.654493

Raymond CM, Frantzeskaki N, Kabisch N et al (2017) A framework for assessing and implementing the co-benefits of nature-based solutions in urban areas. Environ Sci Pol 77:15–24. https://doi.org/10.1016/j.envsci.2017.07.008

Reynolds CC, Escobedo FJ, Clerici N, Zea-Camaño J (2017) Does "greening" of neotropical cities considerably mitigate carbon dioxide emissions? The case of Medellin, Colombia. Sustainability 9:785. https://doi.org/10.3390/su9050785

Romero-Lankao P, Gnatz DM, Wilhelmi O, Hayden M (2016) Urban sustainability and resilience: from theory to practice. Sustainability 8:1224. https://doi.org/10.3390/su8121224

Romolini M, Bixler RP, Grove JM (2016) A social-ecological framework for urban stewardship network research to promote sustainable and resilient cities. Sustainability 8:956. https://doi.org/10.3390/su8090956

Rousseau DPL (2018) Full-scale applications of constructed wetlands in Africa. In: Artificial or constructed wetlands, 2nd edn. CRC Press, Boca Raton, FL

Santhanam H, Majumdar R (2020) Permeable pavements as sustainable nature-based solutions for the management of Urban Lake Ecosystems. In: Dhyani S, Gupta AK, Karki M (eds) Nature-based solutions for resilient ecosystems and societies. Springer, Singapore, pp 329–345

Scharenbroch BC, Morgenroth J, Maule B (2016) Tree species suitability to bioswales and impact on the urban water budget. J Environ Qual 45:199–206. https://doi.org/10.2134/jeq2015.01.0060

Shafique M, Kim R, Kyung-Ho K (2018) Green roof for stormwater management in a highly urbanized area: the case of Seoul, Korea. Sustainability 10:584. https://doi.org/10.3390/su10030584

Shen L, Shuai C, Jiao L et al (2016) A global perspective on the sustainable performance of urbanization. Sustainability 8:783. https://doi.org/10.3390/su8080783

Sidek LM, Muha NE, Noor NAM, Basri H (2013) Constructed rain garden systems for stormwater quality control under tropical climates. IOP Conf Ser: Earth Environ Sci 16:012020. doi: https://doi.org/10.1088/1755-1315/16/1/012020

Staddon C, Ward S, De Vito L et al (2018) Contributions of green infrastructure to enhancing urban resilience. Environ Syst Decis 38:330–338. https://doi.org/10.1007/s10669-018-9702-9

Stefanakis AI (2016) Constructed wetlands: description and benefits of an eco-tech water treatment system. Impact of water pollution on human health and environmental sustainability. https://www.igi-global.com/chapter/constructed-wetlands/www.igi-global.com/chapter/constructed-wetlands/140180. Accessed 7 Jul 2021

Suárez M, Manuel BFD, Méndez-Fernández L et al (2018) Nature-based solutions and resilience as complementary strategies for urban governance and planning: a review of assessment methodologies 1. https://doi.org/10.3390/ifou2018-05959

Tan PY, Jim CY (2017) Greening cities: forms and functions. Springer, Singapore

Thorne CR, Lawson EC, Ozawa C et al (2018) Overcoming uncertainty and barriers to adoption of blue-green infrastructure for urban flood risk management. J Flood Risk Manag 11:S960–S972. https://doi.org/10.1111/jfr3.12218

Tusinski O, Balbo A (2011) Introduction: frameworks for local action – challenges and proactive recommendations. In: Otto-Zimmermann K (ed) Resilient cities. Springer Netherlands, Dordrecht, pp 109–110

Valente de Macedo LS, Barda Picavet ME, Puppim de Oliveira JA, Shih W-Y (2021) Urban green and blue infrastructure: a critical analysis of research on developing countries. J Clean Prod 313: 127898. https://doi.org/10.1016/j.jclepro.2021.127898

Vargas-Hernández JG, Zdunek-Wielgołaska J (2021) Urban green infrastructure as a tool for controlling the resilience of urban sprawl. Environ Dev Sustain 23:1335–1354. https://doi.org/10.1007/s10668-020-00623-2

Viecco M, Vera S, Jorquera H et al (2018) Potential of particle matter dry deposition on green roofs and living walls vegetation for mitigating urban atmospheric pollution in semiarid climates. Sustainability 10:2431. https://doi.org/10.3390/su10072431

Vijayaraghavan K (2016) Green roofs: a critical review on the role of components, benefits, limitations and trends. Renew Sust Energ Rev 57:740–752. https://doi.org/10.1016/j.rser.2015.12.119

Watkin LJ, Ruangpan L, Vojinovic Z et al (2019) A framework for assessing benefits of implemented nature-based solutions. Sustainability 11:6788. https://doi.org/10.3390/su11236788

Wilhelm M (2011) The role of community resilience in adaptation to climate change: the urban poor in Jakarta, Indonesia. In: Otto-Zimmermann K (ed) Resilient cities. Springer Netherlands, Dordrecht, pp 45–53

Yao X, Zhao M, Escobedo FJ (2017) What causal drivers influence carbon storage in Shanghai, China's Urban and Peri-Urban forests? Sustain For 9:577. https://doi.org/10.3390/su9040577

Zevenbergen C, Fu D, Pathirana A (2018) Transitioning to sponge cities: challenges and opportunities to address urban water problems in China. Water 10:1230. https://doi.org/10.3390/w10091230

Zhang X, Li H (2018) Urban resilience and urban sustainability: what we know and what do not know? Cities 72:141–148. https://doi.org/10.1016/j.cities.2017.08.009

Zhang S, Zevenbergen C, Rabé P, Jiang Y (2018) The influences of sponge city on property values in Wuhan, China. Water 10:766. https://doi.org/10.3390/w10060766

Zheng D, Ducey MJ, Heath LS (2013) Assessing net carbon sequestration on urban and community forests of northern New England, USA. Urban For Urban Green 12:61–68. https://doi.org/10.1016/j.ufug.2012.10.003

Ziervogel G, Cowen A, Ziniades J (2016) Moving from adaptive to transformative capacity: building foundations for inclusive, thriving, and regenerative urban settlements. Sustainability 8:955. https://doi.org/10.3390/su8090955

Shalini Dhyani is a Senior Scientist at Critical Zone Group (CZO) of Water Technology and Management Division (WT&MD), CSIR-National Environmental Engineering Research Institute (CSIR-NEERI), Nagpur, India.

Sunidhi Singh is a Researcher and Project Associate at Critical Zone Group (CZO) of Water Technology and Management Division (WT&MD), CSIR-National Environmental Engineering Research Institute (CSIR-NEERI), Nagpur, India.

Mrittika Basu is an Assistant Professor in the Laboratory of Sustainable Rural Development, Graduate School of Global Environmental Studies, Kyoto University, Japan.

Rajarshi Dasgupta is a Senior Policy Researcher in the Institute for Global Environmental Strategies (IGES), Kanagawa, Japan.

Harini Santhanam is an environmental scientist working as an Assistant Professor with the School of Natural Sciences and Engineering at the National Institute of Advanced Studies (NIAS), Bengaluru, India.

Part I

Opportunities and Advances

Regional Trends in Social-Ecological-Technological (SET) Approaches to Sustainable Urban Planning: Focus on Asia

2

Swetha Thammadi, Nidhi Nagabhatla, Sateesh Pisini, Stephanie Koza, and Ashraf Mahmood

Abstract

Rapid urbanization coupled with inadequate infrastructure development impacts urban air and water quality amidst other challenges. Sustainable urban planning considers the integration of blue-green infrastructure (BGI) and ecosystems to produce environmental benefits together with improvement in the quality of life. In this context, the social-ecological-technological (SET) framework provides guiding principles for projects visioning sustainable urban futures. Based on the case study analysis and review of integrated SET frames, BGI innovations, and nature-based solutions (NBS) approaches, it is suggested that the policies to improve the urban landscape could consider interlinkages of environmental, economic, and social systems as important at all stages of planning. Drawing on the key observations from the past and ongoing NBS- and BGI-focused projects and programs in selected cities of Asia, this chapter highlights the role of co-designing, technological innovations, participatory implementation and

S. Thammadi (✉) · S. Pisini
Department of Civil Engineering, Fiji National University, Suva, Fiji
e-mail: swetha.thammadi@fnu.ac.fj

N. Nagabhatla
The United Nations University Institute on Comparative Regional Integration Studies (UNU-CRIS), Brugge, Belgium

School of Geography, Environment and Society (SGES), McMaster University, Hamilton, ON, Canada

S. Koza
School of Geography, Environment and Society (SGES), McMaster University, Hamilton, ON, Canada

A. Mahmood
School of Agricultural Equipment Engineering, Jiangsu University, Zhenjiang, China

S. Dhyani et al. (eds.), *Blue-Green Infrastructure Across Asian Countries*,
https://doi.org/10.1007/978-981-16-7128-9_2

evaluation, and up-to-date knowledge as significant to address challenges in operationalizing the sustainable urban planning vision. Furthermore, Sustainable Urban Natural Resources Management framework is proposed as model for integration of air pollution and water quality management with socio-technical options supported by institutions, legislations, and finance to boost ecological sustainability, disaster risk reduction, and climate change adaptation. Overall, the synthesis will help to understand and evaluate the underlined concepts/ frameworks which are essential to transform these approaches beyond project-based interventions into broader urban sustainability paradigms.

Keywords

Urbanization · Blue-green infrastructure (BGI) · Nature-based solutions (NBS) · Social-ecological-technological (SET) · Sustainable Urban Natural Resources Management (SUNRM)

2.1 Introduction

Urbanization is a defining phenomenon and process of this century (Haas 2012). In 2008, for the first time, the global urban population exceeded the non-rural population, and it is estimated, by 2050, 70% of the global population will reside in cities, with >50% of them in Asia (Seto and Shephard 2009). Increasing urbanization impacts water demand, energy demand, infrastructure capacity, pollution trends, and waste management amidst other challenges. It is to be noted that haphazard urban planning could lead to serious negative effects on water availability, air quality, and provision of basic services and can create major setbacks for the urban sustainability agenda (López-Valencia 2019). On a global scale, water crisis, population growth, disasters, climate change, as well as the dynamics of frequency, intensity, and spatial patterns of temperature, precipitation, and other meteorological factors (IPCC 2015) are projected to have severe impacts on urban spaces and population. For instance, future scenarios and projections for the urban regions, particularly in the context of climate change scenarios, show that cities are at high risk of increasing extreme events (Rosenzweig et al. 2011). Therefore, focus on context-specific and location-based solutions remains pertinent for ensuring sustainable urban futures.

Sustainable urban planning will depend on a balanced approach to developing urban infrastructure while fulfilling the green growth targets (Mell 2009; Breuste et al. 2015). Blue-green infrastructure (BGI) is an “interconnected network of designed and natural landscape components, including water bodies and green and open spaces” such as green rooftops, retention and detention ponds, re-naturalized and de-culverted rivers, swales, and “bioswales” or rain gardens (Abbott et al. 2013). BGI is a term that is commonly used to represent a multifaceted approach to ecosystem-based planning where several ecological functions, such as water flow regulation, air and water purification, are considered (Lee et al. 2018). Local climate regulation and adaptation (Lehmann et al. 2014), biodiversity conservation (Watts et al. 2010), carbon storage and sequestration (Mensah et al. 2016), accessibility for amenities, environmental education, and recreation (Wolsink 2016), and other ecological services could be arranged concurrently in the urban planning agenda through BGI. Key dimensions of BGI planning include connectivity, multifunctionality, applicability, integration, diversity, multiscale, governance, and continuity (Renato et al. 2020). Sustainable urban planning could consider integration of the BGI framework and acknowledge the distinctive capabilities of green space and water—and the ecosystems in which they exist—to produce environmental benefits along with improvement in the quality of life (Daniel et al. 2020). Green infrastructure solutions are a key component of an integrated/hybrid approach with a focus on existing natural capital such as wetlands, bioshields, buffer zones, green roofing, street-side swales, porous pavements, wetlands, mangrove ecosystems, etc. It is to be noted that in literature, BGI often tends to comprehend what we define here as green infrastructure.

At length, in the past, governments have implemented hard engineering or gray infrastructure solutions, and currently, there is a growing interest in an integrated approach to tackle contemporary challenges in urban centers. For example, traditional urban drainage techniques have generally focused on the volume of stormwater to be moved, i.e., to move it far away and as quickly as possible from the city. Water quality and the intrinsic significance of watercourses to various forms of life, maintenance of biodiversity, and provision of recreational space to urban inhabitants have long been neglected by policymakers. Gray infrastructure technologies (i.e., hard or engineering approaches) have not been sufficient and effective to manage contamination in the culverted watercourses, and aquifer recharge, and often these approaches do not consider the inherent potential of rivers and streams and related environmental services (Castro Fresno et al. 2005; CIRIA 2015; CIWEN 2007; Dhakal and Chevalier 2016; Burian and Edwards 2002). The volume of stormwater increases when natural hydrologic functions such as interception, evapotranspiration, retention, and infiltration of rainwater are reduced, which raises the peak, rate of flow, and frequency of flooding (Dhakal and Chevalier 2016). Responses to these concerns now indicate a paradigm shift. The novel responses such as BGI seek to replicate the natural mechanisms of absorption and retention as close as possible to the site of origin.

Furthermore, hybrid and green-gray approaches which utilize combined gray and green infrastructures are gaining global consensus to address the shortcomings of traditional gray engineering solutions to tackling urban drainage. For instance, for coastal flood protection, wetlands restoration is combined with engineering measures such as levees. Bioswales, rain gardens, green roofs, street trees installed in sidewalk tree pits, and other engineered ecosystem approaches to climate change adaptation and disaster risk reduction are commonly discussed in literature and development programs (Yaella and Timon 2017).

In this context, the social-ecological-technological (SET) approach broadens the acknowledgment of technological interventions that include focus on ecological functions and has better social appeal and acceptability. In other words, SET perspective aims to address the limitations of a socio-ecological approach that sometimes tends to overlook the role of infrastructure and technology, vital to shaping urban system dynamics (McPhearson et al. 2016). SET also presents as a fitting framework for researchers and practitioners to explore various adaptation options to climate change's impact on urban systems. Adaptation strategies in urban systems are notably hybrid approaches that work across interacting SETs. Hybrid techniques, therefore, combine engineering and ecosystem functions and are located in the SET framework's ecological and technological intersections. For instance, in urban settings, where simply green approaches may be insufficient to tackle the escalating consequences of climate change and other urbanization-related difficulties such as limited space and cost-effectiveness, hybrid approaches are critical. And there is growing evidence that hybrid approaches are cost-effective and offer a platform for integration of multi-objective agendas (Yaella and Timon 2017).

In this chapter, we provide an overview of the SET approaches in the Asia-Pacific context and within the purview of Sustainable Development Goal (SDG) 11: making cities inclusive, safe, resilient, and sustainable. The chapter is presented in two key sections:

- BGI and nature-based solutions (NBS) within the SET context using case studies from the Asia-Pacific region.
- Sustainable Urban Natural Resources Management (SUNRM) framework with a focus on common solutions to air and water quality management.

2.2 Blue-Green Infrastructure and Nature-Based Solutions: Focus on the Asia-Pacific Region

Within the scope of SET systems, the BGI approach is increasingly promoted in the urban landscapes owing to the "multiple benefits narrative in the context of sustainability agenda." Multiple benefits of these approaches have been observed in the urban areas of Australia, Singapore, the Netherlands, the United Kingdom, and elsewhere (Derkzen et al. 2015; Kilbane 2013; Andersson et al. 2014; Yau et al. 2017; Goh et al. 2017; Young 2011). This is because BGI can be integrated into economically efficient solutions for physical challenges like stormwater management and heat mitigation while also improving the social well-being and nature restoration in the urban landscapes (Lovell and Taylor 2013). In most instances, these interventions are typically implemented for a specific purpose such as flood mitigation or to improve local aesthetics (Chin 2015; Vincent et al. 2017). The selected case studies will highlight the BGI and nature-based solutions within the SET context in urban settings of the Asia-Pacific region, i.e., developing, emerging, and developed economies.

2.2.1 Singapore

Singapore, like many other densely populated cities, faces a significant risk of urban flooding. In 2006, Singapore's National Water Agency (PUB) launched the Active, Beautiful, Clean Waters (ABC Waters) Programme to integrate water bodies with nature-based solutions and built infrastructure—turning Singapore into a "City of Gardens and Waterscapes." Furthermore, it is one of the few countries in the world that harvests considerable amount of urban runoff for its water supply, with two-thirds of the state serving as a water supply catchment. Rainwater collection is coordinated through an extensive network of drains, canals, rivers, stormwater collection ponds, and reservoirs before its treatment for drinking water supply (Lim and Lu 2016).

In 2008, ABC Waters Programme initiated the first rain garden in the country which was completed on the 1.5-acre Balam Estate residential complex. The garden spread is 240 m^2 (4% of its catchment area) and drains a highly urban catchment via a system of detention pond layer (100 mm), filtration layer (400 mm), saturated anaerobic zone (400 mm), and drainage layers (150 mm). The water filtered through the system is discharged into a storm drain that flows into the Marina Reservoir, Singapore's first urban supply reservoir. Water quality and hydrological monitoring were conducted after the completion of the project to assess the performance of the rain garden. This rain garden performed effectively in eliminating total suspended solids (TSS) and nitrogen. Overall, an average reduction in total nitrogen (46%), total phosphorous (21%) and TSS (57%) was reported (PUB 2014). The saturated anaerobic layer of this intervention appeared to enhance nitrogen removal by converting soluble nitrogen to nitrogen gas. Results indicate that the system was functioning within its design capability, with some temporal variability in results. The experiment also presented the challenges of managing leaching problems of ammonium and phosphorus, a common occurrence observed for bioretention systems with saturated anaerobic zones. The case study provides an example how a state and resource managers are trying to understand barriers and success rates of an NBS-focused intervention and using that information to improve the efficiency of the system.

In the country, NBS solutions such as bioretention systems and constructed wetlands are used to treat runoff and reduce the peak flow generated from rain falling on impervious surfaces (Benjamin 2012). The city of Singapore is well protected from floods according to an assessment of the Singapore ABC Waters Programme and related projects (World Bank 2012). In another intervention from the country, in 2014, stormwater codes required all new developments and redevelopments of 0.2 hectares or more to implement solutions to slow down stormwater runoff entering the public drainage system by 25–35%. These on-site measures include NBS oriented solutions such as rain gardens, bioswales, and rooftop gardens, as well as detention tanks. Moreover, the long-term land use and transport plan—2011 concept plan—represents strategic planning focused on BGI vision to guide the 40–50-year sustainability planning horizon for the country. Overall, in alignment with the guiding principle of a SET framework, foresight in designing integrated solutions as demonstrated in Singapore paves a way for the region to adopt and adapt some of these practices at various levels. Taking note of that experience, the country is planning collaboration between various land use agencies and the Land Transport Authority to accommodate demand-supply of provisioning services for anticipated population rise and meet the targets of economic growth and environmental revitalization. This plan incorporates proposals from >20 government ministries and agencies into a national development policy document. The concept plan is translated into operational details in the master plan via medium-term land use and transport plans that provide a guideline for development and implementation with solutions that will determine the use of natural resources for the 10–15-year time frame. At the local level, urban design guidelines consider physical integration between transport nodes and surrounding developments. The integrated framework bears the potential to serve as beneficial for managing ecological and development needs and goals (Toan and Van 2020).

The case study demonstrates that carefully planned and implemented investments in NBS and BGI interventions can help shape a more resilient city and a more sustainable society in the long term while also creating more social spaces for communities to meet and interact (Soz et al. 2016).

2.2.2 India

The Asian Cities Climate Change Resilience Network (ACCCRN), Surat, Gujarat, has designed strategies for better management of natural water bodies and prevented construction on the floodplains in the city. Similar practices have been adopted by Burhanpur and Indore in Madhya Pradesh with the support of the Ministry of Environment, Forest and Climate Change (MoEFCC). A key aspect of these interventions focuses on community participation while designing innovative solutions and conserving and managing traditional water management practices. On the otherhand, in Kolkata (West Bengal), wetlands are utilized to clean the city's wastewater. This has not only saved the cost of constructing a wastewater treatment plant but also provided sustenance and livelihood opportunities to 50,000 people through pisciculture and agriculture (Browder et al. 2019).

2.2.3 Sri Lanka

The Sri Lankan capital city of Colombo is situated on a low-lying river estuary and is highly vulnerable to flooding. Like many developing urban zones, Colombo has encountered flooding risk due to a mix of factors acting simultaneously, i.e., rapid economic growth with an imbalance in a change of land use patterns, haphazard land use planning, and reclamation of the city's unique marshlands without a proper environmental assessment. In May 2010, floods paralyzed the city, leaving 36,000 families homeless, marooning traffic, and submerging the country's parliament in 4 ft. of water (Athas 2010). Economic and financial losses were estimated at US$

50 million, although actual losses reached around US$100 million. Rozenberg et al. (2015) reiterated that natural wetlands in this urban landscape had played a key role in flood management while capturing around 40% of floodwaters during storms. However, degradation and loss of wetland systems at a rate of 1.2% (23 hectares/year) has caused several challenges to the city, including but not limited to loss of 1% of its GDP on average per year due to damages from flooding events such as that of 2010 (World Bank 2016).

To address the above mentioned challenges, the Government of Sri Lanka developed a "Wetland Management Strategy" in 2006 in partnership with the World Bank that allocated US$120 million, designed to preserve wetlands, educate the public, and reduce the social and economic impacts of floods in Colombo. In line with the SET context principles, this project uses a mix of green and gray infrastructure with multiple benefits, i.e., reduction of flood risks, improvement of drainage, and creation of recreational opportunities in the catchment area of the Colombo Metropolitan Region water basin. NBS interventions such as wetland protection and restoration were implemented in addition to traditional approaches such as bank protection walls. The investment of >1 million USD in restoring and protecting the 18-hectare region of Beddagana Wetland Park in the center of the city is a part of urban sustainability strategy, primarily toward flood management goals and to boost the value of wetland ecosystem restoration and conservation while promoting ecotourism and ecological space/aesthetics of the city. The income potential of recreational opportunities was estimated at around $13.6 million/year, i.e., >10 times the initial investment. The Park also provides a refuge for flora and fauna and balances the temperature and air quality of the surrounding region (World Bank 2016). This example demonstrates how, in the recent times, the urban landscape management interventions, urban infrastructure investments, planning, and programs are reflective of the emerging paradigms such as BGI and NBS.

2.2.4 China

China's cities face serious challenges related to urban flooding as well as water shortages. During the last several decades, urban sprawl has increased the impervious zone and destroyed/degraded natural resources like forests, lakes, and wetlands, causing a high risk of flooding, stormwater runoff, and pollution. Urban flooding is causing massive loss of property and human lives. Inundation and water shortage challenges prompted the government to design urban water management interventions in 2014 through Sponge City Program (SPC) (Li et al. 2016) with a NBS design and to address the agenda of comprehensive urban water management strategies implementation. 10 cities were selected by the government as SPC's pilot cities in March 2015, and the "sponge city" concept was applied to 30 cities in 2017. By 2020, the government aimed that 20% of the built area of each pilot district characterize a sponge city and 70% of stormwater runoff should be captured, reused, or absorbed by natural surfaces, and by 2030, 80% of each urban center should meet this requirement.

In the year 2008, >100,000 sqm of roofs in the city of Shanghai were vegetated or had green roofs with the coverage doubling the following year and reaching 900,000 sqm in 2010. Noting multitude of benefits (Qian 2009), such as reduction in the runoff, mitigation of the heat island effect, filtration of air, regulation of building temperature, and garden space for urban agriculture, Zhang (2010) analyzed that the typical green roof could reduce annual rooftop runoff by 55%, while another study by Roehr and Yuewei (2010) documented 75% decline in annual rainwater runoff. Therefore, green rooftops are relatively cost-effective when compared to engineered solutions. In Minhang, the cost estimate for the intervention was 125 yuan (US$18.30)/sqm for rooftop lawns and 370 yuan/sqm for a rooftop garden, and an intensive rooftop park costs 125 USD/sqm and an average of 300–400 yuan/sqm for a simple park. It costs only about 1 USD/sqm for the maintenance of these green rooftops Roehr and Yuewei 2010. Further, the "Grain for Green" program or Program of Returning Cultivated Lands into Forest and Grassland was introduced in 2002 to reconvert agricultural fields in steep slopes into forests by providing farmers with cash and grain subsidies.

The set of initiatives documented above point to the fact that the local government agencies and planners in the urban settings are leading efforts to promote interventions that integrate the urban sustainability agenda targets such as green roofs through demonstration projects, promoting incentive structure, and organizing capacity/educational opportunities. Some districts give advice on suitable plants, trees, and flowers and give incentives to encourage private builders to plant green rooftops. Individuals can "adopt" trees on public rooftops by making donations. Moreover, government agencies have designed rooftop demonstrations in public areas to stimulate individuals and citizens to adopt the practice as the city offers around 19 million sqm of roof areas suited for scaling such interventions as per the survey conducted by the Shanghai Landscaping Bureau in 2008 (Soz et al. 2016). However, less attention is given to explain the cost-benefit analysis and precautionary principles that apply in operationalizing BGI and NBS frameworks in short, medium, and long term.

The Natural Forest Protection Program (NFPP) (experimented in 1998) or Natural Forest Conservation Program (NFCP) (launched in 2002) provides both evidence of success in meeting China's goals and illustrates many of the challenges and potential failures of NBS initiatives. In 1998, devastating floods, attributed to overlogging and steep cultivation in the upper Yangtze, Songhua, and Nenjiang Rivers in China (Tianjie 2008), caused a total loss of 166.6 billion yuan (US$ 26 billion). In response, China introduced the NFPP, which called a logging ban to help protect against erosion and rapid runoff. Forest loss in provinces enrolled in the NFCP was >3 times lower compared to non-NFCP provinces (0.62% versus 2.7% forest loss), and program expansion was estimated to grow with annual output from the forest sector by 5.8 billion yuan and increase employment by 0.84 million by 2010. The range of benefits included a reduction in soil erosion and biodiversity loss (Ren et al. 2015). Amid these interventions, the trade-offs associated with NFCP were presented by critics, pointing to the fact that China has become one of the leading timber importers in the world because of the timber restrictions (Tianjie

2008). In essence, the program has exported (teleporting) deforestation to other parts of the world; some of those regions are now losing biodiversity and forest cover at alarming rates. Further, many of the projects undertaken as part of this program involved monoculture plantations of trees that are not native, do not tolerate local conditions, and fail to provide quality habitat for wildlife (Luoma 2012).

2.2.5 Nepal

Rapid and haphazard urbanization in the Kathmandu Valley in this state has witnessed severe wastewater management problems. Studies show that only about 12% of urban households are connected to sewer systems. Wastewater treatment is virtually nonexistent and almost all the wastewater is discharged into nearby rivers without any treatment. In general, wastewater generated by about two million residents in the city has severely deteriorated the water quality of the Bagmati River (WASH 2011; WaterAid 2006). This has primarily affected the poor people who live in the basin and are most exposed to pollution, degraded and contaminated natural resource systems. In the late 1990s, the Environment and Public Health Organization (ENPHO), with the support from WaterAid in Nepal, UN-Habitat (United Nations program for human settlements and sustainable urban development), and ADB (Asian Development Bank), piloted the concept of constructed wetlands as a small-scale decentralized wastewater treatment strategy. The Sunga wetlands, like most constructed wetlands in Nepal, used a reed bed treatment system (RBTS) that constitutes a bed of uniformly graded sand or gravel with plants such as reeds growing on it. Wastewater is evenly distributed on the bed and flows through it either horizontally or vertically. As the wastewater flows through the bed of sand and reeds, it gets treated through natural processes like mechanical filtering, chemical transformations, and biological consumption of pollutants in the wastewater. The process employs simple natural phenomena and native plants (most commonly, *Phragmites karka*) as it is effective, inexpensive, and easy to manage. The 375 m^2 Sunga constructed wetland can treat 50 m^3 of wastewater/day, the approximate amount produced by 200 households (Tuladhar et al. 2008).

Community support was noted as a key to the success of the intervention after referring to the incident, i.e., failed effort to construct a wastewater treatment wetland in the nearby municipality of Siddhikali due to protest by a few community members. In the case of Sunga wetlands, the planning community was approached to discuss plans for building the wastewater treatment wetland; further they were actively involved (provided labor during construction) and formed a committee for construction and maintenance operation as per the general guidelines of the SET approach. The key highlight is the demonstration of a participatory approach to NBS oriented solutions, buy-in by the local communities, reduced cost of construction, and a better guarantee of the long-term sustainability of the intervention. Monitoring data showed that the system is effective in removing pollutants, such as suspended particles, ammonia nitrogen, BOD (biochemical oxygen demand), COD (chemical oxygen demand), and pathogens. The total construction cost of the wetland amounted to approx. US$ 26,000 at around US$ 40 per m^2 with an average annual operation and maintenance cost of about US$ 290 (Water Aid 2008).

This example shows how NBS is applied as location-based integrated solution. As such, restoration of natural wetlands or maintenance of constructed wetlands for pollution mitigation has significant momentum in the wastewater management segment, more recently as an NBS solution (Nagabhatla and Metcalfe 2018). Also, the case of Sunga wetlands restoration set a precedent for scaling in other urban ecological systems in Nepal and other countries in the region with similar socioeconomic and sociocultural settings. The national urban development projects in Nepal, such as the Urban Environment Improvement Project, have integrated this as a case of best practice; however, a major challenge to scaling of this SET approach is the availability of land to promote and expand the use of constructed wetlands.

2.2.6 Fiji

The rivers and coastline of Lami Town in the Republic of the Fiji Islands are prone to flash and surge flooding. A study by Rao et al. (2013) provided a cost-benefit analysis as part of the Climate Change Initiative, UN-Habitat Cities, and UNEP Ecosystem-Based Adaptation Flagship program. It has been envisioned to guide the decision-makers when considering several available options for climate change adaptation. Adaptation responses were categorized into ecosystem-based adaptation options, social/policy options, and gray engineering options.

Life cycle costs including sensitivity analysis were conducted for these four scenarios: (a) ecosystem-based adaptation options, (b) social/policy options, (c) engineering options, and (d) inaction. It was concluded that ecosystem-based adaptation options integrated with engineering options, i.e., BGI provides a greater benefit-to-cost return in terms of avoiding damages and providing ecosystem services such as supporting inshore artisanal fisheries. The most vulnerable areas of Lami being near rivers, coast damages worth nearly US$115 million were estimated. However, the implementation of adaptation options costs approximately US$ 12 million over 20 years. It was recommended that strategic planning and prioritization of adaptation strategies given the benefits from various options and identification of potential co-benefits such as employment generated would benefit wide range of stakeholders and facilitate regular monitoring and evaluation of the adaptation plans.

2.2.7 Thailand

Koh Mueng in Thailand experiences flooding despite a dike that provides primary flood protection of the area. To assess conventional and green infrastructure, a framework consisting of four main components had been proposed: (1) identification and valuation of ecosystem services (flood regulation, education, tourism, recreation, and art/culture) for all possible adaptation options including pre-mitigation scenario; (2) hydrodynamic simulations used to assess the most effective flood mitigation techniques, as well as a cost-benefit analysis to assess their economic viability; (3) flood protection measures selected based on a thorough understanding of ecosystem services as well as stakeholder/community participation; and (4) development of an abstract landscape layout plan. The solution options were evaluated for flood risk reduction effectiveness using assessments of economic and physical vulnerability, flood hazards, and ecosystem services. The cost-benefit analysis evaluated direct and indirect losses through the physical and economic vulnerability of cultural artifacts, infrastructure, tourism industry, and building stock. Results of the study indicated that a holistic perspective of economic assessments and ecosystem services, integrated with active participation from all stakeholders, has the potential to provide more environmentally friendly and socially acceptable flood protection measures in places especially with cultural heritage (Vojinovic et al. 2016).

2.2.8 Philippines

The country is susceptible to typhoon devastation. The growing scientific evidence and the experiences of local communities on the role of natural infrastructure such as mangroves to protect from waves and storm surges have catalyzed the development of a comprehensive National Coastal Greenbelt Action Plan (World Bank 2015)—intending to support the protection of coastal vegetation and mangroves for risk reduction and conservation through the establishment of 100-meter-wide zones of vegetation. The program prioritized the eastern Pacific seaboard of the Philippines where typhoons make landfall.

In December 2020, the *Philippine Information Agency*, an official public information arm of the government, supported the ASEAN Centre for Biodiversity (ACB) and the Philippines' Climate Change Commission discourse on biodiversity and building resilience emphasizing to incorporate NBS as part of the approach in addressing climate change adaptation.

2.3 Sustainable Urban Natural Resources Management (SUNRM)

Many cities around the world, especially in developing countries, are experiencing rapid growth of the urban population with domestic and commercial activities and increasing volume of transport and industrialization. These developments have resulted in severe water and air pollution affecting the environment and human health. In the absence of adequate urban sustainable planning policy and action, this growth could occur at an ascending social and economic cost. The World Health Organization (WHO) and other international agencies have long identified urban air pollution as a critical health problem. Air pollution puts a strain on sustainable urban development, which includes economic growth, human well-being, social inclusion,

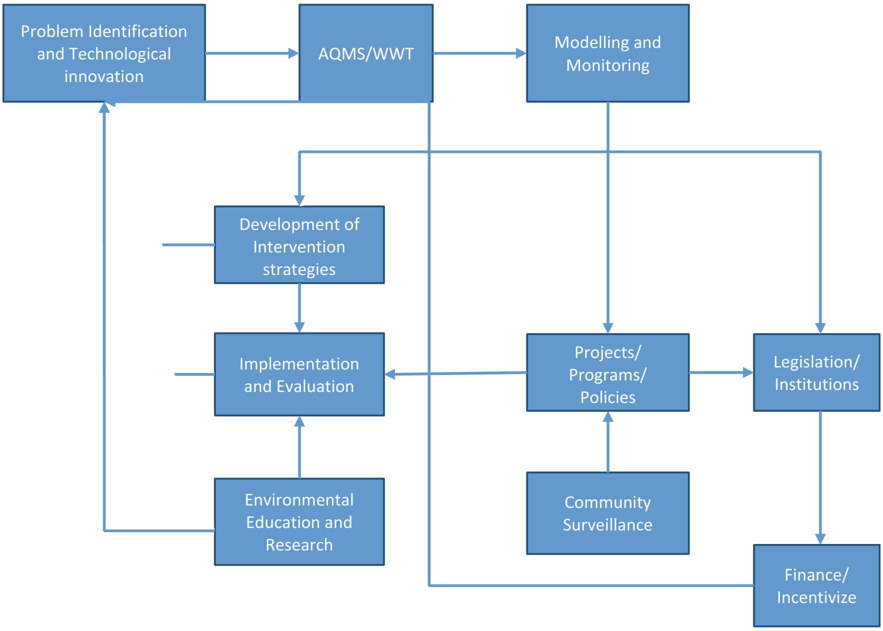


Fig. 2.1 SUNRM (Sustainable Urban Natural Resources Management) framework outline

and the environment. Studies during the past decades have attributed air pollution in megacities in developing countries to emissions from various sources, including industry, vehicular and inadequate inspection, and maintenance programs (Molina et al. 2007; Singh et al. 2007; Wang et al. 2010). A study by Baldasano et al. (2003) provides an account of megacities like Shanghai, New Delhi, Mumbai, Guangzhou, Chongqing, Calcutta, Beijing, and Bangkok which often record ambient particulate matter concentrations violating WHO guidelines. World Bank UFCOP (2016) synthesis reflects that nearly 90% of new urban residents in Africa and Asia reside in underdeveloped, developing, and emerging countries of these regions. The water pollution scenarios are not much different. Water quality is intrinsically linked with human health, poverty reduction, gender equality, food security, livelihoods, and the preservation of ecosystems as well as economic growth and social development (Nagabhatla and Metcalfe 2018). Economic development agendas and environmental sustainability guidelines typically present a challenge of trade-offs in the context of sustainable urban planning.

Urban pollution not only has immediate localized impacts on human health and well-being but also contributes to regional and global air pollution and water cycles due to the "urban heat island" effect. For example, the emission of greenhouse gases (GHGs) resulting from the combustion of fossil fuels in the industrial and transportation sectors contributes to global climate change and are estimated to grow significantly in the cities of developing countries (Johnson et al. 2011).

The Sustainable Urban Natural Resources Management (SUNRM) approach (Fig. 2.1 presents a schematic presentation of the framework) involves a combination of various air and water quality management approaches and tools which could enable planning strategies to improve air and water quality. While air quality management approaches exist in various regions, water quality management strategies are not standardized or lack consistency, although water resources management in general is part of urban planning agendas.

Keypoints of SUNRM Framework

The political will to transform the best available scientific and technological knowledge into action, backed by strong societal support, is the most crucial factor in successful environmental management (Molina et al. 2019). Note that the adoption of comprehensive policies and integrated framework to addressing underlying causes rather than focusing on these challenges in isolation remains key to achieving urban sustainability. In this context, a ten-point agenda is suggested for consideration and implementation by the city/urban authority to successfully tackle pollution challenges and assist their transition to sustainable BGI/NBS paradigms.

1. Problem identification and technological innovations in air/water pollution control aligned to social-ecological-technological approach.
2. Introduction of Air Quality Management System (AQMS) for baseline air quality assessment and management and wastewater treatment (WWT) for water quality management.
3. Introduction of real-time smart air/water quality modeling and monitoring programs—national to community monitoring networks.
4. Identification of gaps and development of intervention strategies such as Environmental Impact Assessment and Water Quality Impact Assessment, promotion of NBS interventions like urban green spaces, terrace garden, etc.
5. Implementation and evaluation of changes as well as impacts.
6. Development and enforcement of projects, programs, and policies for the promotion of NBS/BGI.
7. Legislations and institutions are to be established to regulate commercial activities that do not comply with/subscribe to the norms of air/water pollution management.
8. Provide fiscal incentives and tax exemptions to promote application/scaling of green and clean technologies.
9. Integration of environmental education and SDGs into education curricula and enabling research collaboration across the nations.
10. Establishment of community monitored surveillance system of defaulters and champions.

In the above context, Annexures 1 and 2 outline programs and policies incorporating the focus on innovation and smart interventions as key mechanisms for sustainable urban development, including the agenda highlighted in SDG 11 goals and targets, like Target 11.B calling for a substantial increase in the number of cities and human settlements adopting and implementing integrated policies and plans toward inclusion, resource efficiency, and mitigation of and adaptation to climate change. Also, Target 11.6 aims at reduction of adverse per capita environmental impact on cities, including paying special attention to air quality and municipal and other waste management. The interventions showcased in the Annexure are example of programs that apply integrated framework such as SUNRM. These examples were selected to reflect how small and medium towns and megacities in the Asian region are addressing the set of challenges specific to their context. These interventions do reflect a shift in paradigms toward inclusive and sustainable urban growth and water management solutions. While smaller cities appear to be more specific and tailored to the city's unique needs and available resources, in the large cities, dealing with high levels of water and air pollution issues, energy demands, incorporation of green infrastructure norms and regulations, and environmental sustainability obligations—balancing economic growth and ecological restoration can be a challenging task and makes it difficult to implement the sustainable urban planning. Altogether, the impacts of ongoing set of projects/programs may not reach the desired level, however, these proposed interventions offer potential towards the creation of vision and strategy to combat the challenges and to support the vision of sustainable urban future scenarios that promise social, technical, and ecological equilibrium.

2.4 Discussion Points

Rapid population growth and increasing energy use in sectors like transportation and industry, particularly such activities in the urban region, generate high levels of pollution (air and water). Unsustainable environments are created when population density is combined with insufficient provisioning services and haphazard infrastructure development. Various SET systems are available to mitigate urban matters, and many countries have established contamination and pollution management standards and strategies in recent years, which provide an important planning tool to improve environmental and human well-being goals. In many cities and urban landscapes in the Asian region, operationalization of these SET frameworks through project-based interventions and upscaling is limited.

In Asia, Singapore is a leader in employing these new paradigm approaches to designing sustainable urban development plans such as the ABC Waters Programme. In the last two decades, China has implemented flood management regulations and frameworks that are more comprehensive. The National Flood Management Strategy (2005) emphasizes nonstructural measures as a supplement to structural strategies, complementing the 1997 Flood Control Law. Bangladesh is beginning to explore alternatives to traditional methods. Between 1960 and 2008, Dhaka, one of the world's most flood-prone cities, lost 30% of its water bodies due to urbanization, and the wetlands surrounding the city have reduced from 5.85 km^2 to 3.95 km^2 (GCF 2020). Broad solutions are being investigated by the government, including the Dhaka Water Supply and Sewerage Authority, to address the importance of effective stormwater drainage systems and restoration of water bodies and wetlands.

In an island setting, Fiji's Green Growth Framework (GGF), a tool for accelerating integrated and inclusive sustainable development, to strengthen environmental resilience and manage the anticipated negative effects of climate change to restore the balance in economic growth and development was drafted by the Ministry of Strategic Planning, National Development and Statistics. The guiding principles of the tool focused on the reduction of carbon "footprints" at all levels; efficient utilization of resources and productivity; strengthening environmental stewardship and social responsibility through education; adaptation of comprehensive risk management practices; development of an integrated approach with stakeholder collaboration; and financial incentives for investments in an effective use of resources. GGF presents an approach to support truly sustainable development by identifying ten thematic areas under three pillars—environment, social, and economic. While the environment pillar focuses on building resilience to disasters and climate change, sustainable resources, and waste management, the social pillar emphasizes inclusive social development, water resources and sanitation management, and food security. And the economic pillar aims at energy security, sustainable transportation, green tourism and manufacturing industries, and technology and innovation.

The set of challenges in many countries in the Asia-Pacific region include operationalizing and institutionalizing BGI/NBS agenda in the existing policies and support systems, often due to limited technical and financial capacity (Narayan et al. 2015; Jupiter 2015). While advanced economies have progressed in implementing such solutions, developing countries' interest in the socio-technical approach, BGI, and NBS is expanding (Nagabhatla and Metcalfe 2018). For example, in South Australia, an emphasis on water-sensitive urban design encourages the sustainable use and reuse of water in the urban settings—the intervention is supported by the government as a strategy to combat droughts and a way to cope with water scarcity.

We argue that policies to improve the urban landscape could consider integrated socio-technical management frameworks, BGI innovations, and NBS oriented solutions while pointing to the need to carefully evaluate challenges and opportunities for upscaling. For instance, the case study from China reflects while these urban planning paradigms aim multiple-objective agendas—i.e., mitigating the flood risk, creating urban green spaces, wastewater dilution/treatment plans through constructed wetlands, etc.—the goals and metrics used to evaluate these programs are not framed comprehensively to reflect multiple benefits of the urban planning paradigms. The case studies also point to a common issue with NBS monitoring programs that they tend to assess "easier" evaluation metrics (i.e., hectares reforested), rather than a multitude of direct and indirect suit of impacts or outcomes (i.e., reduction in expected annual damages).

The legislative and regulatory frameworks in many developing countries are emerging to promote the adoption of integrated solutions, as indicated in the water-air pollution section and programs/projects in Annexures 1, 2, and 3. Although the investment in hybrid projects is beginning to rise in the developing countries of Asia and the Pacific, the impact and success of these projects are yet to be perceived, assessed, analyzed, and reported. The World Bank report (2016) enlists that most NBS-based DRM (disaster risk management) interventions are applied in Africa and the Middle East. In 2017–2018, the regions of East Asia and the Pacific, Latin America, and the Caribbean reported a significant growth in the use of NBS for disaster risk management. Additionally, the report elucidates that the investments are still heavily dominated by built infrastructure projects, as clear guidelines on perceptions and implementation of BGI/NBS solutions are limited. Still, the narratives that claim BGI/NBS as cost-effective alternative complementing built infrastructure with co-benefits such as poverty reduction/better employment options/socially inclusive strategy remain strong in theory, and only few of these measures are put in place by urban planners.

Sustainable Asset Valuation (SAVi) developed by IISD (International Institute for Sustainable Development) demonstrates that governments, citizens, and investors can get an attractive return on investment in sustainability-focused assets, programs, and strategies. The ASEAN Catalytic Green Finance Facility for accelerating green finance in Southeast Asia, the Green Climate Fund (GCF), and Green Infrastructure Financing programs by World Bank are a few of many organizations committed to supporting developing countries' climate change mitigation and adaptation commitments and their SDG-related obligations. For example, the GCF report (2020) states that 36% of global GCF ($2.6 billion) is directed to the Asia-Pacific region including 12% ($ 849.9 million) in SIDS (Small Islands Developing States) nations.

The process of securing financing varies significantly across public and private sponsored projects and regions, with significant disparities in funds/financing mechanisms in developing and developed economies. In developing countries, for instance, numerous evolving SET innovations are supported by international donors and multilateral agencies. The emerging and developed economies are taking active measures to commit state financing through a blend of government funding and private sector/equity committed for sustainable urban planning. In that context, insurance policies and products are also evolving to accommodate this agenda. However, such efforts remain mostly noted in developed economies where insurance mechanisms are established and integrated into the existing sectoral operations and guidelines. In the developing states in the region, multilateral institutions such as the World Bank and GCF are providing support by funding initiatives that present a potential to be effective socio-technical systems based on BGI/NBS principles.

2.5 Concluding Notes

To achieve the goal of resilient infrastructure by 2030 as outlined in the SDG agenda, Browder et al. (2019) estimated the need for $90 trillion funding for infrastructure, which underscores the merits of adapting NBS- and BGI-based solutions. To this vision, the central theme of the programs and projects noted in

Annexure 1 reflects on the interconnectedness aspect in BGI, NBS, and the socio-technical approaches. The existing efforts reflect the necessity of regional collaboration along with the cooperation of states and communities for effective implementation of socio-technological oriented solutions created to balance development and sustainability objectives. In addition, the urban regions can design interventions that consider local−/context-specific needs. For example, the Green Bangkok 2030 Project benefits from converting the unused land into green spaces towards a sustainable city vision and addressing integrated goals of air, water, and energy security. However, these solutions are not linear or straightforward in all instances and settings, as many dimensions may apply such as financial commitment, the capacity of the program manager, and acceptability by citizens and communities. Annexure 3 shows emerging collaborations in the Asia-Pacific region—the programs that are aimed to provide support through project funding, sharing knowledge from networking opportunities, and implementation of research. Some programs contain multiple agendas and pledges of participation in a wide range of sustainability (BGI, NBS, SUNRM)-based interventions.

Noting that the urban areas once established cannot be moved, any measure to adopt inclusive development should entwine with the urban ecosystem protection and restoration agenda at the national, regional, and global frameworks. Although investment in BGI and NBS within the socio-technical setups remains essential for sustainable urban infrastructure, a lot of countries are pressed with challenges such as lack of human capacity, financial resources, or understanding of short-, medium-, and long-term trade-offs. As Luoma (2012) explains about the NFPP in China, the trade-off of NBS implementation, the State Forestry Administration has begun collaborating on projects aimed specifically at restoring native species and is working with the Climate, Community & Biodiversity Alliance (CCBA), whose members include Conservation International, The Nature Conservancy, and the Rainforest Alliance (the emerging challenge of teleporting needs attention).

It is evident from the case studies in this chapter that the hybrid engineering solutions have intensely focused on stormwater management to handle urban flooding with few studies on coastal flooding and erosion protection, construction of wetlands, and mangrove-dike solutions for flood management. The SET framework provides guiding principles for projects visioning sustainable urban futures. As we see in the case of Nepal where community intervention resulted in the closure of a project of importance, emphasis on local settings, social and ecological goals, and technological innovation are to be balanced carefully for desired outcomes. Most of the existing solutions in developing countries are focused on a narrow scale and are in the process to configure multi-benefits through boosting infrastructure resilience. This progress will broaden the scope of the NBS/BGI approach in multiple areas with proven evidence that it empowers communities, enhancing project sustainability with cost-effective multiple benefits (economic and non-economic).

Long-term funding is another key challenge in developing countries that are highly dependent on bilateral or multilateral funding for such projects. Besides, the lack of technical guidance for BGI/NBS implementation is one of the most cited barriers in all regions and refers to the understanding and knowledge to assess the performance of such interventions by the policymakers, regulators, and/or permitting agencies, who often prioritize gray infrastructure over such options because of familiarity, existing guidelines on compliance, and permissions. A multilevel incentive structure can serve as a driver for inclusive participation and successful implementation of the outlined agendas. Additionally, forward-looking strategies such as the Sustainable Urban Natural Resources Management (SUNRM) approach derived from the SET framework could be promoted and supported under ecological sustainability, disaster risk reduction, and climate change adaptation measures. For these urban planning paradigms to be adopted widely, incentives need to be created for local stakeholders through public and private financing options, technical support, and policy instrument.

In closing, note that SET innovations and integrated agenda bear potential to balance urban growth, smart employment, ecological sustainability, and more while contributing to the interlinked plan of SDGs, i.e., to SDG 8, decent work and economic growth, and SDG 11—sustainable cities and communities. However, a barrier such as knowledge and capacity gaps, lack of governance structures for managing these multifunctional systems, and balancing trade-offs while delivering multiple goals largely determines the feasibility and endorsement of these planning paradigms. In the long term, success and acceptance of SUNRM framework depends both on the efficiency of technological interventions as well as mechanisms for community involvement and social inclusion. In addition, like for any other development-focused intervention, public acceptance, financial commitment, and policy support remain pertinent to sustain these urban planning pathways. The challenge associated with maintenance, monitoring and evaluation, and upscaling is also crucial towards certifying the sustainability of NBS and green infrastructure approaches in the urban planning context.

With better and more sustainable infrastructure, these integrated solutions can serve useful to managing inequality and social injustice linked to challenges outlined in SDG 6 (water availability and accessibility to all), mainly for the urban poor. It is to be noted that the technological and the social component of the SET framework are aligned with SDG 1 (that includes urban poverty), SDG 2 (managing hunger), water and clean air, and reducing the impacts of climate change. Alignment of SET framework to achieving SDG 7 (affordable and clean energy) and SDG 3 (good health and well-being) is also apparent, as is SDG 5 (gender-focused) agenda. The technological aspect of the SET framework calls for reduced emissions, projecting nature-based solutions bearing potential as a carbon sink, besides as a mechanism to boost climate resilience tying to SDG 13 (climate action), SDG 14 (coastal and marine environmental protection), and SDG 15 (better land management) directly or indirectly.

Conflict of Interest Statement The authors report no conflict of interest for this publication.

Annexure 1

Institutional and policy support systems in selected cities and mega urban centers in Asia that align with the scope of Sustainable Development Goals, particularly SDG 11

City(mega, emerging, or developing city)	Policy/ programLaunch year	Summary and notesReference
Singapore Megacity	Singapore's Voluntary National Review Report 2018	Some of the strategies to achieve SDG 11 are transit-oriented development and planning, promoting public transport, walking, cycling plans, inclusive transport, safer streets, green buildings and spaces, and international collaborations https://sustainabledevelopment.un.org/content/documents/19439Singapores_Voluntary_National_Review_Report_v2.pdf
	Urban Redevelopment Authority (URA) 2011 and 2019	2011 concept plan—Long-term strategic land use and smart transportation (in next 40–50 years) Singapore has a limited land capacity to establish a long-term land use plan that balances land use needs, such as housing, industry, commerce, parks, transport, defense, community facilities https://www.ura.gov.sg/Corporate/Planning/Concept-Plan/About-Concept-Plan
		2019: The master plan is a short-term strategic land use plan (for the next 10–15 years) Proposes zoning strategy to show the permissible land use developments Plan to be reviewed every 5 years and translates the plan's ideas to guide land development https://www.ura.gov.sg/-/media/Corporate/Planning/Master-Plan/MP19writtenstatement.pdf?la=en https://www.ura.gov.sg/Corporate/Planning/Master-Plan
Hong Kong Megacity	Future Hong Kong 2020	To meet SDG 11, Hong Kong has created Future Hong Kong 2030 to promote sustainable development. Numerous strategies developed to drive sustainability. Some of

(continued)

City(mega, emerging, or developing city)	Policy/ programLaunch year	Summary and notesReference
		which are: Implementing wastepaper collection and recycling services to help stabilize the price and quantity of local waste management Adopting *electric vehicles*, introducing a smart power grid, and artificial intelligence-driven technology can optimize energy consumption Cleaner production partnership program to encourage local-owned factories to adopt cleaner technologies Set up an HKD 200 million green tech fund to support the R&D and application of decarbonization and green technologies https://assets.kpmg/content/dam/kpmg/cn/pdf/en/2020/04/future-hong-kong-2030.pdf
Tokyo, Japan Megacity	Tokyo's Environmental Plan 2020	Tokyo's strategy toward building a more sustainable society and honoring their commitment to the Paris commitment. And for sustainable buildings, the Tokyo cap-and-trade program, carbon reduction reporting program, and green building program. Aim is to promote energy-efficient homes and expand renewable energy resources to reduce GHG emissions https://www.kankyo.metro.tokyo.lg.jp/en/about_us/videos_documents/documents_1.files/creating_a_sustainable_city_2020_eng.pdf
Shimokawa Town (Hokkaido) *Town referred to as a model for sustainable development Advanced Urban Center in a Developed Nation	Shimokawa Town The Sustainable Development Goals Report 2018	Report promotes comprehensive development strategies such as the Ichi-no-hashi BioVillage, which addresses economic, social, and environmental issues They created an on-demand local *public transportation system* for more efficient traveling To prevent elders from getting isolated/lost, they developed a senior watch system The town is taking measures to

(continued)

City(mega, emerging, or developing city)	Policy/ programLaunch year	Summary and notesReference
		preserve water resources, make its forest more resilient to disasters, and establish headwater forests guidelines https://www.iges.or.jp/en/publication_documents/pub/policyreport/en/6571/Shimokawa_SDGsReport_EN_0713.pdf
Toyama, Japan Urban Center in a developed nation	Toyama City The Sustainable Development Goals Report 2018	Has seven plans developed that address SDG 11: (1) Second Comprehensive Plan 2017–2026, (2) Basic Environment Plan 2017–2026, (3) Environmental Model City Action Plan, (4) Land Tolerance Regional Plan, (5) Environment FutureCity Plan, (6) Comprehensive Strategy for City, People and Work (2015–2019), and (7) Resilience Strategy (30-Year Plan) By 2025, approximately 30% of the entire population of Toyama City will be senior citizens. Therefore, the city wants to revitalize public transport, promoting health and an overall better state of well-being *City will make efforts to reduce the heavy reliance on cars*, create a walkable city, and recover the number of public transport users that have declined in recent years https://www.local2030.org/library/478/Toyama-City-the-Sustainable-Development-Goals-Report-Compact-City-Planning-based-on-Polycentric-Transport-Networks.pdf
Kitakyushu, Japan Emerging Urban Center in a developed nation	Kitakyushu City The Sustainable Development Goals Report 2018	Kitakyushu has developed 17 specific actions to achieve the SDGs. To meet the SDG goals, some of Kitakyushu efforts include: Building motivation in life for the elderly; promoting education for sustainable development (ESD) activities; increasing urban resilience by supporting the development of a voluntary disaster-prevention system. Developing an intensive-type

(continued)

City(mega, emerging, or developing city)	Policy/ programLaunch year	Summary and notesReference
		urban structure promotes people- and environmentally friendly *transport strategies*. Promoting public facility management Developing products that can spread worldwide, such as soap-based firefighting foam https://www.uncclearn.org/wp-content/uploads/library/kitakyushu_sdgsreport_en_0713.pdf
Bangkok Megacity	Bangkok Declaration for 2020 Sustainable Transport Goals for 2010–2020 2020	Bangkok's main priority outlined in the policy is to *improve transportation* and technologies in the city. Goals include improving public transport; reducing the use of private motorized vehicles through transportation demand management; and achieving more sustainable intercity passenger and goods transport (i.e., high-quality long-distance bus, inland water transport, high-speed rail over car and air passenger travel, and priority for train and barrage freight over truck and air freight by building supporting infrastructure such as dry inland ports) https://sdgs.un.org/sites/default/files/documents/bangkok_declaration.pdf
Shanghai Megacity	Promoting health in the SDGs 2016	One way in which Shanghai intends on implementing SDG 11 is by enforcing a smoke-free law and promoting and providing universal access to safe, inclusive, and accessible green and public spaces https://www.who.int/publications/i/item/WHO-NMH-PND-17.5
Guangzhou Megacity	UN SDGs Guangzhou Voluntary Local Review 2020	Guangzhou has many goals outlined to achieve SDG 11. Some of these include: Preserving the urban green ecological spaces Refining the quality and the design of the city and highlight its personality promote collaboration Participating and sharing common interests in the community Building sustainable communities

(continued)

City(mega, emerging, or developing city)	Policy/ programLaunch year	Summary and notesReference
		Increasing efforts to build public transportation facilities and optimize the traffic Developing innovations in green technologies and promoting the application of green energy https://sdgs.un.org/sites/default/files/2021-01/VLR%20Guangzhou%2C%20China-compressed.pdf
Surabaya, Malaysia Emerging Urban Center	SDG Summit 2019	Different initiatives taken by Surabaya to achieve the SDGs Prioritized disaster risk management against extreme weather They have implemented alternative energy sources such as using waste for fuel to create energy Public and social facilities are provided for free (this includes 49 broadband learning centers, 475 public parks, 524 sports fields, learning center, and community hall) https://sustainabledevelopment.un.org/content/documents/25068Leaders_Dialogue_4_Localizing_the_SDGs_Mayor_Tri_Rismaharini.pdf
Muangklang, Thailand Emerging urban center	Could not find specific policies but it is a famous green city NA	Muangkland, Thailand, is one of the three model towns in Thailand's low Carbon City program Small town with limited resources but has managed to become famous for its green-city development with its many green activities The town created a simple outdoor conveyor belt to separate waste, reuse, and recycle, significantly reducing waste in the municipal landfill. The operation is compensated for by selling compost, recyclable materials from the landfill, and locally grown organic vegetables The city also converted unused land to promote urban farming of vegetables and rice—This project aimed to reduce food miles and energy from food transportation https://wwf.panda.org/?229194/Muangklang-low-carbon-city

Annexure 2

Selected projects and programs in urban landscapes in Asia aligning with agenda outlined in the Sustainable Development Goals, in particular SDG focused on urban development

City/region/agency (mega, emerging, or developing city)	Project/programYear	Summary and notesReference
Programs/projects and case studies		
Yokohama, Japan (Megacity)	Yokohama Partnership of Resources and Technologies (Y-PORT) Project 2015	The city of Yokohama was faced with various urban issues because of the high concentration of the population due to significant economic growth and urbanization To overcome these challenges, such as delayed infrastructure development and pollution from the rapidly increasing population, Yokohama developed a sustainable and environmentally friendly city Now, Yokohama uses its experience in urban development and technologies to help other emerging cities https://yport.city.yokohama.lg.jp/en/y-port-project
ASEAN Southeast Asia	ASEAN SDGs Frontrunner Cities Programme (SDGs-FC) 2018	An initiative under the AWGESC funded by the Japan-ASEAN integration fund (JAIF) This program aims to raise the capacity and profile of 27 ASEAN cities and develop and improve practices/policies toward clean and green sustainable development https://sustainabledevelopment.un.org/partnership/?p=29570 http://urbansdgplatform.org/pdf/IGES%20Policy%20Brief%20-%20ASEAN%20Cities%20Early%20Reactions%20to%20SDGs%20Final%207May2018_FINAL.pdf
	ASEAN Working Group on Environmentally Sustainable Cities (AWGESC) 2009	Improve regional involvement to address the effects of climate change on socioeconomic development in ASEAN Address regional priorities, concerns, and interests Has seven strategic priorities in the plan: (1) nature conservation and

(continued)

City/region/agency (mega, emerging, or developing city)	Project/programYear	Summary and notesReference
		biodiversity, (2) coastal and marine environment, (3) water resources management, (4) environmentally sustainable cities, (5) climate change, (6) chemicals and waste, (7) environmental education and sustainable consumption and production https://environment.asean.org/about-asean-cooperation-on-environment/ https://www.doe.gov.my/portalv1/en/info-umum/info-hubungan-antarabangsa/asean-working-group-awg-2/324045#:~:text=The%20ASEAN%20Working%20Group%20on,a%20clean%20and%20green%20environment
USAID (International Cooperation Agency of the United States) Mekong region	Pact and the Mekong Partnership for the Environment (MPE) 2013	There is accelerated growth in the Mekong region which led to the development of this pact. MPE reinforces the responsible development of counties in the lower Mekong region through the constructive engagement of different stakeholders such as governments, businesses, and civil society Promotes responsible investment and encourages public participation through good environmental impact assessment (EIA) policy and practice MPE supports strategies that facilitate socially and environmentally responsible development decision-making https://www.pactworld.org/mekong-partnership-environment#:~:text=In%202013%2C%20USAID%20awarded%20Pact,the%20Lower%20Mekong%20sub%2Dregion
Malaysia	Malaysia Sustainable Cities Program 2013–2018	The goal of the program is to study the sustainable city development efforts in Malaysia Scholars from around the world researched Malaysia Transform findings into instructional materials to enhance and spread sustainable city development lessons across universities in the global south

(continued)

City/region/agency (mega, emerging, or developing city)	Project/programYear	Summary and notesReference
		Graduate students and faculty at MIT and UTM studied, reviewed, and refined the research direction MSCP encouraged additional reports, theses, and studies to be conducted in Malaysia https://scienceimpact.mit.edu/malaysia-sustainable-cities-program
Shimokawa Town (Hokkaido Emerging Urban center in Japan)	Ichi-no-hashi BioVillage 2018	Town with a high aging population that experienced hardships living in a colder climate (e.g., removing heavy snow) Shimokawa implemented a new housing community with a woody-biomass district heat supply system to improve elders' quality of life Their energy cost decreased because of well-insulated homes and biomass fuel Also, they created 30 jobs and US$ 0.7 million worth of mushroom production https://www.town.shimokawa.hokkaido.jp/section/2018/05/sustainable-forest-future-community-ichinohashi-bio-village-of-shimokawa-town.html
Toyama (Developing Urban Region of Japan)	Toyama City Low Carbon Farming Village Model 2018	Agricultural land use has decreased as farmers become dependent on non-farming income Toyama is implementing the Toyama City low-carbon farming model to revitalize the abandoned farmlands using renewable resources and providing farmers with other crops than rice, such as vegetables that have a low crop acreage The facility uses renewable power sources to power agricultural machinery and air-conditions greenhouses for crops The produce is shared among the community https://www.local2030.org/library/478/Toyama-City-the-Sustainable-Development-Goals-Report-Compact-City-Planning-based-on-Polycentric-Transport-Networks.pdf

(continued)

City/region/agency (mega, emerging, or developing city)	Project/programYear	Summary and notesReference
Kitakyushu (Emerging)	City Forest Project 2018	Launched a city forest project to create urban development that coexists between cities and the natural environment Kitakyushu leases idle company-owned land, unused city-owned land, and sections of parks to local groups that use community involvement to develop green areas These activities may provide new life to idle and unused land, which have become problematic in local areas otherwise https://www.uncclearn.org/wp-content/uploads/library/kitakyushu_sdgsreport_en_0713.pdf
Kuala Lumpur (Emerging)	Urban Mass rapid Transit System—MRT 2016	The advanced and newly established transportation system will provide an efficient and environmentally friendly transportation network in Kuala Lumpur Its purpose is to enhance access and mobility to and from the city center for its 400,000 daily commuters https://aseanup.com/kuala-lumpur-sustainable-development-initiatives/
	River of Life Project 2012	The river cuts through the city and influences the livability and atmosphere of Kuala Lumpur The project will have three phases: (1) clean the river, (2) install gross contaminant traps, and (3) build two wastewater treatments https://www.mymrt.com.my/public/mrt-need-to-know/
Bangkok (Megacity)	The Green Bangkok 2030 Project 2019	The environment department, Bangkok metropolitan administration (BMA) goal is to take advantage of the unused spaces scattered throughout Bangkok (that belong to the government and private agencies) to create more green spaces. https://www.c40.org/case_studies/the-green-bangkok-2030-project
Manila (Developing)	Escuela Taller de Filipinas Foundation, Inc. 2019	Nonprofit organization located in Intramuros, Manila, that implements skills development and training targeted toward indigent youth Students learn about the protection,

(continued)

City/region/agency (mega, emerging, or developing city)	Project/programYear	Summary and notesReference
		conservation, and restoration of cultural heritage sites The organization highlights the importance of education and training programs to address challenges in other SDGs and sectors, such as heritage and culture conservation (under SDG 11) https://sustainabledevelopment.un.org/content/documents/23366Voluntary_National_Review_2019_Philippines.pdf

Annexure 3

Regional initiatives, alliances, and coalitions to promote BGI/NBS and integrated natural resource management initiatives in the Asian region

Program	Description	Main agendaReference/source
Asia Smart City Alliance	A platform for different stakeholders (i.e., cities, governments, private companies, international institutions, and academics active in smart city development) in Asia to share knowledge and facilitate discussions	Organizes annual Asia Smart City Conference (ASCC) https://yport.city.yokohama.lg.jp/en/city-promotion/asia-smart-city-alliance-asca
Association of Southeast Asian Nations (ASEAN)	Founded by Indonesia, Malaysia, Philippines, Singapore, and Thailand (10 members) The objectives include: • To accelerate economic growth, social progress, and cultural development • Promote regional peace and stability, respect for justice and the rule of law • Increase collaboration across various economic, social, cultural, technical, scientific, and administrative spheres	The goal is to maintain close and beneficial cooperation between countries using existing international and regional organizations with similar aims and purposes (7 aims found in the ASEAN declaration) https://asean.org/asean/about-asean/ https://asean.org/storage/2020/10/ASEAN-SDG-Indicator-Baseline-Report-2020.pdf
ASEAN ESC Model Cities Programme	Created to encourage the development of environmentally sustainable cities by conducting activities at the local, national,	Model cities receive several benefits, including funding, training, and regional networking opportunities

(continued)

Program	Description	Main agendaReference/source
	and regional levels Supports national focal points by: • Mainstreaming the SDGs; boosting incentives for cities to better fulfill the ASEAN clean land, clean air and clean water indicators • Strengthening or creation of national model cities networks	The last report issued from the program discusses its achievements from 3 years (last report from 2017) of existence Model cities continue to make improvements to local environmental quality by scaling up a variety of innovations https://www.iges.or.jp/en/pub/asean-esc-model-cities-year-3-201617/en#:~:text=The%20ASEAN%20ESC%20Model%20Cities,local%2C%20national%20and%20regional%20levels
Economic and social Commission for Asia and the Pacific (ESCAP)	Largest regional intergovernmental platform with 53 member states and 9 associate members	Goal is to develop inclusive, sustainable, economic, and social development in the Asia-Pacific region Priority is aligned with the implementation of the 2030 Agenda for Sustainable Development and the achievement of the Sustainable Development Goals https://www.unescap.org/resources/sdg11-goal-profile https://www.unescap.org/our-work
Institute for Global Environmental Strategies (IGES)	Strategy aims to achieve a new paradigm for civilizations through conducting innovative policy development and research for environmental measures, incorporating the research into political decisions for sustainable development in the Asia-Pacific region and globally Recognizes sustainable development in the Asia-Pacific region is critical for international growth	Undertakes different programs and projects. Main coordinating body for APAN Collaborates with USAID In charge of hosting ISAP (International Forum for Sustainable Asia and the Pacific 2018) Research and implementation of Japan's Joint Crediting MECHANISM (JCM) https://archive.iges.or.jp/en/bangkok/index.html https://www.iges.or.jp/en/about
Asia Pacific Adaptation Network (APAN)	APAN aims to equip Asia and the Pacific Region with the knowledge for designing and implementing climate change adaptation measures Operations are carried out by subregional nodes: Central Asia, Northeastern Asia, Pacific, South Asia, and Southeast Asia	Publishes the Asia-Pacific Climate Change Adaptation Forum (Seventh APAN Forum) The conference was held recently in March 2021 http://www.asiapacificadapt.net/about-apan/

(continued)

Program	Description	Main agendaReference/source
USAID Adapt Asia-Pacific	Assists vulnerable countries to receive financing to address climate change impacts Links climate funding organizations with eligible Asia-Pacific countries to help prepare projects that increase resilience to climate change's negative impact	USAID and the US Department of State-funded "Climate Change Adaptation Project Preparation Facility for Asia and the Pacific Activity" (Adapt Asia-Pacific) specifically 13 countries in Asia and 14 Pacific Small Island Developing States The project improved the government's climate change adaptation strategies and provided technical assistance to allow organizations to access and receive climate funding for projects that increased resilience to climate change Adapt Asia-Pacific was granted over $576 M in financing for climate change adaptation projects, which benefited almost one million people https://www.weadapt.org/organisation/usaid-adapt-asia-pacific https://www8.climatelinks.byf1.io/sites/default/files/asset/document/2017_USAID_ADAPT%20Asia-Pacific%20Final%20Report.pdf https://www.climatelinks.org/projects/adapt-asia-pacific

References

Abbott J, Davies P, Simkins P, Morgan C, Levin D, Robinson P (2013) Creating water sensitive places – scoping the potential for water sensitive urban design in the UK. CIRIA, London

Andersson E, Barthel S, Borgström S, Colding J, Elmqvist T, Folke CÅ, Gren (2014) Reconnecting cities to the biosphere: stewardship of green infrastructure and urban ecosystem services. Ambio 43:445–453

Athas I (2010) Record rains flood Sri Lanka, leaving 36,000 families homeless, CNN, November 11, 2010, sec. World. http://www.cnn.com/2010/WORLD/asiapcf/11/11/sri.lanka.floods/index.html

Baldasano JM, Valera E, Jimenez P (2003) Air quality data from large cities. Sci Total Env 307: 141–165

Benjamin L (2012) A selection of plants for bioretention system in the tropics. In: Nparks and Singapore Delft Water Alliance, Research Technical Note - Urban Ecology Series. National University of Singapore, Singapore

Breuste J, Artmann M, Li J, Xie M (2015) Special issue on green infrastructure for urban sustainability. J Urban Plan Dev 141:A2015001. https://doi.org/10.1061/(asce)up.1943-5444.0000291
Browder G, Ozment S, Rehberger B, Irene GT, Lange GM (2019) Integrating green and gray: creating next generation infrastructure. World Bank and World Resources Institute, Washington, DC
Burian S, Edwards F (2002) Historical perspectives of urban drainage. In Proceedings of the 9th International Conference on Urban Drainage. American Society of Civil Engineers, Portland, USA, 8–13 September 2002
Castro Fresno D, RodríguezBJ RHJ, Ballester MF (2005) Sistemas urbanos de drenaje sostenible (SUDS). Interciencia 30:255–260
Chin SW (2015) A guide to landscape weed management. Center for Urban Greenery and Ecology, Singapore
CIRIA (2015) The SuDS manual construction industry research and information association (CIRIA). CIRIA, London
CIWEM (2007) Policy position statement on deculverting of water courses. London, Chartered Institution of Water & Environmental Management
Daniel K, Hayley H, Alejandro M, Demián R, Rodolfo A (2020) Sust 12:2163
Derkzen ML, Van Teeffelen AJA, Verburg PH (2015) Review: quantifying urban ecosystem services based on high-resolution data of urban green space: an assessment for Rotterdam, the Netherlands. J Appl Ecol 52:1020–1032
Dhakal KP, Chevalier LR (2016) Urban Stormwater governance: the need for a paradigm shift. Environ Manag 57:1112–1124
Johnson TM, Sarath G, Wells GJ, Artaxo P, Bond TC, Russell AG, Watson JG, West J (2011) Tools for improving air quality management: a review of top-down source apportionment techniques and their application in developing countries. ESMAP formal report; no. 339/11. World Bank, Washington, DC. © World Bank. https://openknowledge.worldbank.org/handle/10986/17488. License: CC BY 3.0 IGO
GCF Spotlight Asia-Pacific (2020). www.greenclimate.fund. Accessed 13 Nov 2020
Goh XP, Radhakrishnan M, Zevenbergen C, Pathirana A (2017) Effectiveness of runoff control legislation and active, beautiful, clean (ABC) waters design features in Singapore. Water 9:627
Haas (2012) Sustainable urbanism and beyond. In: Haas T (ed) Sustainable urbanism and beyond: rethinking cities for the future. Rizzoli, New York, pp 8–13
IPCC (2015) Climate change 2014: synthesis report. Intergovernmental panel on climate change (IPCC). IPCC, Geneva
Jupiter S (2015) Policy brief: valuing Fiji's ecosystems for coastal protection
Kilbane S (2013) Green infrastructure: planning a national green network for Australia. J Landscape Archit 8:64–73
Lee JG, Nietch CT, Panguluri S (2018) Drainage area characterization for evaluating green infrastructure using the storm water management model. Hydrol Earth Syst Sci 22:2615–2635. https://doi.org/10.5194/hess-22-2615-2018
Lehmann I, Mathey J, Rößler S (2014) Urban vegetation structure types as a methodological approach for identifying ecosystem services—application to the analysis of micro-climatic effects. Ecol Indic 42:58–72. https://doi.org/10.1016/j.ecolind.2014.02.036
Li X, Junqi L, Xing F, Yongwei G, Wenliang W (2016) Case studies of the Sponge City Program in China. In:295–308. https://doi.org/10.1061/9780784479858.031
Lim HS, Lu XX (2016) Sustainable urban stormwater management in the tropics: an evaluation of Singapore's ABC waters program. J Hydrol 538:842–862
López-Valencia AP (2019) Vulnerability assessment in urban areas exposed to flood risk: methodology to explore green infrastructure benefits in a simulation scenario involving the Cañaveralejo River in Cali, Colombia. Nat Haz 99:217–245. https://doi.org/10.1007/s11069-019-03736-8

Lovell ST, Taylor JR (2013) Supplying urban ecosystem services through multifunctional green infrastructure in the United States. Landsc Ecol 28:1447–1463

Luoma J (2012) "China's reforestation programs: big success or just an illusion?" Yale E360 (blog). January 17, 2012. https://e360.yale.edu/features/chinas_reforestation_programs_big_success_or_just_an_illusion

McPhearson T, Haase D, Kabisch N, Gren Å (2016) Advancing understanding of the complex nature of urban systems. Ecol Indic. https://doi.org/10.1016/j.ecolind.2016.03.054

Mell IC (2009) Can green infrastructure promote urban sustainability? Proc Inst Civ Eng Eng Sustain 162:23–34. https://doi.org/10.1680/ensu.2009.162.1.23

Mensah S, Veldtman R, Du Toit B et al (2016) Aboveground biomass and carbon in a south African Mistbelt forest and the relationships with tree species diversity and forest structures. Forests. https://doi.org/10.3390/f7040079

Molina LT, Kolb CE, de Foy B, Lamb BK, Brune WH, Jimenez JL, Ramos-Villegas R, Sarmiento J, Paramo-Figueroa VH, Cardenas B, Gutierrez-Avedoy V, Molina MJ (2007) Air quality in North America's most populous city – overview of the MCMA–2003 campaign. Atm Chem and Phy 7(10):2447–2473

Molina LT, Velasco E, Retama A, Zavala M (2019) Experience from integrated air quality management in the Mexico City Metropolitan Area and Singapore. Atmosphere 10:512. https://doi.org/10.3390/atmos10090512

Nagabhatla N, Metcalfe CD (eds) (2018) Multifunctional wetlands, Environmental Contamination Remediation and Management- New and Forthcoming Series. Springer Nature. ISBN 978-3-319-67416-2

Narayan S, Cuthbert R, Neal E, Humphries W, Ingram JC (2015) Protecting against coastal hazards in Manus and New Ireland provinces. Assessment Of Present And Future Options. Report for AUSAID, Papua New Guinea

PUB (2014) Managing stormwater for our future. Singapore National Water Agency. https://www.pub.gov.sg/Documents/ManagingStormwater.pdf

Qian Z (2009) When green is good but land is scarce, plant rooftop gardens in the air. Shanghai Daily, April 13, 2009, sec. Health and Environment. https://www.shine.cn/archive/feature/health-and-environment/When-green-is-good-but-land-is-scarce-plant-rooftop-gardens-in-the-air/shdaily.shtml

Rao NS, Carruthers TJB, Anderson P, Sivo L, Saxby T, Durbin, T, Jungblut V, Hills T, Chape S (2013) An economic analysis of ecosystem-based adaptation and engineering options for climate change adaptation in Lami Town, Republic of the Fiji Islands. A technical report by the Secretariat of the Pacific Regional Environment Programme. Apia, Samoa

Ren G, Young SS, Wang L, Wang W, Long Y, Wu R, Li J, Zhu J, Yu DW (2015) Effectiveness of China's National Forest Protection Program and nature reserves. Cons Bio 29(5):1368–1377. https://doi.org/10.1111/cobi.12561

Renato M, José CF, Paula A (2020) Green infrastructure planning principles: an integrated literature review. Land 9:525. https://doi.org/10.3390/land9120525

Roehr D, Yuewei K (2010) Runoff reduction effects of green roofs in Vancouver, BC, Kelowna, BC, and Shanghai, P.R. China. Can Water Res J 35(1):53–68. https://doi.org/10.4296/cwrj3501053

Rosenzweig C, Solecki WD, Hammer SA, Mehrotra S (eds) (2011) Climate change and cities: first assessment report of the urban climate change research network. Cambridge University Press, Cambridge/New York

Rozenberg JM, Simpson L, Bonzanigo M, Bangalore L, Prasanga (2015) Wetlands conservation and management: a new model for urban resilience in Colombo. World Bank Group, Washington, DC. https://collaboration.worldbank.org/servlet/JiveServlet/downloadBody/21539-102-5-27686/final_report_wetlands_Colombo_mtdf.pdf

Seto CK, Shepherd JM (2009) Global urban land-use trends and climate impacts. Curr Opin Environ Sustain 1:89–95

Singh AK, Gupta HK, Gupta K, Singh P, Gupta VB, Sharma RC (2007) A comparative study of air pollution in Indian cities. Bull Environ Contam Toxicol 78:411–416

Soz SA, Jolanta KW, Zuzana S (2016) The role of green infrastructure solutions in urban flood risk management

Tianjie M (2008) Interconnected forests: global and domestic impacts of China's forestry conservation. Wilson Center China Environment Forum

Toan TD, Van DD (2020) Integrated transport planning for sustainable urban development – Singapore' approach and lessons for Vietnam

Tuladhar B, Prajwal S, Rajendra S (2008) Decentralised wastewater management using constructed wetlands. Beyond construction: use by all: a collection of case studies from sanitation and hygiene promotion practitioners in South Asia, 86–94

Vincent SU, Radhakrishnan M, Hayde L, Pathirana A (2017) Enhancing the economic value of large investments in sustainable drainage systems (SuDS) through inclusion of ecosystems services benefits. Water 9:841

Vojinovic Z, Weeraya K, Sutat W, Ranko SP, Neiler M, Alida A (2016) Combining ecosystem services with cost-benefit analysis for selection of green and Grey infrastructure for flood protection in a cultural setting. Environment 4(3). http://www.mdpi.com/2076-3298/4/1/3

Wang H, Fu L, Zhou Y, Du X, Ge W (2010) Trends in vehicular emissions in China's mega cities from 1995 to 2005. Environ Pollut 158:394–400

WASH (2011) Water supply, sanitation and hygiene, Sector Status Report. Government of Nepal, Ministry of Physical Planning and Works, Kathmandu, Nepal

WaterAid (2006) Sunga constructed wetland for wastewater management: a case study in community based water resource management

WaterAid (2008) Decentralised wastewater management using constructed wetlands in Nepal. WaterAid in Nepal, Kathmandu, Nepal

Watts K, Eycott AE, Handley P et al (2010) Targeting and evaluating biodiversity conservation action within fragmented landscapes: an approach based on generic focal species and least-cost networks. Landsc Ecol 25:1305–1318. https://doi.org/10.1007/s10980-010-9507-9

Wolsink M (2016) Environmental education excursions and proximity to urban green space—densification in a 'compact city'. Environ Educ Res 22:1049–1071. https://doi.org/10.1080/13504622.2015.1077504

World Bank (2012) Grow in concert with nature: green water defense for flood risk Management in East Asia. World Bank, Washington, DC

World Bank (2016) Preserving the Beddagana wetland for flood protection, conservation education, and improved quality of life. World Bank June 17, 2016. http://www.worldbank.org/en/news/feature/2016/06/17/preserving-beddagana-wetlands-flood-protection-conservation-education-improved-quality-life

World Bank, UFCOP (Urban Floods Community of Practice) (2016) Role of Green Infrastructure solutions in urban flood risk management, Washington, Dc

World Bank WBCSD (2015) The business case for natural infrastructure. http://www.naturalinfrastructureforbusiness.org/wp-content/uploads/2016/02/WBCSD_BusinessCase_jan2016.pdf

Yaella D, Timon M (2017) Integrating the grey, green, and blue in cities: nature-based solutions for climate change adaptation and risk reduction. Nature-Based Solutions to Climate Change Adaptation in Urban Areas, pp. 91–109

Yau WK, Radhakrishnan M, Liong SY, Zevenbergen C, Pathirana A (2017) Effectiveness of ABC waters design features for runoff quantity control in urban Singapore. Water 9:577

Young RF (2011) Planting the living city. J Am Plan Assoc 77:368–381

Zhang Q (2010) The challenge of rooftop gardens. Shanghai Daily, July 26, 2010. https://www.shine.cn/archive/feature/The-challenge-of-rooftop-gardens/shdaily.shtml

Swetha Thammadi is an Environmental Engineering Professional and Spatial Analyst currently working as Lecturer in Civil Engineering, Fiji National University, Fiji.

Nidhi Nagabhatla is a Sustainability Science Specialist and a Systems Analyst working with the United Nations University Institute on Comparative Regional Integration Studies (UNU-CRIS), Belgium.

Sateesh Kumar Pisini is a Principal Lecturer in Civil Engineering at Fiji National University, Fiji.

Stephanie Koza is a Master Student at School of Geography, Environment and Society (SGES), McMaster University, Hamilton, ON, Canada.

Ashraf Mahmood is working at BRAC, an international development organization based in Bangladesh. He is implementing WASH (water, sanitation and hygiene) programmes for Rohingya people in Cox's Bazar, Bangladesh.

3 A Risk Assessment Approach to Urban Resilience

Debbie Bartlett

Abstract

This chapter begins by focusing on the title of this volume and the implications of the words 'resilience' and 'sustainable' and the complexities of addressing these issues from economic, environmental and social perspectives in the context of climate change. A risk assessment-based approach is proposed, with the first step being to fully understand the current situation and the second to identify future risk and finally an options appraisal reviewing different ways the risk could be reduced and determining which would be the most appropriate for the specific situation. The way in which this approach can be implemented is described with the advantages and disadvantages of different interventions considered. The need for regions, cities and neighbourhoods to take a strategic approach to improve urban resilience to minimise climate-associated risk is discussed, drawing on experience in Europe and beyond.

Keywords

Risk assessment · Climate proofing · Urban resilience · Blue-green infrastructure

3.1 Introduction

My first response when asked to contribute a chapter for this book was decline as, although I have worked in Bangladesh, India and Nepal, my experience on this topic is from Northern Europe, a very different context. However, the editors felt this was useful to bring in a different perspective.

D. Bartlett (✉)
University of Greenwich, London, UK
e-mail: D.Bartlett@greenwich.ac.uk

S. Dhyani et al. (eds.), *Blue-Green Infrastructure Across Asian Countries*,
https://doi.org/10.1007/978-981-16-7128-9_3

To begin I'd like to return to the title of this volume 'Improving Urban Resilience and Sustainability by Integrating Blue-Green Infrastructure Across Asian Countries' and suggest considering what this really means. The word 'resilience' is variously defined as the ability to recover quickly from difficulties or for a substance or object to spring back into shape after stress. These imply a return to a former state after short-term event. Sustainability is a frequently used word that can be applied to the economic, environmental and social contexts and, while always desirable, can be difficult to measure. In reality we are facing real, sustained, environmental change, and this is likely to be increasing in intensity in the foreseeable future. The multiple impacts of climate change, specifically global warming, increasing frequency and intensity of heat waves and extreme rainfall events, are having significant impact, and, as more people are living in cities than ever before, this is being felt particularly in the urban environment.

This results in a 'wicked problem', a term first proposed by Rittel and Webber (1973) for the complexities involved in identifying solutions to planning and social policy problems. These authors outlined ten characteristics of such problems, including multiple possible solutions, that the problem is symptomatic of other problematic issues and that defining an end point, i.e. when the 'problem' has been solved, maybe impossible. Climate change falls into this category with multiple effects on urban communities, particularly those on low incomes, those living in poor quality housing and specific vulnerable groups such as the old, the young and those with existing health conditions or disabilities. Clearly there is no simple solution. While efforts are being made at global, national, regional and local scales to reduce the rate of emissions, this will not prevent the situation from getting worse; only when drawdown and carbon sequestration exceeds emissions will this begin to be addressed; even under the most optimistic scenarios, things are not going to get better any time soon. Environmental change is occurring at an unprecedented rate and slowing this will be challenging. There may well be more surprises in the future—the COVID-19 pandemic has clearly demonstrated the unimaginable can become a reality. The need for adaptation to deal with changing environmental conditions is urgent—and may need to go beyond 'resilience' as return maybe impossible and a 'new normal' may need to be accepted. But how can this be done and where does responsibility for action lie? These questions will be explored in the following sections.

3.2 Nature-Based Solutions

The IUCN has defined nature-based solutions (hereafter referred to as NbS) as 'Actions to protect, sustainably manage, and restore natural or modified ecosystems, that address societal challenges effectively and adaptively, simultaneously providing human well-being and biodiversity benefits'.[1] However, the European Commission, in transposing NbS into policy, gives a subtly different emphasis, stating that NbS harness the power and sophistication of nature to turn environmental, social and economic challenges into innovation opportunities (European Commission 2015). Fundamental to achieving this is understanding what is meant by 'nature', and what 'actions' or 'solutions' are required. Bridgewater (2018) identified the starting point for implementation to be understanding the environmental issue—or problem—and then reviewing the range of the potential solutions to identify the most appropriate. The human context is crucial; NbS are framed as solutions to 'societal challenges' (IUCN) and to 'environmental, social and economic challenges' (European Commission 2015), and these elements must be considered simultaneously. The most effective way to do this is by considering the ecosystem services any NbS delivers (Diaz et al. 2018) and factoring this into the decision-making process.

This leads to consideration of what is meant by 'nature' as little—if any—of our environment can be considered as natural, particularly in urban areas, which are examples of extreme ecosystem modification. Trees are generally considered 'natural' and so planting these an obvious action and many tree planning initiatives, in both rural and urban contexts, have been stimulated by the desire to mitigate climate change by storing carbon. This is not always appropriate and can have a negative impact on when, for example, this is at the expense of other important ecosystems such as grasslands (e.g. Veldman et al. 2015) often an important component of public open space such as city parks and recreation areas. There are also many examples, such as the planting of *Prosopis juliflora* in Northwest India to limit the spread of deserts, where this has had unintended—and seriously damaging—consequences (Bartlett et al. 2017). A further factor to be considered in the selection of appropriate species for planting is the changing growing conditions and spread of pests and diseases as a consequence of climate/environmental change (e.g. White et al. 2019).

Blue-green infrastructure is a term encompassing many different types of intervention, both aquatic and plant-based nature-based solutions. All would be appropriate in the right situation, but how can we ensure the best option is selected and effectively implemented to deliver the maximum benefit and so improve urban resilience and sustainability?

3.3 Societal Challenges in the Urban Environment

The first step is always to understand the current situation and identify all drives of change, both current and predicted, and what the consequences might be. Only then can mitigation measures, to ensure ecosystem services are maintained, be considered

[1] See https://www.iucn.org/commissions/commission-ecosystem-management/our-work/naturebased-solutions

Fig. 3.1 The basic risk assessment process

to improve resilience. Effectively this is a risk assessment—what is likely to happen and how can the consequences be reduced (see Fig. 3.1).

Improving resilience requires modelling and prediction. A brief review of the most likely risks (or societal challenges) to those living in urban environments is given in the following sections as the context for planning to improve resilience, adaptation to changed conditions and sustainability and to reduce negative impact(s).

3.3.1 Extreme Weather Events

Severe storms have become more frequent in recent years, typically of greater intensity than those previously experienced. These have been widely covered in the media, but in 2019 some serious ones were as follows:

- Hurricane 'Dorian' was the second strongest ever recorded in the Atlantic affecting the Bahamas and moving on to Western Canada.
- Cyclone 'Idai' caused deaths in Mozambique, Zimbabwe, Malawi, and Madagascar.
- Typhoon 'Hagibis' caused extensive damage in Japan (Masters 2020)

The extensive damage to buildings and infrastructure, the disruption to services and human misery have long-term social and economic consequences and require lengthy recovery periods. The psychological impact on those experiencing repeat events can only be imagined. An example is given by Kayaga et al. (2020) who investigated the impact of flooding and heat waves on water and electricity supply in low-income urban settlements in Ghana, Africa. They found flood events often led to contamination of water supplies, with implications for the spread of disease, and to power cuts. During heat waves demand for both water and power increased, and, as Ghana generates about 40% of electricity from hydropower, this is also affected by low flow in rivers. Similar challenges will be faced by supply companies and those on low incomes globally.

In drought-prone countries, rain may be a source of celebration or a disaster. The Indian monsoon of 2019 arrived late, delivered more rain than usual replenishing aquifers which was a relief to farmers (and for food supplies), but also caused extensive flooding and the death of almost 2000 people (Masters 2020). Whenever flooding occurs diseases such as typhoid and cholera become a risk; when water remains it can encourage the breeding of mosquitoes and the spread of malaria and dengue fever (World Health Organisation n.d.). Coastal areas are particularly at risk of storm surges and high tides exacerbated by river discharge into the sea after heavy rainfall.

Another aspect of extreme weather is rising global temperatures and frequency and intensity of heat waves, causing drought, water shortages and concerns about food security and livelihoods. The urban heat island (UHI) effect is the term to describe the warmer temperature of cities compared to the surrounding countryside, particularly at night, due to reduced air flow and many building materials which absorb heat during the day, releasing it when the sun goes down and air temperature falls. This can make it difficult for city dwellers to sleep well, and this can affect concentration and educational performance (Park et al. 2020) and can be a risk for those operating machinery, including vehicles, the next day (Medic et al. 2017). This has knock-on effects on the economy, both locally and for national gross domestic product (Liu et al. 2020).

Global warming is also affecting daytime temperatures, with higher average temperatures and more frequent heat waves across the world (Seneviratne et al. 2012). Heat stress is dangerous. A systematic review of health impacts conducted by Campbell et al. (2018) found little research has focused on the global south and deaths from heat stroke were used to measure impact rather than longer-term effects and morbidity. The working population, particularly those engaged in manual labour, or working in confined spaces, are likely to be particularly affected reducing productivity, and this has led to calls for revised working conditions and employment legislation (in Brazil, Bitencourt et al. 2020; in India, Rao et al. 2020; in Thailand, Boonruksa et al. 2020.). In the general population, the elderly, the young, the disabled and anyone with an existing health condition are likely to be particularly vulnerable to heat stress, feeling uncomfortable and less willing to undertake any exertion.

The above paragraphs provide a brief review of the main consequences of climate and environmental change posing risk to those living in urban areas (see Fig. 3.2). Taking a risk assessment approach requires that, following identification and assessment, steps are taken to reduce severity of impact. In the past engineering and technological solutions were favoured, for example, using drains to move water away from residential areas and streets as fast as possible into rivers. This results in fast-flowing rivers and, when their capacity is exceeded, flooding of riverside land. Warm nights and heat stress can be alleviated by installing air conditioning units and refrigeration systems, but these increase air temperature outside buildings and require electricity. Unless this is generated from renewable sources, it will be

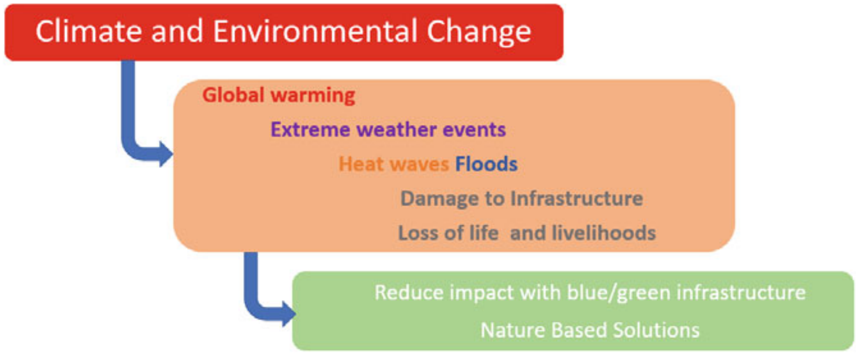


Fig. 3.2 A simple risk assessment approach applied to the urban environment

increasing emissions. Using NbS is undoubtedly a more sustainable approach and there are likely to be additional benefits.

3.4 Options Appraisal

The main risks related to climate change affecting everyone in every city globally result from extreme weather, manifested as storms, floods and heat waves. These need to be managed and impact minimised to increase resilience/enable adaptation. The potential for blue-green infrastructure to reduce these risks is clear, but how do we choose the most appropriate option for a particular situation?

3.4.1 City Scale

The urban heat island (UHI) effect is caused by the density of buildings and the ability of many building materials to absorb heat on hot days releasing it when the sun goes down. Painting buildings white reflecting heat reduces UHI potential, and this strategy is now being applied to 'cool' pavements, with reflective coatings promoted as a simple low-cost solution for the UHI (Middel et al. 2020). However, this can increase heat stress in pedestrians (Taleghani and Berardi 2018) and wall and internal building temperature (Nouri 2015). Similar approaches have been developed for roofs (Macintyre and Heaviside 2019) although there are sustainability issues as manufacture of these materials tends to use more energy and carbon than conventional ones (Gilbert et al. 2017). Yu et al. (2020) critically reviewed increasing green and blue elements across cities and concluded this was both more cost-effective and politically/locally acceptable than using cooling materials.

At city scale a tree canopy cover ratio of 30% has been found effective in reducing UHI in sub-tropical cities (Ouyang et al. 2020), but the proportion of green space is also important with parks and grassed areas having significant cooling effect that extends beyond their boundaries. Green roofs, whether designed into new build or effectively home gardens, with plants in pots housed on roofs are also effective (Mutani and Todeschi 2020). It is the cumulative area of greenery, including domestic gardens, that not only mitigates UHI and local heat stress but has a myriad of additional benefits, from food production to improving air quality, benefiting wildlife, intercepting rainfall (reducing intensity) and wellbeing and aesthetic pleasure for city dwellers. This equally applies to the overall area of 'blue' surface, although the larger the individual feature, the greater the effect. Gober et al. (2010) investigated strategies using water to mitigate UHI and found position to be important with greatest benefit felt downwind. Hathway and Sharples (2012) recorded an average reduction of 1 °C when air temperatures exceeded 20 °C extending up to 30 m from a river. Locating large water bodies, for example, for flood water storage, to the windward side of the city would be helpful; any existing wetlands should be preserved.

Extreme weather events and even prolonged heavy rainfall can lead to flooding, caused not only by amount of water but also the capacity of waterways and land to absorb it. In many cities the original waterways have been canalised, culverted or diverted through pipes, and buildings and roadways present impermeable surfaces—so where can the water go? This is a real problem in built-up urban areas with a potential solution exemplified by the 'Sponge City Program,' adopted by the Chinese Government in 2013. This is based on creating wetlands and planting trees to retain water, a reversal of the technological approach of moving water away as fast as possible and so moving the problem downstream, potentially flooding agricultural land and destroying crops. After initial pilots in 30 cities, this strategy has now been extended across China and beyond (Qi et al. 2020). Originally focused on flood mitigation, this has also mitigated the urban heat island effect and provided an opportunity for public-private partnerships to fund tree planting and management (He et al. 2019).

3.4.2 The Neighbourhood Approach

Implementing any city scale strategy will, of necessity, require local action, and this is where detailed examination of available options is required. Trees are good, contributing to the total canopy cover of the urban area, but individual trees are part of local identity, serving as landmarks, meeting places and the character of the street, square or neighbourhood. There is almost always potential to increase trees' number, and/or add additional shrubs and vegetation, and this will always increase the thermal comfort of residents.

Urban forest initiatives are emerging, aiming to increase tree canopy cover at city scale, and, although space is often at a premium, the multiple benefits—including on wellbeing, biodiversity, air quality and carbon capture—are a strong incentive for funding from the authorities. Communities often actively protect existing trees, particularly when these are old or in prominent positions, and value small areas of green space or 'pocket parks'. The long-term success of any blue-green infrastructure scheme will depend on it being accepted—and ideally welcomed—by local residents. This will increase the likelihood of them watering plants during dry spells and reduce risk of vandalism.

Change can be challenging. Adding additional planting can alter the local character, and while as outsiders we might feel this is for the better, locals might disagree. It is vital to understand the specific site, how it is used and how existing features/ facilities are valued before deciding on the most appropriate blue-green element. Participatory Landscape and Ecosystem Service Assessment techniques combine professional desk-based study and fieldwork with input from local people so that their views can be fully incorporated into plans and projects. For a description of these techniques, see Bartlett et al. (2017); a description of use for selection of nature-based solutions is given in Bartlett (2020).

Trees that have been planted to provide shade maybe reaching the end of their lives and planting a replacement required. It is tempting to use the same species, perhaps even propagating from them to produce the next generation; however, in the rapidly changing environment we are currently experiencing and with many trees taking decades to mature, is this the best approach? In the UK the London iTree Eco Project investigated London's urban forest (Forest Research 2015), revealing it comprises 8,421,000 trees. Detailed survey found sycamore (*Acer pseudoplatanus*) and the London plane (*Platanus x hispanica*) the most common street trees although neither is considered native to England. This contrasts with the common emphasis on selecting natives in planting scheme, but these have survived the harsh urban environment despite pollution and soil compaction, whereas native species, growing successfully in the countryside, cannot. The oaks (*Quercus* spp.) considered the predominant English tree are found in parks, but there is increasing concern about oak decline—a disorder severely damaging their condition, as well as the invasive alien oak processionary moth (*Thaumetopoea processionea*) which causes defoliation and serious human skin rashes.

Trees grow slowly and take decades to reach maturity, so risks to survival must be considered. What will the climatic conditions be in 100 years? Will the species that grow successfully now be able to adapt to future conditions? While this applies to all plants, including those relied on for food, the life span of trees makes this particularly important. Climatic zones are shifting challenging our conventional ideas reminding us the future will not be the same as the past. Increasing resilience (in the sense of returning to a former state) requires critical examination and using ecological concepts to ensure the species selected can thrive now and in the future. Survival depends on three critical factors: precipitation, CO_2 concentration and temperature. Prediction of what and how these will change over the lifetime of a tree is challenging but must be the route to long-term sustainability. This approach has been taken by Alizadeh and Hitchmough (2020), and these authors advise sourcing planting stock from places currently experiencing the conditions for the scenario predicted for the site under consideration.

This approach may lead to change, and even the use of non-native species, but survival is important—dead trees will not improve resilience. It is the value of the trees and other vegetation to local people and the ecosystem services delivered that are, ultimately, the important factors. In earlier sections it has been seen that canopy cover is the parameter for measuring UHI mitigation effect and this is independent of species. At street level thermal comfort is increased by shade; the larger the tree and the denser the shade, the greater the effect; but there is little evidence of differences between species. The significance of trees to local people needs to be understood, and this is usually done using the participatory ecosystem service assessment techniques previously mentioned. This can reveal trees are valued for providing fruit, nuts, flowers or fibre (provisioning services), have medicinal properties or provide resources for wildlife. Analogue species providing similar resources may be acceptable to local people.

Blue infrastructure is often thought of as visible water, such as ponds, streams, rivers and wetlands, but water flows freely through the soil, depending on structure and water table. This must be included in any consideration of the urban water resource and the potential for water storage. Trees provide cool shade but also reduce air temperature by evapotranspiration. Ground water is essential for this, so ensuring water is held in the soil rather diverted is beneficial. Hard impermeable surfaces, such as tarmac, paving and compacted soil, prevent infiltration and can exacerbate flooding. Using permeable surface materials allows water to percolate into the soil when it rains, cooling the surroundings as it evaporates in hot dry weather. A wide range of materials are available to create permeable pavements, walkways or robust hard surfaces containing voids but with the same structural integrity as conventional pavements. Examples include porous asphalt or open graded friction course asphalt pavements (also improving road friction in wet weather), and rubberised asphalt (also reduces noise), pervious concrete, brick or concrete pavement blocks (Wang et al. 2019). Vegetated permeable pavements use plastic, metal or concrete lattices so grass or other low vegetation can grow and are suitable in areas with low traffic flow. Most research into evaporative pavements has focused on their potential to mitigate the UHI, for example, the review conducted by Manteghi and Mostofa (2020), but these strategies are equally effective at local level, particularly for reducing surface water flood risk. Surrounding trees with permeable surfaces ensures water can percolate though soil to their roots—it is often forgotten that these can extend to as far as the tree's canopy.

An extension of this approach aimed to increase flood resilience at neighbourhood scale is Sustainable Urban Drainage Systems, commonly shortened to SuDS. Davis and Naumann (2017) discuss the potential for these as effective nature-based solutions ranging from large-scale interventions, such as creating wetlands and digging retention ponds, to simple 'rain gardens', where slopes direct surface water into planted areas which act as soakaways. Rainwater harvesting and storage can be done by individuals and households and deploy guttering and containers to channel water from sloping roofs into water butts. Multiple small-scale interventions at neighbourhood scale can have significant impact in reducing flood risk.

Tree pits are increasingly used in SuDS strategies combining ensuring ideal growing conditions for trees, while supporting surfaces to reduce root compaction, and facilitating slow flow of water through the soil and, when this is at capacity, into the drainage system. One example is the GreenBlue Urban RootSpace® system[2] which comprises strong, lightweight modular frames made of recycled material. Although installation requires excavation of a relatively large volume of material, these can then be filled with planting medium to support good tree growth and are highly effective in mitigating runoff and removing pollution. The number required for greatest effectiveness is proportional to that of hard surface (Grey et al. 2018).

3.5 Ensuring Sustainability

Whatever the type of vegetation or water feature (SuDS are included in this category) is selected, resilience/adaptation will only be increased if these are maintained in good condition. Planting trees is not enough; it must survive, grow to maturity and be replaced when life span is complete. So then, what are the risks that must be considered and minimised to ensure maximum benefit from blue-green infrastructure? These are shown in the following tables with suggestions for minimising the impact; but it must be noted that it is impossible to remove risk completely, particularly in times of uncertainty, so ongoing vigilance, monitoring and adaptive management is required (Tables 3.1 and 3.2).

They are many additional benefits associated with blue-green infrastructure, often referred to as co-benefits. These will almost certainly far outweigh any potential disadvantages and need to be factored into decision making. However, the emphasis of this chapter is risk, so the balance is tipped towards raising awareness of potential problems so that action is taken to limit these as far as possible. This approach will help to avoid unwelcome surprises and unintended consequences from well-intentioned plans and projects.

3.6 Taking a Strategic Approach to Promote Blue-Green Infrastructure

The previous section has focused on interventions at the local, neighbourhood, scale, and this is where the success or failure of small-scale plantings and SuDS will be determined, often as a result of community support (or lack of it). However, it is the cumulative effect of these that increases resilience/adaptive capacity at town or city scale, with local projects most effectively initiated and implemented in the context of a wider strategy. Many cities now have these, variously called climate adaption strategies or similar, including approaches at different scales. These often focus on identifying existing areas at particular risk and/or with vulnerable residents, as well

[2]For details see https://greenblue.com/gb/products/rootspace/

Table 3.1 Risks associated with blue infrastructure

Risk	Minimisation strategy
Lack of water	• Design to remain attractive even with no water flow • Where plants are included in the feature, ensure these have broad range of tolerance • Involve community members in monitoring and adding water/alerting authorities as appropriate
Too much water	• Design features with overflow provision • Connect features and building storage capacity (such as tree planting pits) • Use features to reduce flow rate • Increase infiltration capacity by using soft (e.g. grass) and permeable surfaces • Trees and other vegetation intercept rainfall and reduce impact on surfaces, reducing runoff
Pollution	• Consider potential sources of pollution in the feasibility study • Add filters as appropriate • Grills can collect large items, such as plastic material • Monitor and act if pollution is detected
Blockages	• Schedule regular maintenance, especially for complex features such as fountains • Involve community members in reporting faults
Health and safety	• Where features are accessible to the public, then checks should be scheduled to ensure any sharp or dangerous objects are removed • An additional benefit of water features is to wildlife. However, these may spread disease such as leptospirosis • In some areas venomous wildlife such as snakes may be found in water courses • Water is a potential breeding ground for insects, such as mosquitoes, which may cause a nuisance and also transmit diseases such as malaria and dengue fever
Public acceptability	• Features, particularly those visible and above ground, are vulnerable to misuse and vandalism. If local people view them as positive, then they are more likely to take care of them • Minimising adverse impacts—Such as disease risk—Will help

as providing incentives for incorporation of NbS in new developments. The potential contribution to the UHI should be included at the Environmental Impact Assessment (or Sustainability Appraisal) stage in the planning process, firstly reducing negative impact and including benefits at the design stage followed by mitigating residual effects using appropriate blue-green options.

We live in a time of change. Climate projections are uncertain. Successful implementation of blue-green infrastructure strategies to increase resilience/adaptation is undoubtedly the best approach, at both local and city-wide scale. It is increasingly recognised that the most successful city strategies are those that facilitate the involvement of local people in decision making, increasing their feeling of ownership, and so encouraging them to care for trees, for example, watering them, discouraging vandalism and acting as the eyes of the authority reporting any problems. Awareness of risk factors and vigilance to identify emerging risks is essential at strategy level, but this must be combined with appropriately funded

Table 3.2 Risks associated with green infrastructure

Risk	Minimisation strategy
Heat compromising establishment and survival	• Selection of an appropriate species for anticipated conditions for the plant's life span, particularly trees • Shading of young, vulnerable plants
Lack of water	• Selection of an appropriate species for the conditions anticipated for the plant's life span, particularly trees • Ensuring the volume of planting medium can hold an adequate water resource • Using tree pits to support trees • Involving local residents in providing water when trees/plantings are suffering water stress • Surrounding plantings with permeable surfaces to permit infiltration
Soil compaction	• Minimise traffic—Both human and vehicles across the root zone • Use paving (ideally permeable) to support the surface
Waterlogging	• SuDS such as tree pits linked to drainage systems • Ensuring planting medium is coarse grained maximising air spaces and water flow
Pollution	• In an urban setting, dust and vehicular emissions are likely to be unavoidable. Species able to tolerate this should be selected
Pests and disease	• Monitoring and swift action to deal with any outbreak • Selection of species considered not to be affected by local and predicted pests and diseases
Vandalism	• Involving the community in selection of the type of green infrastructure for their area is likely to increase their motivation to protect and care for it
Overharvesting	• Some tree species have leaves/branches used for fodder; best avoided in areas with high livestock populations • Where flowers, fruit and nuts are produced, there may be damage by picking, or pulling down tree branches
Irritant pollen/leaves leading to local objection	• Some plants are irritant, and some trees produce allergenic pollen. These should be avoided in residential areas

and resourced neighbourhood action plans; incorporating monitoring and adaptive management will ensure long-term success and the sustainability of blue-green features and the role these play in urban resilience.

Conflict of Interest Statement The authors report no conflict of interest for this publication.

References

Alizadeh B, Hitchmough JD (2020) Designing sustainable urban landscape and meeting the challenge of climate change: a study of plant species adaptation and fitness under different climate change scenarios in public landscape of UK. Landsc Res 45(2):228–246. https://doi.org/10.1080/01426397.2019.1606185

Bartlett D (2020) Chapter 6. Landscape character assessment: a method to include community perspectives and ecosystem services in land use planning. In: Dhyani S, Gupta AK, Karki M (eds) Nature based solutions: science, innovations and strategies in South Asia, Springer Nature Series Disaster Resilience and Green Growth, vol 1. Springer, Singapore, pp 99–111. https://doi.org/10.1007/978-981-15-4712-6

Bartlett D, Gomez-Martin E, Milliken S, Parmar D (2017) Using landscape character assessment and the ecosystem approach to evaluate the role of the invasive plant *Prosopis juliflora* in rural livelihoods of Kachchh, Gujarat, India. Landsc Urban Plann 167:257–266

Bitencourt DP, Alves LM, Shibuya EK, da Cunha I, de Souza JPE (2020) Climate change impacts on heat stress in Brazil—Past, present, and future implications for occupational heat exposure. Int J Climatol. https://doi.org/10.1002/joc.6877

Boonruksa P, Maturachon T, Kongtip P, Woskie S (2020) Heat stress, physiological response, and heat-related symptoms among Thai sugarcane workers. Int J Environ Res Public Health 17(17): 6363. https://doi.org/10.3390/ijerph17176363

Bridgewater P (2018) Whose nature? What solutions? Linking Ecohydrology to nature-based solutions. Ecohydrol Hydrobiol 18:311–316

Campbell S, Remenyi TA, White CJ, Johnston FH (2018) Heatwave and health impact research: a global review. Health Place 53:210–218. ISSN 1353-8292

Davis M, Naumann S (2017) Making the case for sustainable urban drainage systems as a nature-based solution to urban flooding. In: Kabisch N, Korn H, Stadler J, Bonn A (eds) Chapter 8 in Nature-based solutions to climate change adaptation in urban: areas linkages between science, policy and practice. Springer, Cham, Switzerland. Springer Open Access. https://doi.org/10.1007/978-3-319-56091-5

European Commission (2015) Towards an EU research and innovation policy agenda for nature based solutions and re-naturing cities. Final Report of the Horizon 2020 Expert group on nature based solutions and re-naturing cities (full version). Brussels

Forest Research (2015) Valuing London's Urban Forest. https://www.forestresearch.gov.uk/documents/7885/London-i-Tree-Report.pdf

Gilbert HE, Rosado PJ, Ban-Weiss G, Harvey JT, Li H, Mandel BH, Millstein D, Mohegh A, Saboori A, Levinson BM (2017) Energy and environmental consequences of a cool pavement campaign. Energy Build 157:53–77. https://doi.org/10.1016/j.enbuild.2017.03.051

Gober P, Brazel A, Quay R, Myint S, Grossman-Clarke S, Miller A, Ross S (2010) Using watered landscapes to manipulate urban heat island effects: how much water will it take to cool Phoenix? J Am Plann Assoc 76(1):109–121. https://doi.org/10.1080/01944360903433113

Grey V, Livesley SJ, Fletcher TD, Szota V (2018) Tree pits to help mitigate runoff in dense urban areas. J Hydrol 565:400–410. ISSN 0022-1694. https://doi.org/10.1016/j.jhydrol.2018.08.038

Hathway E, Sharples S (2012) The interaction of rivers and urban form in mitigating the urban heat island effect. Build Environ 58:14–22. ISSN 0360-1323. https://doi.org/10.1016/j.buildenv.2012.06.013

He B-J, Zhu J, Zhao D-X, Gou Z-H, Qi J-D, Wang J (2019) Co-benefits approach: opportunities for implementing sponge city and urban heat island mitigation. Land Use Policy 86:147–157. ISSN 0264-8377. https://doi.org/10.1016/j.landusepol.2019.05.003

Kayaga SM, Amankwaa EF, Gough KV, Wilby RL, Abarike MA, Codjoe SNA, Kasei R, Nabilse CK, Yankson PWK, Mensah P, Abdullah K, Griffiths P (2020) Cities and extreme weather events: impacts of flooding and extreme heat on water and electricity services in Ghana. Environ Urban 33(1):131–150. https://doi.org/10.1177/0956247820952030

Liu H, Huang B, Yang C (2020) Assessing the coordination between economic growth and urban climate change in China from 2000 to 2015. Sci Total Environ 732:139283. https://doi.org/10.1016/j.scitotenv.2020.139283

Macintyre HL, Heaviside C (2019) Potential benefits of cool roofs in reducing heat-related mortality during heatwaves in a European city. Environ Int 127:430–441. https://doi.org/10.1016/j.envint.2019.02.065

Manteghi G, Mostofa T (2020) Evaporative pavements as an urban heat island (UHI) mitigation strategy: a review. Int Transac J Eng Manag Appl Sci Technol. https://tuengr.com/V11/11A01Q.pdf

Masters J (2020) The top 10 weather and climate stories of 2019: near-record arctic melting, a bountiful but deadly monsoon and three highly destructive tropical cyclones highlight the earth's second warmest year on record. Scientific American. https://blogs.scientificamerican.com/eye-of-the-storm/the-top-10-weather-and-climate-stories-of-2019/

Medic G, Wille M, Hemels ME (2017) Short- and long-term health consequences of sleep disruption. Nat Sci Sleep 9:151–161. https://doi.org/10.2147/NSS.S134864

Middel A, Turner VK, Schneider FA, Zhang Y, Stiller M (2020) Solar reflective pavements—A policy panacea to heat mitigation. Environ Res Lett 15:6. https://doi.org/10.1088/1748-9326/ab87d4/meta

Mutani G, Todeschi V (2020) The effects of green roofs on outdoor thermal comfort, urban Heat Island mitigation and energy savings. Atmosphere 11(2):123. https://doi.org/10.3390/atmos11020123

Nouri AS (2015) A framework of thermal sensitive urban design benchmarks: potentiating the longevity of Auckland's public realm. Buildings 5:252–281. https://doi.org/10.3390/buildings5010252

Ouyang W, Morakinyo TE, Ren C, Ng E (2020) The cooling efficiency of variable greenery coverage ratios in different urban densities: a study in a subtropical climate. Build Environ 174:106772. https://doi.org/10.1016/j.buildenv.2020.106772

Park RJ, Goodman J, Hurwitz M, Smith J (2020) Heat and learning. Am Econ J Econ Pol 12(2): 306–339. https://doi.org/10.1257/pol.20180612

Qi Y, Chan FKS, Thorne C, O'Donnell E, Quagliolo C, Comino E, Pezzoli A, Li L, Griffiths J, Sang Y, Feng M (2020) Addressing challenges of urban water management in Chinese sponge cities via nature-based solutions. Water 12(10):2788. https://doi.org/10.3390/w12102788-08

Rao K, Lakshmi Kumar TV, Kulkarni A, Ho CH, Mahendranath B, Desamsetti S, Patwardhan S, Dandi AR, Barbosa H, Sabade S (2020) Projections of heat stress and associated work performance over India in response to global warming. Sci Rep 10(1):16675. https://doi.org/10.1038/s41598-020-73245-3

Rittel HW, Webber MM (1973) Dilemmas in a general theory of planning. Policy Sci 4(2): 155–169. https://www.cc.gatech.edu/fac/ellendo/rittel/rittel-dilemma.pdf

Seneviratne SI, Nicholls N, Easterling D, Goodess CM, Kanae S, Kossin J, Luo Y, Marengo J, McInnes K, Rahimi M, Reichstein M, Sorteberg A, Vera C, Zhang X (2012) Changes in climate extremes and their impacts on the natural physical environment. In: Field CB, Barros V, Stocker TF, Qin D, Dokken DJ, Ebi KL, Mastrandrea MD, Mach KJ, Plattner GK, Allen SK, Tignor M, Midgley PM (eds) Managing the risks of extreme events and disasters to advance climate change adaptation, A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change (IPCC). Cambridge University Press, Cambridge/New York, NY, pp 109–230

Taleghani M, Berardi U (2018) The effect of pavement characteristics on pedestrians' thermal comfort in Toronto. Urban Clim 24:449–459. https://doi.org/10.1016/j.uclim.2017.05.007

Veldman JW, Overbeck GE, Negreiros D, Mahy G, LeStradic S, Fernandes GW, Durigan G, Buisson E, Putz FE, Bond WJ (2015) Where tree planting and forest expansion are bad for biodiversity and ecosystem services. Bioscience 65(10):1011–1018. https://doi.org/10.1093/biosci/biv118

Wang J, Meng Q, Zhang LV, Zhang Y, He J, Zheng S, Santamouris M (2019) Impacts of the water absorption capability on the evaporative cooling effect of pervious paving materials. Build Environ 151:187–197. https://doi.org/10.1016/j.buildenv.2019.01.033

White RM, Marzano M, Leahy S, Jones G (2019) Are we defending the indefensible? Reflecting on policy and practice around 'the border' in plant biosecurity for tree health. Forests 10:716. https://doi.org/10.3390/f10090716

World Health Organisation (n.d.) Flooding and communicable diseases fact sheet. https://www.who.int/hac/techguidance/ems/flood_cds/en/#:~:text=Floods%20can%20potentially%20increase%20the,fever%2C%20and%20West%20Nile%20Fever

Yu Z, Yang G, Zuo S, Jørgensen G, Koga M, Vejre H (2020) Critical review on the cooling effect of urban blue-green space: a threshold-size perspective. Urban For Urban Green 49:126630. ISSN 1618-8667. https://doi.org/10.1016/j.ufug.2020.126630

Debbie Bartlett is a Professor of Environmental Conservation Faculty of Engineering and Science at the University of Greenwich, UK. She is also a Chartered Landscape Architect and Fellow of the Chartered Institute for Ecology and Environmental Management.

4 Promoting Blue-Green Infrastructure in Urban Spaces Through Citizen Science Initiatives

Indu K. Murthy and Monowar Alam Khalid

Abstract

The compounded effects of urbanization and climate change are taking a serious toll on rapidly growing urban spaces around the world. Blue-green infrastructure offers a host of opportunities and benefits for addressing the multiple challenges of environment, social well-being and climate change. Cities can mobilize key actors for crosscutting and inclusive action, bringing diverse stakeholders such as national governments, private sector, civil society and common citizens together. This chapter discusses the role of citizen science which is now seen as a tool for educating citizens on scientific research, engaging them where possible and considering views and expectations of different stakeholders. Citizen science can play a role at different stages of development of urban spaces, and they include (i) project demand, (ii) project design, (iii) project implementation and delivery and (iv) project monitoring and maintenance. For facilitating and promoting enhanced participation of citizens through the entire project cycle of blue-green infrastructure, appropriate policy instruments, ranging from legal to market-based to communication to organizational, are needed.

Keywords

Blue-green infrastructure · Urban spaces · Cities · Climate change · Citizen science · Sustainable development

I. K. Murthy (✉)
Center for Study of Science, Technology and Policy, Bangalore, Karnataka, India
e-mail: indukmurthy@cstep.in

M. A. Khalid
Integral University, Lucknow, Uttar Pradesh, India

S. Dhyani et al. (eds.), *Blue-Green Infrastructure Across Asian Countries*,
https://doi.org/10.1007/978-981-16-7128-9_4

4.1 Introduction

Cities present enormous potential to anchor in wealth generation and economies. According to the UN Department of Economic and Social Affairs report, by 2030, there would be 43 megacities globally with more than ten million population each—mostly in the developing regions (United Nations 2018). The world's cities that occupy just 3% of the land account for 60–80% of energy consumption and 75% of the carbon emissions globally.[1] Increasing and rapid urbanization is exacerbating the pressure on freshwater supplies, sewage, the living environment and public health.[2] This is leading to scarcity of resources, lack of basic services, increased congestion and decline in infrastructure. Unplanned sprawl as cities spill beyond formal boundaries threatens developmental planning and attainment of global goals of sustainable development.[3] Shao et al. (2020) analysed the extent and pattern of urban sprawl in Morogoro urban municipality and concluded that urbanization affects the quality of urban life and its sustainable development.

In India, as per the 2011 census, 31% of people live in urban areas, and by 2025, 46% of Indians will live in cities with more than one million people. By 2030, the number of cities with more than one million population will grow from 42 to 68 and is expected to grow to 814 million by 2050 (McKinsey 2010). Oxford Economics Global cities report (2016) estimated that 17 of the 20 fastest-growing cities in the world will be from India during 2019 and 2035. Rapid urbanization poses multiple challenges with regard to liveability. As the cities are expanding in an unplanned manner, they are ill-equipped to deliver basic services of housing, infrastructure, water and sanitation. This is evident from the report of Economist Intelligence Unit's Global Liveability Index 2019 covering 140 cities, which ranks New Delhi and Mumbai in the 118th and 119th position. This index is developed by a city being assigned a rating of relative comfort for over 30 qualitative and quantitative factors across 5 broad categories. These include culture and environment, healthcare, education, stability and infrastructure which are rated as acceptable, tolerable, uncomfortable, undesirable or intolerable. While a rating is awarded based on the judgment of in-house analysts and in-city contributors for qualitative indicators, the rating is calculated based on the relative performance of a number of external data points for quantitative indicators. The scores are then compiled and weighted to provide a score of 1–100, where 1 is considered intolerable and 100 is considered ideal.

The challenges to urban spaces could be overcome through improved resource use such as better water and waste management and by building cities that offer job opportunities and provide access to basic services like energy, housing and transportation. This is because cities can either dissipate energy or help optimize energy use by reducing energy consumption and adopting green energy systems (Kennedy

[1] Cities—United Nations Sustainable Development

[2] Goal 11 targets; UNDP

[3] SDG 11: Sustainable Cities and Communities

et al. 2009). Therefore, building cities that are inclusive and sustainable is not an option but a requirement.

The Government of India through its Smart Cities Mission, the Jawaharlal Nehru National Urban Renewal Mission (JNNURM) and the Atal Mission for Rejuvenation and Urban Transformation (AMRUT) is working to address the challenge of improving urban spaces. However, the challenges of congestion, pollution, housing, sanitation, energy access, transport, unemployment, waste management and poverty remain (Aijaz 2016). Blue-green infrastructure—an approach to building resilience through capitalizing the benefits of working with urban green spaces and naturalized water flows (Lamond and Everett 2019)—offers an opportunity to manage multiple challenges of urbanization such as infrastructure and water demands, waste management, etc., in addition to providing climate change mitigation and adaptation benefits. In this chapter we explore the multiple co-benefits of promoting blue-green infrastructure, and also how citizen science—involving general public—could provide the required impetus to have cities that are sustainable and inclusive.

4.2 Cities, Climate Change and Sustainable Development

Cities are centres of commerce, culture and innovation. The effects of urbanization and climate change consequences are taking a serious toll on the rapidly growing urban pockets across the world (Carter et al. 2015). A growing number of people will continue to face unprecedented negative impacts, both due to climate change and reduced economic growth, quality of life and increased social instability (Hoegh-Guldberg et al. 2018). About 70% of cities are already dealing with the effects of climate change and nearly all are at risk, according to the C40 report.[4] Cities are sources and sinks of emissions (Hoornweg et al. 2011; Lin et al. 2018). According to the C40 report[4], two-thirds of the world's energy is consumed by cities, and they are a source of 75% of global CO_2 emissions, with transport and buildings being the biggest contributors. According to Rosenzweig et al. (2015), "temperatures are already rising in cities around the world due to both climate change and the urban heat island effect." In this study for 100 cities, Rosenzweig et al. (2015) reported the following:

- The mean annual temperature increase in about 39 cities around the world is at a rate of 0.12–0.45 °C per decade during 1961 to 2010.
- The mean annual temperature is projected to increase by 0.7–1.5 °C by the 2020s and 1.3–3.0 °C by the 2050s.
- The mean annual precipitation is projected to change in the range −7 to +10% by the 2020s, and −9 to +15% by the 2050s.
- Sea level is projected to rise in the coastal cities by 4–19 cm by the 2020s and 15–60 cm by the 2050s.

[4] https://www.c40.org/ending-climate-change-begins-in-the-city

The impacts of climate change on urban ecosystems are multiple—both direct and indirect as biodiversity in urban ecosystems and the ecosystem services that they provide for human health and well-being is impacted, making them vulnerable (Emilsson and Ode Sang 2017).

The Goal 11 of the UN Sustainable Development Goals (SDGs) is "sustainable cities and communities." SDG 11 aims at safe and affordable housing, affordable and sustainable transport systems, inclusive and sustainable urbanization, protecting the world's cultural and natural heritage, reducing the adverse effects of natural disasters, reducing the environmental impact on cities, providing access to safe and inclusive green and public spaces, strong national and regional development planning, implementing policies for inclusion, resource efficiency and disaster risk reduction and supporting least developed countries in sustainable and resilient building. SDG 11 is thus a transformational element of the 2030 Agenda as it is location-specific at a manageable scale, highlighting the interlinkages and opportunities cities provide across sectors and goals—being microcosms of all the other SDGs.

4.3 Citizen Science and Blue-Green Infrastructure

In this section, we define citizen science and green and blue infrastructure and also discuss the evolution of the concept over time, along with looking at citizen science in conjunction with green and blue infrastructure.

Citizen science: Citizen science is the process of producing scientific knowledge in which non-scientific or non-professional actors, individuals or groups actively and intentionally participate (Francois Houllier Merilhou-Goudard 2016). In other words, citizen science can be defined as the involvement of public or people from non-academia in the process of scientific research. It is also referred to as participatory action research (Pettibone et al. 2016), civic science, amateur science (Finke 2014), community science and crowd-sourced science. There are also certain related concepts such as community-based monitoring (Mark et al. 2017), stakeholders' engagement, etc. The earliest citizen science programme is believed to be developed in the 1800s by Wells Cooke from the American Ornithologists Union, who looked at the patterns of bird migration under North American Bird Phenology programme, allowing private citizens for the first time to join the government programme. Later, since 1900, the National Audubon Society involved private citizens in their annual Christmas Bird Counts.

Citizen science thus encompasses a diverse range of approaches and, in addition to generation of scientific data, provides engagement benefits and other outcomes such as education, awareness building and action (Kelemen-Finan et al. 2018). Numerous disciplines and research topics are adopting a citizen science approach (see Fig. 4.1), and in addition to researchers, engineers and technicians, a range of actors including individuals as well as groups (associations, companies, regional authorities, etc.) are beginning to engage in citizen science.

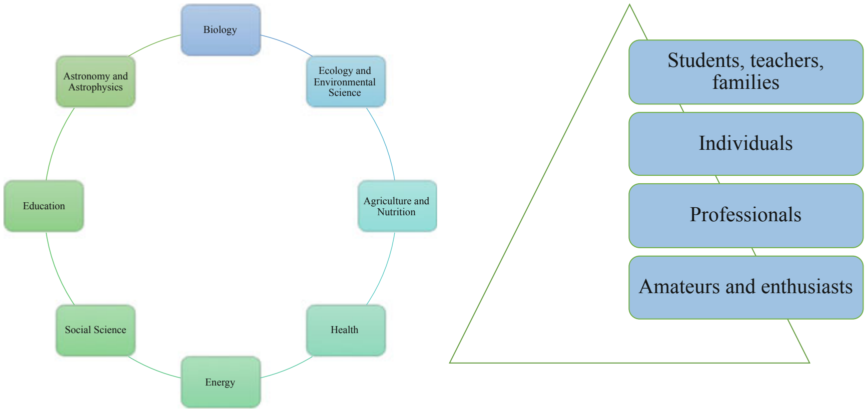


Fig. 4.1 Emerging topics and streams of citizen science engagement and actors

Blue and green infrastructure: Blue infrastructure refers to water elements—rivers, canals, ponds, wetlands, floodplains, water treatment facilities, etc. Green infrastructure refers to trees, lawns, parks, fields, forests, etc. These terms are borrowed from urban planning and land-use planning. Green infrastructure is defined as "the range of measures that use plant or soil systems, permeable pavement or other permeable surfaces or substrates, storm water harvest and reuse, or landscaping to store, infiltrate, or evapo-transpirate storm water and reduce flows to sewer systems or to surface waters."[5] Green infrastructure is a cost-effective, resilient approach to managing wet weather impacts while providing many community benefits.

4.3.1 Citizen Science and Green Infrastructure

Citizen engagement in green infrastructure is driven by the need for "all groups of society having a say in its planning and implementation to ensure that it meets their requirements" (Wilker et al. 2016). Such a need for varied forms of citizen engagement is also highlighted in literature by Mees et al. (2019), Faehnle et al. (2014) and Lovell and Taylor (2013). Citizen participation in green infrastructural development is focused on the early stages of development, advocating collaborative governance and co-production (Frantzeskaki 2019). However, Wilker et al. (2016) argue that current methods adopted for promoting participation such as stakeholder consultations alone are not sufficient but more interactive participation methods such as involving communities in plan and design of projects need to be adopted in order to achieve meaningful outcomes. However, involvement of citizens at the

[5] https://www.epa.gov/green-infrastructure/what-green-infrastructure

later stages such as at the time of maintenance is reported but under-researched (Jerome et al. 2017).

Despite its promise and increasing use, mixed results of participation of citizens in green infrastructure are reported (Burton and Mustelin 2013), underpinning the need for more elaborate forms of citizen engagement such as those reported by Mees et al. (2019) and Faehnle et al. (2014).

4.3.2 Citizen Science and Blue Infrastructure

Use of a citizen science framework for hydrological studies is complex and limited by cost, technological demands and need for spatially and temporally distributed measurements (Paul et al. 2018). However, in the recent times, technological developments with respect to monitoring equipment and volunteered geographical information have improved the rate and quality of data collection through real-time mapping services that are tagged to a location (Newman et al. 2012). This has led to increased application of citizen science in hydrology (Paul et al. 2018).

Water resource monitoring through citizen science has emerged worldwide leading to development of networks of well-monitored sites created over time, improving the spatial coverage of monitoring (Ochoa-Tocachi et al. 2018). Such monitoring programmes include measurements of precipitation, water quality, soil moisture, groundwater level, etc. The input and use of citizen science data in freshwater science has resulted in improvement in the quality of scientific outputs (Thornhill et al. 2019), which certainly will provide new source of valuable and much needed freshwater data and knowledge through involvement of volunteers.

A number of studies demonstrate that humans enjoy visual and physical proximity to water and these settings deliver immense emotional and therapeutic benefit (DePledge and Bird 2009; Wheeler et al. 2012). To capture on the same benefits and provide awareness through involvement of people, citizen science project "FreshWater Watch" was globally launched in 2012 to monitor the health of lakes, rivers, streams, wetlands and reservoirs as part of the HSBC Water Programme (Earthwatch 2012), which, since then, has reached out to volunteers, research organizations and schools across the world and collected more than 26,461 measurements of freshwater data (https://freshwaterwatch.thewaterhub.org/our-data/explore-our-data). Other programmes like BlueCarbonArmy in partnership with Earthwatch and HSBC aimed at sensitizing and educating community on the values of coastal wetlands and contributing to blue carbon research. Few other prominent citizen science programmes are Project BudBurst, BugGuide, FrogWatch USA, NestWatch, Zooniverse, etc.

The concept of citizen science has thus gained increasing attention and popularity in the recent years although citizen involvement in collection of data and specimens of ecological value is not new (Miller-Rushing et al. 2012). According to Kosmala et al. (2016), the number of peer-reviewed publications on citizen science has increased significantly over the last decade. Further, there is increased acceptance of citizen science in the recent decades (Fritsch-Kosmider 2018), and improved

Fig. 4.2 Forms of citizen science engagement

visibility (Mark et al. 2017; Pocock et al. 2018) unlike in the past, when biodiversity data collection by volunteers was seldom acknowledged in scientific publications. Citizen science is now seen as a tool for educating citizens on scientific research, engaging them where possible and considering views and expectations of different stakeholders (Wittmayer and Janssen 2019). This has been brought about due to increased access to new technologies such as the internet, smartphones, apps, etc., allowing better access and sharing of data (Goudeseune et al. 2020). Innovative technologies becoming available such as reliable and relatively cheap environmental sensors that facilitate data collection and reduce errors in spatial and temporal information associated with the records (Skarlatidou et al. 2019) have made citizen involvement easier. Creation of apps and development of website interfaces and platforms have also enabled easy data hosting, analysis of data or even recruitment of volunteers (e.g. SciStarter). Waller (2018) reports that on the Global Biodiversity Information Facility, 50% of occurrence records are citizen science observations and six of the top ten datasets are citizen science datasets.

Reduced budget, capacity and scope for monitoring by institutions (Carlson and Cohen 2018) coupled with increased awareness, increasing public knowledge and concern of citizens on human impacts on ecosystems (Conrad and Hilchey 2011) have created the needed impetus for citizen involvement in environmental monitoring and decision-making. Several models of citizen science ranging from top-down to bottom-up participatory approaches are increasingly being adopted, depending on the level of engagement (Paul et al. 2018; McKinley et al. 2012).

Bonney et al. (2009) distinguish three main forms of engagement (Fig. 4.2):

- Contributory projects where scientist design and citizens contribute data.
- Collaborative projects—where scientists design and citizens contribute data as well as help refine project design, analyse data and/or disseminate findings.
- Co-created projects—where scientists and citizens co-design projects and a few citizens are actively involved during the entire project cycle from conception to dissemination.

According to Bonney et al. (2009), 73% of the studies reviewed were contributory, 23% were collaborative, and 4% were cocreated—employing a deeper citizen involvement (García and Brown 2009). In the contributory category of studies, scientists designed the programme, trained the citizens and adopted quality control measures to ensure credibility of citizen science generated data. Quality control measures include standardized training programmes, simplified data collection protocols, use of time series analysis and comparison of citizen science datasets with standard methods or expert data—as a validation (Weeser et al. 2018; Jollymore et al. 2017; McGoff et al. 2017; Moffett and Neale 2015).

4.4 Blue-Green Infrastructure for Sustainable Development

There are evidences to show that human contact with green and blue spaces can have significant health and well-being benefits, in addition to carbon sequestration by trees, improvement of air quality, dampening of urban heat island effect, flood prevention, etc.—all needed for sustainable living and development. Conservation and promotion of biodiversity in urban spaces helps tide over adverse climatic conditions such as flooding, and act as natural barriers and filters to air pollution. This is at a time when extreme events under climate change are projected to increase (Seneviratne 2012), and traditional grey infrastructure—such as underground drainage systems—are proving to be inadequate to deal with heavy rainfall and flooding events, and increased heat due to rising temperature (Davis and Naumann 2017).

Blue-green infrastructure thus offers a host of opportunities and benefits. The benefits from blue-green infrastructure are summarized in Table 4.1 and Fig. 4.3.

4.5 Citizen Science for Promoting Blue-Green Infrastructure in Urban Spaces

Cities are hubs of innovation in the past two decades and have been incubators for movements demanding improvement in resilience and sustainability. Worldwide, cities are striving to offer desirable living conditions such as clean air and water, sustainable mass transit, expansive green spaces and safe communities that attract people. As such, cities are a complex nexus of social, political, economic and ecological systems. In recent times, it is widely recognized that the way forwards must be an integrated approach to development and resource management. Additionally, it should also create and enable processes that facilitate participation of local and regional governments, and communities (Childers et al. 2015).

Cities can mobilize key actors for crosscutting and inclusive action. Bringing diverse groups—national governments, the private sector, universities, civil society and common citizens—is a challenge since, traditionally, they work in isolation. However, as urban areas are expanding, local governments and communities have

Table 4.1 Benefits of blue-green infrastructure

Benefits	Evidence	Reference
Cooling	– Use of green walls in the United Kingdom reduced indoor temperatures by 4–6 °C during summer	Ip et al. (2010)
	– Retrofitting of roofs of existing buildings with green roofs at a city scale is reported to reduce surface temperatures on roofs by around 20 °C	Charlesworth (2010)
	– Trees close to buildings have been reported to lower indoor summer temperature by 4 °C and increase winter temperatures by 6 °C, compared to no trees next to buildings—Resulting in reduced energy consumption by up to 26%	Bozovic et al. (2017)
Air quality improvement	– Green infrastructure can improve urban air quality – Green hedges between roads and pedestrians and green walls are win-win air pollution measures	Hewitt et al. (2020)
	– Long-term benefits of trees for improved health due to removal of air pollutants, better cooling and carbon storage benefits are reported to be twice the cost of planting and maintenance	McPherson et al. (1994)
Improved physical and mental health	– Improved attention and emotional state	Tzoulas et al. (2007)
	– Higher survival rates of senior citizens with easy access to walkable green space	Takano et al. (2002)
Water regulation and reduced flooding	– Absorption of 100% of incident rainfall on installation of green roofs	Mentens et al. (2006)
	– Use of green roofs, water gardens, etc., for increased infiltration and slower and gradual flow of rain water into drains, reduces the risk of surface water flooding	Ossa-Moreno et al. (2017)
	– Reduced run-off of storm water per building through use of green roofs	ADAS (2019)
Biodiversity conservation	– Urban spaces are reported to support double the biodiversity potential when the tree cover increases from 33% to 52%	Ibid

gradually assumed more responsibilities related to the provision of basic services within cities. Examples of such creative and resourceful projects in response to complex challenges include the bus rapid transit in Bogotá, Colombia; waste management programme in Curitiba, Brazil; and energy saving in Freiburg, Germany.

A review of the 244 SDG indicators by Fraisl et al. (2020) identified SDG targets and indicators to which citizen science is already contributing to and those to which they can potentially contribute to (Fig. 4.4). The number of indicators to which citizen science "could contribute" is 76 (of the 244). Currently, the contribution to indicators of SDG 3 (good health and well-being), SDG 11 (sustainable cities and communities), SDG 15 (life on land) and SDG 6 (clean water and sanitation) is well utilized. Similarly, Bishop Isabel et al. (2020) have explored the potential of citizen science to deliver SDGs through integration into monitoring schemes. Fritz et al. (2019) have

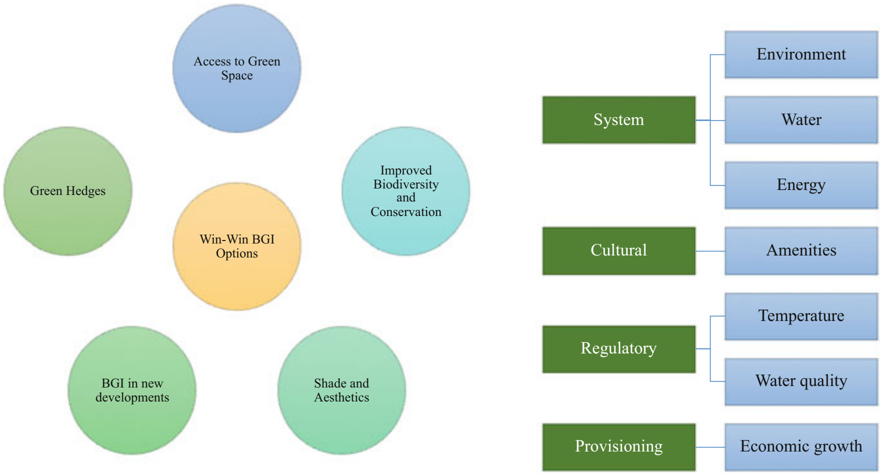


Fig. 4.3 Blue-green infrastructure solutions and likely net benefits. *Created by authors*

created a road map for citizen science and SDG reporting and identified relevant citizen science projects. SDG 11—sustainable cities and communities—is one of them. Thus, the potential of blue-green infrastructure to contribute towards sustainable development and the feasibility of adopting citizen science approaches for promoting them are established.

It is clear from these studies that citizens can play a key role in promoting resilience and sustainability. In particular, the feasibility of adopting a citizen science approach for SDG 11 which relates to sustainable cities (urban spaces) and communities has been demonstrated.

Increasing the level of participation of citizens in blue-green infrastructure has wider societal benefits if all stakeholders in a society have a say in its planning and implementation—ensuring it meets their requirements (Wilker et al. 2016). In literature, involvement of citizens in blue-green infrastructure is largely reported to be focused on the early stages of development. However, what is required is collaborative governance and co-production (Frantzeskaki 2019), in order to ensure legitimate outcomes (Wilker et al. 2016).

The various stages (Fig. 4.5) at which citizen science can play an important role include (i) project demand, (ii) project design, (iii) project implementation and delivery and (iv) project monitoring and maintenance.

4.5.1 Project Demand

Citizen science programmes can play an important role in creating the demand for blue-green infrastructure in cities. Ongoing citizen science programmes on urban tree monitoring, water quality monitoring and air quality monitoring could serve as data sources to understand the issues in urban spaces, and also the potential for

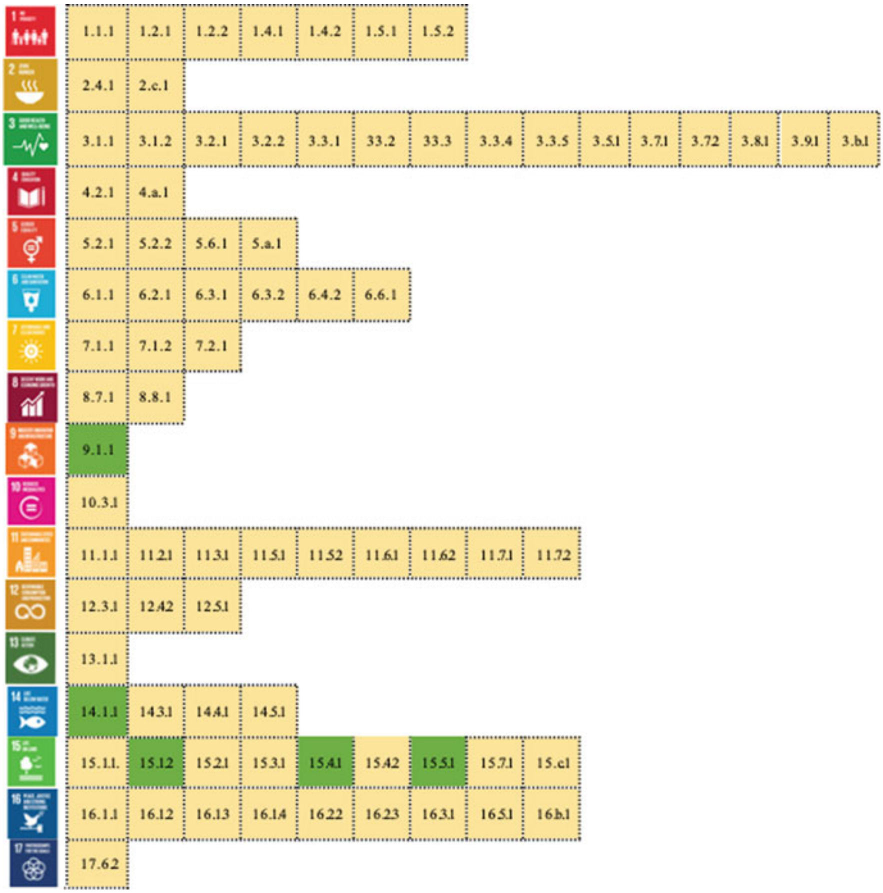


Fig. 4.4 Contribution of citizen science to monitoring of SDGs; "already contributing" (in green), "could contribute" (in yellow). Adapted from Fraisl et al. 2020

creating blue-green infrastructure. This can be derived through documenting existing structures, the issues and also the scope for development of blue-green infrastructure. They could further create awareness which in turn motivates citizens to demand for improved blue-green infrastructure in cities, if research groups coordinating these programmes build consciously a component of imparting information on blue-green infrastructure and its benefits, as well as how cities around the world have successfully integrated this into urban planning.

4.5.2 Project Design

Citizen involvement at the time of design revolves around promoting engagement with the living environment, creating awareness and promoting partnership and

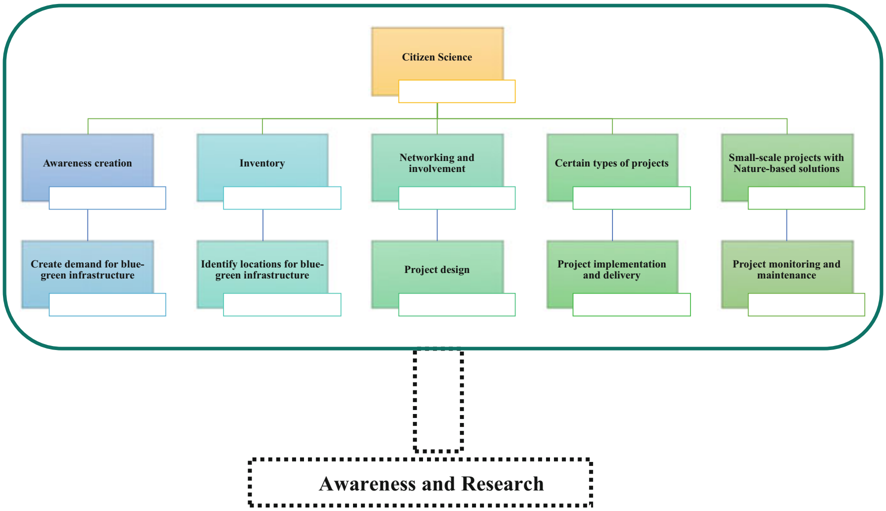


Fig. 4.5 Phases and stages for embracing citizen science in promoting blue-green infrastructure in urban spaces

coalition, so they become involved in project design. Such an example is seen in projects implemented at Gothenburg and Antwerp (van Popering-Verkerk and van Buuren 2017). In Antwerp, the opportunity to create green infrastructure was seen as a means to involve land owners and local residents as it impacts them too, and therefore their involvement in design, maintenance and delivery was sought. Likewise, in Gothenburg where the goal was to transform the Frihamnen area, an uninhabited harbour area, into a residential neighbourhood, local residents were involved in co-designing the project, thereby increasing their awareness of the hitherto uninhabited area (Willems et al. 2020). Yet another example is the city of Dordrecht,[6] wherein investments that were planned for improving the living conditions and sewage systems were combined to create green infrastructure through a comprehensive plan that brought together residents, NGOs and local organizations.

Thus, public participation in spatial planning provides an opportunity to take into consideration local knowledge in decision-making, which otherwise would be lost (Chaffin et al. 2016). Davis and Naumann (2017) also indicated the increasing social inclusion in green infrastructure planning process. Previous studies suggest the importance of involving citizens in the planning process (Anderson et al. 2019), to promote multifunctionality, and more equitable access to green space services (Hansen et al. 2017), and strengthening of green infrastructure resilience (Monteiro et al. 2020).

[6] file:///Users/indukmurthy/Downloads/BGI%20poster%20BEGIN.pdf

4.5.3 Project Implementation and Delivery

The role of citizen science at project delivery phase and the scope for involving citizens in these projects are quite limited, given the need for green skills for implementing and delivering projects. Even in ongoing or recently completed green infrastructure projects such as the one in Bergen and Bradford for providing light rail transport, and in Aberdeen and Hamburg for creating sustainable urban drainage system, and water storage systems, opportunity for citizen involvement was limited to consultations and awareness building as these are predominantly engineering-oriented but focused on creating climate adaptation measures (Willems et al. 2020). However, the Sustainable Urban Drainage Systems in Aberdeen is more nature-based, using ecosystem principles in technical design, and involved creation of rain gardens along streets—with the scope for citizen involvement (Willems et al. 2020).

4.5.4 Project Monitoring and Maintenance

Governance is one of the principles of green infrastructure planning, aimed at effective collaboration between the government actors and citizens. According to Monteiro et al. (2020) "this principle assumes great importance to the development and implementation of green infrastructure because green spaces offer a wide range of recreational functions, focused on people, and their management and maintenance depend directly on the population."

While the project design phase is aimed at building networks and bridging interests of a diverse set of stakeholders, the scope for involvement of citizens in project maintenance is determined by the scale and nature of the blue-green infrastructure. For instance, small-scale infrastructure could be maintained by citizens through regular monitoring. In Kent[7] and Enfield,[8] with rain gardens and wetlands, respectively, co-maintenance by involving local voluntary groups, potentially stimulating social cohesion and lowering of budget for maintenance, has been achieved.

Further, citizen science programmes could provide opportunities for promoting monitoring of tree and air and water quality and infrastructure through involvement of volunteers and scientists, thus providing impetus to research understanding and awareness among citizens for its safeguard and in turn increasing the demand for blue-green infrastructure in urban spaces.

[7] Kent, Interreg VB North Sea Region Programme

[8] https://northsearegion.eu/begin/bgi-pilot-projects/enfield/

4.6 Widening the Niche for Blue-Green Infrastructure in Urban Spaces

Blue-green infrastructure holds promise for adaptation to rapidly changing human and environmental circumstances and therefore needs to be recognized and internalized in the planning process. This has the potential to (i) secure water during the dry season and droughts or filter and enable water drainage during flooding, (ii) create jobs and (iii) mitigate and help to adapt climate change. Given the interconnectedness of natural and anthropocentric systems, and issues in an urban system, well-thought-out interventions such as promotion of blue-green infrastructure would be successful when communities and systems for which these are implemented are sensitized and made aware of the workings and benefits of blue-green infrastructure (Sposito et al. 2014).

Implementing blue-green infrastructure in urban spaces will result in both, local, regional and global benefits. It can help to improve biodiversity, groundwater storage, water quality and water purification. Additionally, through increase in green spaces, it can lead to incremental addition of carbon sequestration, thereby mitigating the impact of climate change. Chen (2015) estimates, based on empirical data, that carbon stored in vegetation of urban green infrastructure of 35 major Chinese cities was 18.7 million tons, with an average carbon density of 21.34 t/ha. Further, Daniel et al. (2020) state that blue-green infrastructure is an environmentally friendly and cost-effective approach to carbon sequestration. Also, these trees will in turn promote biodiversity, both flora and fauna, create habitat niches, improve water holding capacity of soils, reduce erosion and improve the overall flow of ecosystem services. Blue-green infrastructure can also help create spaces for social and recreational activities, thereby contributing to improved physical and mental health, and help people connecting with nature, making the general living conditions of an urban system attractive. There are case studies of dementia-friendly parks contributing to well-being of people with dementia in Canada,[9] Netherlands[10] and Scotland.[11] Further Zeisel et al. (2003) report positive outcomes in behavioural outcome of Alzheimer's special care units and environment. Additionally, Kuo and Sullivan (2001) report lower levels of fear, fewer incivilities and less aggressive and violent behaviour among residents living in green surroundings. If appropriately designed, blue-green infrastructure can be a significant tool for designing resilient urban spaces, with improved flexibility and adaptability.

In order to promote enhanced participation of citizens through the entire project cycle of blue-green infrastructure, there is a need for appropriate policy instruments. These could possibly range from legal to market-based to communication to

[9] https://vancouversun.com/news/local-news/canadas-first-dementia-village-to-open-in-langley-next-year

[10] https://hogeweyk.dementiavillage.com/en/

[11] https://www.pathsforall.org.uk/news-post/scotlands-first-dementia-friendly-park-is-launched-in-stirling

organizational policy instruments deployed at various stages of implementation. Putting in place such policy instruments will facilitate enhanced citizen participation at all stages of blue-green infrastructure implementation, unlike traditional systems which are hierarchical and engineering/design driven.

Acknowledgements Authors sincerely thank the Center for Study of Science, Technology and Policy and the Department of Environmental Sciences, Integral University, for supporting this research.

Conflict of Interest Authors declare no conflict of interest for this publication.

References

ADAS (2019) Committee on climate change: research to provide updated indicators of climate change risk and adaptation in England

Aijaz R (2016) Challenges of making smart cities in India. Asie Visions No. 87 Ifri

Anderson EC, Egerer MH, Fouch N, Clarke M, Davidson MJ (2019) Comparing community garden typologies of Baltimore, Chicago, and New York City (USA) to understand potential implications for socio-ecological services. Urban Ecosyst 22:671–681. https://doi.org/10.1007/s11252-019-00855-9

Bishop Isabel J, Warner S, Toos CGE, van Noordwijk TC, Nyoni FC, Loiselle S (2020) Citizen science monitoring for sustainable development goal indicator 6.3.2 in England and Zambia. Sustainability 12:10271. https://doi.org/10.3390/su122410271

Bonney RH, Ballard R, Jordan E, McCallie T, Phillips J, Shirk CC, Wilderman (2009) Public participation in scientific research: defining the field and assessing its potential for informal science education. A CAISE inquiry group report. Center for Advancement of informal science education (CAISE), Washington, DC

Bozovic R, Maksimovic Č, Mijic A, Smith KM, Suter I, Van Reeuwijk M (2017) Blue green solutions. A systems approach to sustainable, resilient and cost-efficient urban development. https://doi.org/10.13140/RG.2.2.30628.07046

Burton P, Mustelin J (2013) Planning for climate change: is greater public participation the key to success? Urban Policy Res 31(4):399–415

Carlson T, Cohen A (2018) Linking community-based monitoring to water policy: perceptions of citizen scientists. J Environ Manag 219:168–177. https://doi.org/10.1016/j.jenvman.2018.04.077

Carter JG, Cavan G, Connelly A, Guy S, Handley J, Kazmierczak A (2015) Climate change and the city: building capacity for urban adaptation. Prog Plan 95:1–66. ISSN 0305-9006

Chaffin BC, Garmestani AS, Gunderson LH, Benson MH, Angeler DG, Tony CA, Cosens B, Craig RK, Ruhl JB, Allen CR (2016) Transformative environmental governance. Annu Rev Environ Resour:41399–41423. https://doi.org/10.1146/annurev-environ-110615-085817

Charlesworth SM (2010) A review of the adaptation and mitigation of global climate change using sustainable drainage in cities. J Water Clim Change 1(3):165–180. https://doi.org/10.2166/wcc.2010.035

Chen WY (2015) The role of urban green infrastructure in offsetting carbon emissions in 35 major Chinese cities: a nationwide estimate. Cities 44:112–120., ISSN 0264-2751. https://doi.org/10.1016/j.cities.2015.01.005

Childers DL, Cadenasso ML, Morgan Grove J, Marshall V, McGrath B, Pickett STA (2015) An ecology for cities: a transformational nexus of design and ecology to advance climate change resilience and urban sustainability. Sustainability 2015(7):3774–3791. https://doi.org/10.3390/su7043774

Conrad CC, Hilchey KG (2011) A review of citizen science and community-based environmental monitoring: issues and opportunities. Environ Monit Assess 176:273–291. https://doi.org/10.1007/s10661-010-1582-5

Daniel K, Hayley H, Alejandro DCM, Demián R, Rodolfo A (2020) Blue-green infrastructure (BGI) in dense urban watersheds. The case of the Medrano Stream Basin (MSB) in Buenos Aires. Sustainability 12:2163. https://doi.org/10.3390/su12062163

Davis M, Naumann S (2017) Making the case for sustainable urban drainage systems as a nature-based solution to urban flooding. In: Kabisch N, Korn H, Stadler J, Bonn A (eds) Nature-based solutions to climate change adaptation in urban areas. Theory and Practice of Urban Sustainability Transitions. https://doi.org/10.1007/978-3-319-56091-5_8

DePledge M, Bird W (2009) The blue gym: health and wellbeing from our coasts. Mar Pollut Bull 58:947–948

Earthwatch Institute (2012) Fresh Water Watch, a global citizen science project as part of the HSBC Water Programme. https://freshwaterwatch.thewaterhub.org/our-data/explore-our-data

Emilsson T, Ode Sang Å (2017) Impacts of climate change on urban areas and nature-based solutions for adaptation. In: Kabisch N, Korn H, Stadler J, Bonn A (eds) Nature-based solutions to climate change adaptation in urban areas. Theory and Practice of Urban Sustainability Transitions. https://doi.org/10.1007/978-3-319-56091-5_2

Faehnle M, Bäcklund P, Tyrväinen L, Niemelä J, Yli-Pelkonen V (2014) How can residents' experiences inform planning of urban green infrastructure? Case Finland. Landsc Urban Plan 130:171–183

Finke P (2014) Citizen Science: Das unterschätzteWissen der Laien München: oekom Verlag Quoted in Pettibone et al 2016

Fraisl D, Campbell J, See L, When U, Wardlow J, Gold M, Moorthy I, Arias R, Piera J, Oliver JL et al (2020) Mapping citizen science contributions to the UN sustainable development goals. Sustain Sci 15(6):1735–1751

Frantzeskaki N (2019) Seven lessons for planning nature-based solutions in cities. Environ Sci Pol 93:101–111. https://doi.org/10.1016/j.envsci.2018.12.033

Fritsch-Kosmider P (2018) Citizen science is needed to track biodiversity. New Sci 239(3191):52. https://www.newscientist.com/letter/mg23931910-900-citizen-science-is-needed-to-track-biodiversity-1/

Fritz S, See L, Carlson T, Haklay M, Oliver JL, Fraisl D, Mondardini R, Brocklehurts M, Shanley LA, Schade S et al (2019) Citizen science and the United Nations sustainable development goals. Nat Sustain 2:922–930. https://doi.org/10.1038/s41893-019-0390-3

García CER, Brown S (2009) Assessing water use and quality through youth participatory research in a rural Andean watershed. J Environ Manag 90:3040–3047. https://doi.org/10.1016/j.jenvman.2009.04.014

Goudeseune L, Eggermont H, Groom Q, Le Roux X, Paleco C, Roy HE, van Noordwijk CGE (2020) BiodivERsA citizen science toolkit for biodiversity scientists. BiodivERsA Report https://doi.org/10.5281/zenodo.3979343

Hansen R, Rall E, Chapman E, Rolf W, Pauleit S (2017) Urban green infrastructure planning: a guide for practitioners. 88 Hislop M Sc. http://greensurge.eu/working-packages/wp5/. Accessed 1 June 2017

Hewitt CN, Ashworth K, MacKenzie AR (2020) Using green infrastructure to improve urban air quality (GI4AQ). Ambio 49:62–73. https://doi.org/10.1007/s13280-019-01164-3

Hoegh-Guldberg O, Jacob D, Taylor M, Bindi M, Brown S, Camilloni I, Diedhiou A, KL RD, Ebi F, Engelbrecht J, Guiot Y, Hijioka S, Mehrotra A, Payne SI, Seneviratne A, Warren TR, Zhou G (2018) Impacts of 1.5°C Global Warming on Natural and Human Systems. In: Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty. Cambridge University Press, Cambridge

Hoornweg D, Sugar L, Trejos Gómez CL (2011) Cities and greenhouse gas emissions: moving forward environ. Urban 23:207–227

Ip K, Lam M, Miller A (2010) Shading performance of a vertical deciduous climbing plant canopy. Build Environ 45(1):81–88. https://doi.org/10.1016/j.buildenv.2009.05.003

Jerome G, Mell I, Shaw D (2017) Re-defining the characteristics of environmental volunteering: creating a typology of community-scale green infrastructure. Environ Res 158:399–408

Jollymore MJ, Haines T, Satterfield MSJ (2017) Citizen science for water quality monitoring: data implications of citizen perspectives. J Environ Manag 200(2017):456–467. https://doi.org/10.1016/j.jenvman.2017.05.083

Kelemen-Finan J, Scheuch M, Winter S (2018) Contributions from citizen science to science education: an examination of a biodiversity citizen science project with schools in Central Europe. Int J Sci Educ 40:2078–2098

Kennedy C, Steinberger J, Gasson B, Hansen Y, Hillman T, Havránek M, Pataki D, Phdungsilp A, Ramaswami A, Mendez GV (2009) Greenhouse gas emissions from global cities. Environ Sci Technol 43(19):7297–7302. https://doi.org/10.1021/es900213p

Kosmala M, Wiggins A, Swanson A, Simmons B (2016) Assessing data quality in citizen science. Front Ecol Environ 14(10):551–560. https://doi.org/10.1002/fee.1436

Lamond J, Everett G (2019) Sustainable blue-green infrastructure: a social practice approach to understanding community preferences and stewardship. Landsc Urban Plan 191:103639. ISSN 0169-2046

Lin JC, Mitchell L, Crosman E, Mendoza DL, Buchert M, Bares R, Fasoli B, Bowling DR, Pataki D, Catharine D, Strong C, Gurney KR, Patarasuk R, MunkhbayarBaasandorj AJ, Hoch S, Horel J, Ehleringer J (2018) CO_2 and carbon emissions from cities: linkages to air quality, socioeconomic activity, and stakeholders in the Salt Lake City urban area. Am Meteorol Soc 99(11):2325–2339. https://doi.org/10.1175/BAMS-D-17-0037.1

Lovell ST, Taylor JR (2013) Supplying urban ecosystem services through multifunctional green infrastructure in the United States. Landsc Ecol 28(8):1447–1463

Mark C, See L, Copas K, Bonde AMZ, López BC, Danielsen F, Legind JK, Masinde S, Miller-Rushing AJ, Newman G, Rosemartin A, Turak E (2017) Contribution of citizen science towards international biodiversity monitoring. Biol Conserv 213:280–294

McGoff F, Dunn LM, Cachazo P, Williams J, Biggs P, Nicolet NCE (2017) Finding clean water habitats in urban landscapes: professional researcher vs citizen science approaches. Sci Total Environ 581(2017):105–116. https://doi.org/10.1016/j.scitotenv.2016.11.215

McKinsey Global Institute (2010) India's urban awakening: building inclusive cities, sustaining economic growth

McKinley DC, Briggs RD, Bartuska AM (2012) When peer-reviewed publications are not enough! Delivering science for natural resource management. For Policy Econ 21(2012):1–11. https://doi.org/10.1016/j.forpol.2012.03.007

McPherson EG, Nowak DJ, Rowntree RA (1994) Chicago's Urban Forest Ecosystem: Results of the Chicago Urban Forest Climate Project. Gen. Tech. Rep. NE-186 US Department of Agriculture, Forest Service, Northeastern Forest Experiment Station, Radnor, Pennsylvania

Mees HL, Uittenbroek CJ, Hegger DL, Driessen PP (2019) From citizen participation to government participation: an exploration of the roles of local governments in community initiatives for climate change adaptation in the Netherlands. Environ Policy Gov 29(3):198–208. https://doi.org/10.1002/eet.1847

Mentens J, Raes D, Hermy M (2006) Green roofs as a tool for solving the rainwater runoff problem in the urbanised 21st century. Landscape Urban Plan 77:217–226. https://doi.org/10.1016/j.landurbplan.2005.02.010

Miller-Rushing A, Primack R, Bonney R (2012) The history of public participation in ecological research. Front Ecol Environ 10(6):285–290. https://doi.org/10.1890/110278

Moffett ER, Neale MW (2015) Volunteer and professional macroinvertebrate monitoring provide concordant assessments of stream health. N Z J Mar Freshw Res 49(2015):366–375. https://doi.org/10.1080/00288330.2015.1018913

Monteiro R, Ferreira J, Antunes P (2020) Green infrastructure planning principles: an integrated literature review. Land 9:525. https://doi.org/10.3390/land9120525
Newman G, Wiggins A, Crall A, Graham E, Newman S, Crowston K (2012) The future of citizen science: emerging technologies and shifting paradigms. Front Ecol Environ 10(6):298–304
Ochoa-Tocachi W, Buytaert J, Antiporta L, Acosta JD, Bardales R, Célleri P, Crespo P, Fuentes J, Gil-Ríos M, Guallpa C, Llerena D, Olaya P, Pardo G, Rojas M, Villacís M, Villazón P, Viñas BD, Bièvre (2018) High-resolution hydrometeorological data from a network of headwater catchments in the tropical Andes. Sci Data 5:Article 180080
Ossa-Moreno J, Smith KM, Mijic A (2017) Economic analysis of wider benefits to facilitate SuDS uptake in London UK. Sustain Cities Soc 28:411–419
Paul JD, Buytaert W, Allen S, Ballesteros-Cánovas JA, Bhusal J, Cieslik K, Clark J, Dugar S, Hannah DM, Stoffel M (2018) Citizen science for hydrological risk reduction and resilience building Wiley. Interdiscip Rev Water 5:e1262
Pettibone L, Vohland K, Bonn A, Richter A, Bauhus W, Behrisch B, Borcherding R, Brandt M, Bry F, Dörler D, Elbertse I, Glöckler F, Göbel C, Hecker S, Heigl F, Herdick M, Kiefer S, Kluttig T, Kühn, et al (2016) Citizen science for all – a guide for citizen science practitioners. BürgerSchaffenWissen (GEWISS) publication. German Centre for integrative biodiversity research (iDiv) Halle-Jena-Leipzig, Helmholtz Centre for Environmental Research (UFZ), Leipzig; Berlin-Brandenburg Institute of Advanced Biodiversity Research (BBIB), Museum fürNaturkunde (MfN) – Leibniz Institute for Evolution and Biodiversity Science: Berlin. www.buergerschaffenwissen.de
Pocock MJO, Chandler M, Bonney R, Thornhill I, Albin A, August T, Bachman S, Brown PMJ, Cunha DGF, Grez A, Jackson C, Peters M, Rabarijaon NR, Roy HE, Zaviezo T, Danielsen F (2018) A vision for global biodiversity monitoring with citizen science. Adv Ecol Res 59:169–223. https://doi.org/10.1016/bs.aecr.2018.06.003
Rosenzweig CW, Solecki P, Romero-Lankao S, Mehrotra S, Dhakal T, Bowman, Ibrahim SA (2015) ARC3.2 summary for city leaders urban climate change research network. Columbia University, New York
Seneviratne SIN, Nicholls D, Easterling CM, Goodess S, Kanae J, Kossin Y, Luo J, Marengo K, McInnes M, Rahimi M, Reichstein A, Sorteberg C, Vera X, Zhang (2012) Changes in climate extremes and their impacts on the natural physical environment. In: Managing the risks of extreme events and disasters to advance climate change adaptation a special report of working groups I and II of the intergovernmental panel on climate change (IPCC). Cambridge University Press, Cambridge/New York, pp 109–230
Shao Z, Sumari NS, AlekseiPortnov FU, Musakwa W, Mandela PJ (2020) Urban sprawl and its impact on sustainable urban development: a combination of remote sensing and social media data. Geo Spatial Inf Sci 24(2):241–255. https://doi.org/10.1080/10095020.2020.1787800
Skarlatidou A, Ponti M, Sprinks J, Nold C, Haklay M, Kanjo E (2019) User experience of digital technologies in citizen science. J Sci Commun 18(01). https://doi.org/10.22323/2.18010501
Sposito V, Faggian R, Diogo V, Romeijn H (2014) Blue-green infrastructure for creating resilient regions, a case study in the Gippsland Region, Victoria, Australia. Technical Report Deakin University
Takano T, Nakamura K, Watanabe M (2002) Urban residential environments and senior citizens' longevity in mega-city areas: the importance of walkable green space. J Epidemiol Community Health 56(12):913–916
Thornhill I, Loiselle S, Clymans W, Van Noordwijk CGE (2019) How citizen scientists can enrich freshwater science as contributors, collaborators, and co-creators. Freshw Sci 38. https://doi.org/10.1086/703378
Tzoulas K, Korpela K, Venn S, Yli-Pelkonen V, Kazmierczak A, Niemela J, James P (2007) Promoting ecosystem and human health in urban areas using green infrastructure: a literature review. Landsc Urban Plan 81:167–178
United Nations, Department of Economic and Social Affairs, Division P (2018) World urbanization prospects: the 2018 revision. Highlights

van Popering-Verkerk J, van Buuren A (2017) Developing collaborative capacity in pilot projects: lessons from three Dutch flood risk management experiments. J Clean Prod 169:225–233

Waller J (2018) Will citizen science take over? GBIF Data Blog. https://data-blog.gbif.org/post/gbif-citizen-science-data/

Weeser J, StenfertKroese SR, Jacobs N, Njue Z, Kemboi A, Ran MC, Rufino L, Breuer (2018) Citizen science pioneers in Kenya – a crowdsourced approach for hydrological monitoring. Sci Total Environ 631–632:1590–1599. https://doi.org/10.1016/j.scitotenv.2018.03.130

Wheeler B et al (2012) Does living by the coast improve health and wellbeing? Health Place 18:1198–1201

Wilker J, Rusche K, Rymsa-Fitschen C (2016) Improving participation in green infrastructure planning. Plan Pract Res 31(3):229–224

Willems JJ, Molenveld A, Voorberg W, Brinkman G (2020) Diverging ambitions and instruments for citizen participation across different stages in green infrastructure projects. Urban Plan 5(1):22–32. https://doi.org/10.17645/up.v5i1.2613. ISSN: 2183–7635

Wittmayer J, Janssen A (2019) Citizen science – towards democratic science and environmental democracy? DRIFT Blog. https://drift.eur.nl/publications/citizen-science-towards-democratic-science-and-environmental-democracy/

Zeisel J, Silverstein NM, Hyde J, Levkoff S, Lawton MP, Holmes W (2003) Environmental correlates to behavioral health outcomes in Alzheimer's special care units. Gerontologist 43:697–711

Indu K. Murthy works as the Sector Head-Climate, Environment and Sustainability at the Center for Study of Science, Technology and Policy (CSTEP), Bengaluru, India.

Monowar Alam Khalid is a Professor and Head, Department of Environmental Science, and Dean, Faculty of Humanities & Social Sciences at Integral University, Lucknow, India.

Is Ensuring the Sustainable Implementation of BGI Possible? System Thinking of Urban Rivers as Social-Ecological Systems

5

Herlin Chien, Osamu Saito, and Kensuke Fukushi

Abstract

With the mounting pressure of urbanization, how innovative blue-green infrastructure (BGI) can restore the ecosystem services of urban rivers is a timely issue for any densely populated city seeking to improve its resilience and sustainability through ecosystem-based solutions. Yet, the implementation of BGI is not hazard-free. Its success usually depends on a variety of contextual attributes.

By discussing field research on two urban streams in southern Taiwan, this chapter adopts a system thinking perspective to explore, evaluate, and search for the combination of contextual attributes that not only enables the development of sustainable urban rivers but also improves the resilience of cities. In particular, to understand the macro system behavior and the problem of social-ecological misfit are the analytical focuses of this study. By analyzing the mental models of two urban river cases, this study identifies three misfit problems pertaining to the contextual attributes that can inhibit BGI-induced urban sustainability in the long run: (1) the problem of missing feedback, (2) the problem of trade-offs, and (3) the lack of systematic resilience strategies. The advantage of using a system thinking approach is that it allows for the holistic implementation of BGI while reminding policymakers and researchers of the need to craft BGI strategies

H. Chien (✉)
National Pingtung University of Science and Technology, Neipu Township, Pingtung County, Taiwan

United Nations University Institute for the Advanced Study of Sustainability, Tokyo, Japan
e-mail: hchien@mail.npust.edu.tw

O. Saito · K. Fukushi
Institute for Global Environmental Strategies, Hayama, Kanagawa, Japan

Institute for Future Initiatives, The University of Tokyo, Tokyo, Japan
e-mail: o-saito@iges.or.jp; kensuke-fukushi@unu.edu

S. Dhyani et al. (eds.), *Blue-Green Infrastructure Across Asian Countries*,
https://doi.org/10.1007/978-981-16-7128-9_5

in connection with, rather than in isolation from, social, economic, and political environments. This study also demonstrates the importance of being aware of the dynamic relationship between resource users, public infrastructure providers, public infrastructure, and resource systems.

Keywords

Grey water · System thinking · Social-ecological misfit · Ecosystem services · Nature for Society

5.1 Introduction

Unlike the conventional urban expansion observed in Western society as "sprawl," with a decreasing trend in population density and a tripling of the area under construction (Carruthers and Ulfarsson 2003; Gómez-Antonio et al. 2016), research from the World Bank in 2015 yielded surprising findings in East Asia (World Bank Group 2015). Their publication suggested an outgrowth of population faster than urban physical footprints, resulting in urban areas becoming denser while medium-sized cities gained the greatest population density. To further challenge the sustainability of future urban planning in Asia, Friedmann and Sorensen (2019) warned that new technologies such as rapid rail systems would encourage medium-sized cities to merge into new scales of conurbation already evident in Japan and China and incipient in India, Indonesia, South Korea, Taiwan, and elsewhere. This new and unprecedented trend of urbanization significantly increases the importance of urban sustainability to ensure the well-being of future urban generations, both native and migratory (Seto 2011), in Asia.

Based on recent comprehensive urban sustainability literature reviews (Journals. elsevier.com 2017; Kaur and Garg 2019), dimensions of sustainability in urban settings include being "smart, efficient, green, and socially just." Yet most common approaches aim at addressing urban environmental problems, promoting the efficient use and protection of natural systems of human and urban species; prevention of air, water, noise, and light pollution; and the management of natural resources, notably via blue-green infrastructure (BGI) (Ahmed et al. 2019; Iojă et al. 2018), in the creation of future blue and green cities (Brears 2018). However, the literature also points to problems and barriers to be overcome[1] in harnessing the maximum benefits of innovative BGI for sustainable urban development.

This chapter aims to supplement the abovementioned research to better understand the challenges of urban sustainability and to seek strategies to improve urban planning. In particular, the narrowed focus of this study is to investigate problems created by the reduced proportion of open green and blue space in densely populated

[1] Blue-Green Cities Research Project (2013–2016), involved by nine UK universities, industry, and local government partner, aimed to investigate how to better harness the benefits of blue-green infrastructure. http://www.bluegreencities.ac.uk/ (accessed on July 10, 2020).

Asian cities (Liao 2019; Wan and Shen 2015) or parts of the cities that were most under pressure and to empirically evaluate how urban river restoration represents unique opportunities for sustainable development by creating and integrating BGI in cities, thus providing multiple social and ecological benefits. Research questions of this study include (1) how dynamics of social-ecological systems (SESs) influence the sustainable implementation of BGI to restore urban rivers, (2) what the systemic fit[2] or misfit is that promotes or impedes the provisioning of urban ecosystem services (UESs), and (3) what the contextual attributes are that can potentially improve BGI-induced urban sustainability in the long run.

To seek answers to these research questions, this study starts with the specific premise that urban rivers are not only a transitional ecosystem (Iojă et al. 2018, p. 217) in space and time but are also contingent on the dynamics of both anthropogenic and natural processes as endogenous/exogenous and fast−/slow-changing variables (e.g., election and climate change). In other words, our goal is to better understand how urban rivers, as SESs, respond and adapt to changes with BGI strategies to improve the resilience of cities. We pursue a system thinking approach focusing on evaluating variability of slow variables (Walker et al. 2012) over time and their gradual interactions, as opposed to static relationship analysis focusing on fast variables and fast feedbacks in action situations (Anderies et al. 2019), which is also important yet less useful to answer our research questions.

The chapter is structured as follows. We begin by discussing how existing literature identified barriers to implementing BGI to improve urban sustainability in general, in urban restoration projects, and the resulting research gap (Sect. 5.2). Next, we design a system thinking-oriented method to evaluate the role of BGI as public infrastructure (Sect. 5.3). The research goal is to (1) understand the macro system behavior of urban river cases and (2) identify systemic misfits that inhibit the implementation of BGI and to derive insights about problems of system resilience based on two empirical urban river cases in Taiwan (Sect. 5.4). We conclude with reflections on the usefulness of the system thinking-oriented analysis to analyze BGI not just as a biophysical component, and we draw attention to the potential human-nature decoupling problem observed in the empirical findings (Sect. 5.5).

5.2 Application of BGI and Its Barriers to Promote Urban Sustainability

The application of BGI is often theoretically framed as a sustainable and novel approach that will save us from the increased intensity and frequency of a changing climate (Ghofrani et al. 2017). Several studies also confirm the multifunctionality of BGI strategies (Lawson et al. 2014; Voskamp and Van de Ven 2015) to increase urban environmental resilience, such as urban flood risk control, with co-benefits

[2] The use of our "systemic fit" refers to what the literature usually labels as "institutional fit" (Epstein et al., 2015) or social-ecological fit (Guerrero et al. 2015).

including energy savings and improved air quality (Alves et al. 2019) while improving human well-being that is closely related to the creation of societal (O'Brien et al. 2017) and economic welfare (Evans et al. 2019). However, currently, there is far more research discussing the benefits of green infrastructure (GI) in developing a healthier city (Hansen and Pauleit 2014; Da Silva and Wheeler 2017, Figs. 5.2 and 5.3) and less focus from the perspective of blue infrastructure (Iojă et al. 2018). Some studies simply consider water infrastructure as one type of GI (Liao 2019) or an integrated part when one considers the whole natural system as infrastructure (McDonald 2015).

In addition, BGI is certainly no panacea. Like all other infrastructure, the innovation of BGI requires effective implementation and maintenance to successfully deliver the benefits or co-benefits it was initially designed for. Researchers, therefore, are just beginning to explore barriers that impede the healthy introduction and practice of BGI to promote urban sustainability, especially regarding how to better integrate the water cycle with urban design. Aside from scientific and technical barriers, the latest research suggests that social-institutional barriers pose the greatest hindrance to the implementation of sustainable water management Schemes (O'Donnell et al. 2017) due to the fact that BGI is still considered a "novel" intervention compared to traditional gray infrastructure. In a similar vein, social, political, or environmental "uncertainty" is identified by practitioners as major impediments to the implementation of BGI (Thorne et al. 2018). These non-engineered barriers associated with a lack of confidence in BGI are found to inhibit action at a level equal to or greater than engineered challenges. These scientific results also pave the way for practical crafting of green and blue practices as the basis for a circular city to consider "not only technology" strategies but also emphasize the need for social commitment and new ways of organizing and management.[3] Lastly, to mainstream BGI, scholars call for more future case studies on practical BGI implementation (Liao et al. 2017) to identify further barriers and devise strategies for different cities with various social-ecological settings.

5.3 Rationale and System Thinking-Oriented Methods

To address the research gaps and needs discussed above to mainstream BGI and thereby improve urban sustainability and resilience, this chapter adopts an alternative research angle—a system thinking-oriented analysis approach—and develops a mental model to (1) iteratively understand the impact of system behavior on the implementation of BGI in empirical case studies, (2) identify systemic fits or misfits that promote or inhibit the ability of BGI to restore UESs, and (3) discuss strategies to enhance systemic fits and fix misfits to increase the probability of BGI successfully contributing to urban sustainability. The next section details the rationale and

[3] See "Not Only Technology" section in https://www.urbangreenbluegrids.com/about/green-and-blue/ (accessed on July 13, 2020).

methods of the system thinking approach and mental models adopted and created by this study.

5.3.1 Usefulness of System Thinking

Despite the implication of BGI in complex systems, i.e., SESs (Flynn and Davidson 2016) or resilience systems (Gunderson et al. 2012; Kofinas and Chapin 2009), dealing with countless social and ecological variables that are intentionally or unintentionally influencing the system, there is a paucity of system thinking approaches (Hjorth and Bagheri 2006) to analyze the barriers of implementing BGI and introducing targeted strategies for overcoming barriers. There are, however, a few projects using a system thinking angle to understand how green or gray infrastructure improve the well-being of urban populations (Svendsen et al. 2012) or to enhance urban sustainability in general (Ahmad and Hills 2008; Shen et al. 2009; Tan et al. 2018).

Theoretically, the usefulness of the system thinking approach (Von Bertalanffy 1968), in contrast to static analysis, is to improve our understanding of the reality that is made out of circularly arranged events, instead of a simple and linear relation. The approach is usually based on the identification and modeling of feedback relations, including time delay, that a specific problem is embedded in (Forrester 1961; Sterman 2000). Haraldsson (2004) referred to such an approach as mental modeling, aiming to explicitly map the understanding of the problem and highlight it for others using causal loop diagrams (CLD) with reinforcing (R) or balancing loop (B) and reference behavior pattern (RBP). To generate a mental model of CLD, seven steps were proposed: (1) define the problem and create the system boundaries; (2) ask the question and state the purpose and goals; (3) identify principal actors in the problem; (4) draw a simple causal loop diagram; (5) create RBP; (6) learn and revise CLD; and (7) conclude (Haraldsson 2004, p.40–41).

One of the system thinking-based frameworks designed to evaluate the governance of shared resources and associated infrastructures is the coupled infrastructure system (CIS) (Anderies et al. 2016), which differs from the institutional analysis and development, which focuses on analyzing static relationships between external structures and the capacity of collective action, the so-called action situation (Ostrom et al. 1994). The application of CIS is wide, encompassing one recent study on a classic example of civil infrastructure, highways (Janssen et al. 2019) to study 700 years of adaptive pathways in Mexico City to minimize water risk (Tellman et al. 2018). Such an approach broadens the scope of analysis to go beyond engineering issues and connects it with the integrated social and political drivers at stake. Through the expanded feedback or causal linkages (Mui et al. 2019), the framework helps to explain the targeted problem not only as a result of biophysical processes but also as iterative consequences of choices made by actors in different organizations and their path dependence.

The latest development of the CIS framework involves the attempt to provide a list of verbs to lay the foundation for a general typology and a standardized protocol for representing dynamics captured in CIS (Anderies et al. 2019), the so-called robustness framework. Figure 5.1 shows one example of archetype robustness framework mappings. The framework is formed with several main building blocks—the resource system (RS), the resource user (RU), the natural infrastructure (NI), the public infrastructure (PI), and the public infrastructure provider (PIP). Verbs 1–6 in Fig. 5.1 are regarded as variables for describing dynamic feedback networks based on "subjectivity," indicating the intention behind the action, such as the goal to restrict, collect, or enable. For instance, a "bridge" as a PI "enables" the pedestrian to cross an urban river yet simultaneously "constrains" the ability of the urban resident as the RU to access the river's water resource freely. Figure 5.1 also reminds researchers to pay attention to the effects of exogenous drivers on human, social, natural, and man-made infrastructures.

The robustness of the CIS framework is based on the premise that proper feedback loops generating positive returns, rather than canceling effects, should be functionally established to ensure the resilience and sustainability of SESs. Yet this emphasis on feedback loops, path dependence, and longer-term processes under the influence of institutional change and interactions between resource users and managerial decisions has received inadequate attention (De Moor et al. 2016; Tekwa et al. 2019). To improve our collective ability to avoid failure of shared resource management, scholars have issued a call to advance (through a post-Ostrom agenda) our understanding of the relationships between institutional structures, processes, contexts, and outcomes (Cumming et al. 2020). They also pointed out that although institutional analysis raises the importance of institutional fit, few theories explicitly specify the combinations of social and/or ecological conditions and the elements of institutions that give rise to fit.

5.3.2 Case Selection for Urban River Mental Modeling

The goal of this study is to identify systematic misfits that inhibit BGI to ultimately promote UESs provided by urban rivers and urban resilience in the long run. By regarding BGI-based urban river restoration as a unique opportunity to improve the urban ecosystem service provisioning in densely populated cities and the human-nature coevolution relationship, two successful urban river restoration programs in densely populated Taiwan are selected as the subjects of this empirical case study for mental modeling. Both cases incorporated BGI as major ecosystem-based strategies to cleanse the degraded urban river, create new recreational green space by riverbanks or in constructed wetlands, and revive the urban economic development of selected cities. Thus, the two cases are selected to provide empirical data and real-life social-ecological interactions to improve our understanding and ability to inductively build an urban river system dynamic model while identifying potential systematic misfits as barriers to implement BGI.

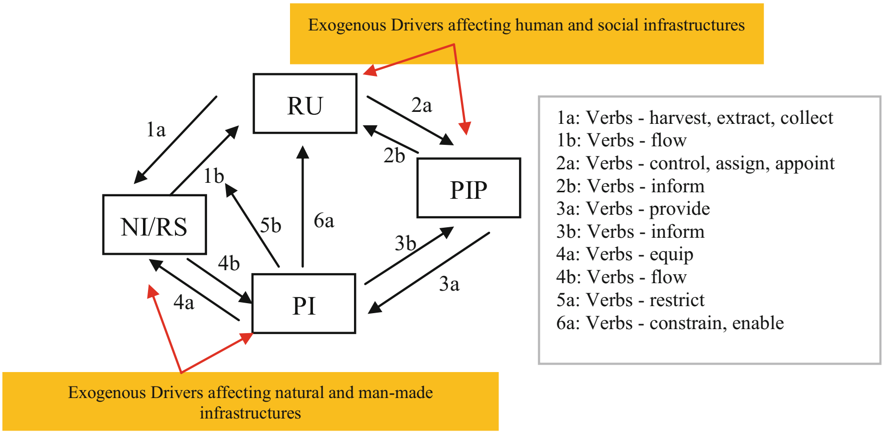


Fig. 5.1 Community governance of shared resource archetype CIS representation sample*. Source: Graph drawn by authors in reference to Anderies et al. (2019) (Figs. 1 and 2, Example 3). *For other SES cases that are the basis of more archetypal models, see System Representation in http://seslibrary.asu.edu

Case A is the Wannian River (Fig. 5.2) in Pingtung City (population density[4] = 3049 per km^2), the second most populated county administrative unit in Taiwan. Case B is Love River (Fig. 5.2) in Kaohsiung City, the second most populated special municipality in Taiwan whose population density[5] (9958 per km^2) is higher than the density of Hong Kong[6] (6690 per km^2). Although the population density in Case A is only one-third of Case B, the Wannian urban river flowing through the city center of Pingtung is also roughly one-third the length of Case B (5.5 km vs. 16 km), and the water quality of both cases for the past decade was classified as moderately polluted (river pollution index of $3.1 < RPI < 6$ by the Taiwan Environmental Protection Administration, EPA) based on concentrations of suspended solids (SS), biochemical oxygen demand, dissolved oxygen (DO), and ammonia nitrogen (NH_3-N) (Putri et al. 2018).

Despite their different administrative scales, historical context, and social composition, the two cities faced similar environmental challenges created by the reduced proportion of open green and blue spaces in densely populated urban areas. The PIP, namely, the local government in both cities, had made an intentional effort to restore the two respective urban rivers by incorporating BGI strategies,

[4] 2017 data; see reference in https://den.ncdr.nat.gov.tw/1178/1661/ (accessed on July 13, 2020).

[5] Kaohsiung metropolitan includes urban and suburb section which merged to be single administrative unit in 2010. Since Love River mostly runs through the urban section of the Kaohsiung, the population density calculation used 2010 data before the administrative merge. See Kaohsiung City Government, Civil Affairs Bureau for data access. http://cabu.kcg.gov.tw/cabu2/statis61B2.aspx (accessed on July 13, 2020).

[6] 2014 data from Hong Kong government. https://www.gov.hk/en/about/abouthk/factsheets/docs/population.pdf (accessed on July 13, 2020).

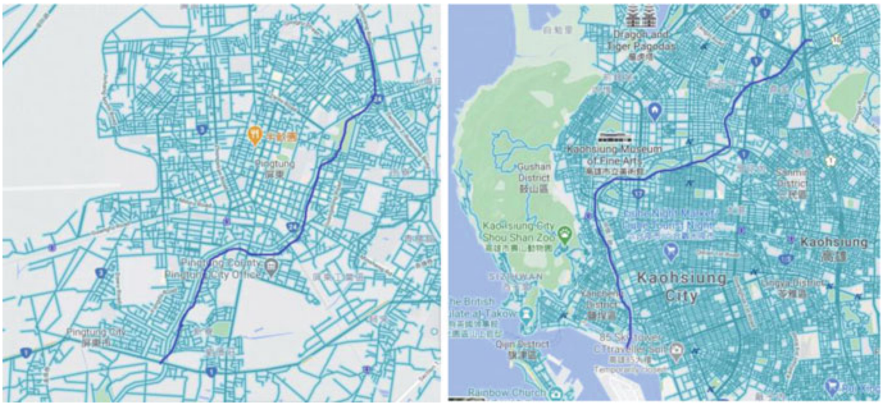


Fig. 5.2 Mappings of the Wannian River (left) and the Love River (right). Source: Drawn by the author with Google Maps as the base map (accessed on February 22, 2021)

including the creation of constructed wetlands and detention ponds as PI (Table 5.1) to purify river water, to minimize flood risk, and to provide extra recreational space. For instance, a total of 23.8 combined hectares of constructed wetlands were added to enhance the ecosystem services of the Wannian River, and a total of 58.1 hectares of BGI were installed for Love River to improve the regulating services and to reduce the flood risk to neighboring communities. These are reasons for comparing the two cases based on the practical implementation of BGI and for identifying their potential systematic barriers to achieving long-term sustainability and resilience and barriers to successfully becoming truly blue-green or ecological cities[7] as envisioned by local authorities.

5.3.3 Steps to Develop and Evaluate Urban River Mental Model

We design four steps to develop and evaluate the urban river mental model—Step 1, operationalizing the data collection; Step 2, drawing a mental map prototype for comparison and backcasting; Step 3, designing system resilience matrix to evaluate the sustainability of system; and Step 4, comparing case studies based on system thinking approach.

[7]Pingtung City Mayor promoted the city as "ecological city" at Millennia Park where Wannian urban river flows through in 2019. https://www.ptcg.gov.tw/Photo_Content.aspx?n=39A07B9207533EAB&s=ACE0F497F4FD8EA5 (accessed on July 13, 2020); the official vision of Kaohsiung City Government is resilience and green ecological city. See goals in Kaohsiung City Government sustainable development and climate change adaptation committee regulation. https://orgws.kcg.gov.tw/001/KcgOrgUploadFiles/258/relfile/15352/55925/45fbed19-7f13-499f-ae85-e475a1f11b05.pdf (accessed on July 13, 2020).

Table 5.1 Comparison of BGI installation

	Name of BGI (NI)	Area (ha)	Year of establishment
Case A: The Wannian River in Pingtung City	Hai-Fong Wetland	10.3	2009
	Chun-Liao Wetland	11.4	2013
	Golden Wetland	2.1	2017
	Total	23.8	
Case B: Love River in Kaohsiung City	Benheli eco detention pond	37.5	2005
	Love River wetland	0.7	2006
	Heart of Love River	3.1	2007
	Shetzulinbi wetland	4.2	2009
	Jungdu wetland	12.6	2011
	Total	58.1	

Source: Compiled by authors based on interviews and archival data collection

5.3.3.1 Step 1: Operationalizing the Data Collection

Based on the CIS framework and the data available from the two selected cases in Taiwan, this study devises a CIS-UES data operationalization design (Fig. 5.3) to facilitate systematic data collection of urban river governance and its outcomes that serves as the basis for causal mental model drawing in the next step. The model consists of two major types of data, CIS data and UES data, to improve our understanding regarding the effect of resource governance on the performance of ecosystems such as urban rivers. Governance aspects of urban rivers as RS are captured by the following five infrastructures—hard human-made infrastructure (HHMI), soft human-made infrastructure (SHMI), natural infrastructure (NI), human infrastructure (HI), and social infrastructure (SI) outlined in the CIS framework (Anderies et al. 2016). By using CIS as a guideline to disassemble governance of urban river restoration, proxy indicators are designed to quantify each type of infrastructure. For instance, HHMI is a proxy for data collected from government procurement websites specifically dealing with the two river restoration projects; NI refers to the number of constructed wetlands or detention ponds; HI reflects the number of urban river restoration-related nongovernmental organizations or educational facilities. They have similar connotations that are parsed from Ostrom's three external or slow variables—biophysical conditions, rules-in-use, and attributes of the community (AC) (Ostrom 2005).

The outcome of urban river resource governance in this study is represented by UESs provided as an outcome of urban restoration efforts through the application of BGI. Based on the Common International Classification of Ecosystem Service (CICES, version 5.1) released by the European Environment Agency in January 2018,[8] three categories of UESs are assessed by using the best available objective open data: the provisioning service, a proxy for the river pollution index; the

[8]Release of CICES version 5.1 can be found in https://cices.eu/ (accessed on July 13, 2020).

CIS (governance of RS)	UES (Outcome of RS)
Hard Human-Made Infrastructure Public procurement investment in river restoration	**Provisioning Service** River Pollution Index
Soft Human-Made Infrastructure Urban river restoration-related formal rules	**Regulating/Maintenance Service** Variety of algae/plants Flood regulation Biodiversity
Natural Infrastructure Artificial wetlands	**Cultural Service** River-related outdoor/indoor events
Human Infrastructure Association or educational facilities promoting river restoration knowledge	Objective data: proxy open data Subjective data: periodic self-reporting by the city government to the city council
Social Infrastructure River-related outdoor/indoor events	

Fig. 5.3 Data operationalization for urban river governance and its outcome

regulating/maintenance service, a proxy for the variety of algae/plants, flood regulation, and biodiversity; and cultural services, a proxy for river-related outdoor and indoor events. To provide further subjective comparisons from the perspective of local governments, periodic reports by city governments to city councils were also collected and analyzed to reveal the self-reporting part of urban ecosystem service performance. The primary data methods used by this study include in-depth interviews and archival data collection (Appendix 1).

5.3.3.2 Step 2: Drawing a Mental Map Prototype for Comparison and Backcasting

Next, in reference to the two selected urban river restoration case studies in Taiwan and the list of verbs provided by Anderies et al. (2019) in Table 5.1 (p. 1904) (based on extant social-ecological system case studies and expert understanding), this study draws a causal mental map similar to but cannot yet be qualified as the standard causal loop diagram[9] to hypothesize a healthy urban river restoration system prototype (Fig. 5.4) as a desirable future for case comparison and backcasting. Considering the CIS framework, each feedback is explained with some demonstrative verbs, which is certainly not a comprehensive list of verbs, contributing positively to the generation of UESs (represented by the green color) provided by the RS.

These positive feedbacks can be further described as balancing or reinforcing loops in the language of system thinking and CLD in future research. However, because of the complexity of variables involved in each listed feedback (1a/b to

[9] Our current mental map lacks clear "plus" or "minus" signs assigned to all feedbacks as a standard CLD, along with reinforcing or balancing loop indication. See Haraldsson (2004) for a standard CLD.

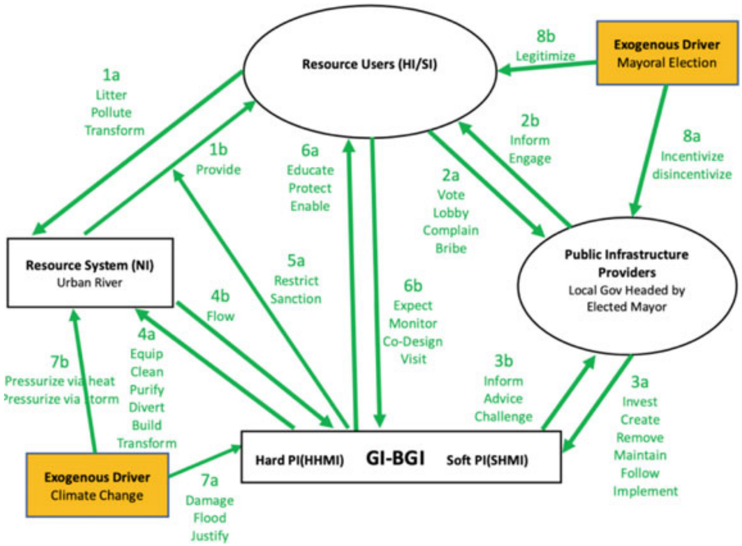


Fig. 5.4 Healthy urban river mental map prototype*. *Depending on various contexts, green represents a balancing (B) or reinforcing loop (R) ensuring a balanced human-nature relationship

8a/b), we acknowledge the limitation of this study. Future research with system thinking or modeling software may further construct the CLD qualitatively and quantitatively to furnish details regarding the status of each feedback loop and its corresponding RBPs. For example, in the feedback of 6a, the BGI of the detention pond as PI "protects" resource users from the threat of flood, in general, enabling ecosystem regulating services. Based on the measurement adopted by researchers, it can be regarded as a "balancing" loop with a plus sign (+) in more creation of detention ponds as PI resulting in a minus sign (−) of RU from the perspective of preventing loss of human asset due to flooding. If contributing negatively to the generation of UESs, the line can be colored as red or as black for unknown or canceling effects. All lines are solid in this visual representation, implying functional feedbacks, whereas missing links can be designated as dashed lines. For demonstration purposes, the thickness of lines is equal in this ideal type, representing reasonable functions in the feedback. Otherwise, a thicker line can signify stronger functionality or more verbs interacting in a specific feedback loop. In contrast, the thinner line signifies a weaker functionality of the feedback.

5.3.3.3 Step 3: Designing System Resilience Matrix to Evaluate the Sustainability of the System

To answer our research question (is ensuring the sustainable implementation of BGI possible?), we need to evaluate the sustainability of the urban river system. We chose system resilience as an indicator, and the main question addressed in this section involves what the characteristics of a resilient urban river system are. In conjunction with indicators developed for the Asian Cities Climate Change Resilience Network

(ACCCRN) funded by The Rockefeller Foundation (Moench et al. 2011), Da Silva et al. (2012; Fig. 5) propose seven characteristics of resilient urban systems: (1) flexibility, (2) redundancy, (3) resourcefulness, (4) safe failure, (5) responsiveness, (6) capacity to learn, and (7) the dependence on local ecosystems. Whereas "flexibility" emphasizes the ability to move beyond business as usual, the ability to evolve and to adopt alternative solutions, and the favoring of "soft" rather than "hard" means for the easiness to change, "redundancy" complements "flexibility" by ensuring multiple pathways and a variety of options to provide and evolve in case one component fails or is disrupted (Godschalk 2003). "Resourcefulness" refers to the ability to mobilize resources, including financial, physical, social, environmental, technological, and information assets. "Safe failure" and "responsiveness" both relate to the system's ability to accept failure and re-establish function to recover from failure. Beyond reorganizing from failure, the "capacity to learn" also expects individuals and institutions to learn from failures. Lastly, the goal is to value the health and stability of "local ecosystems" such as BGI and its role in providing self-organizing ecosystem services for the well-being of natural, social, and economic systems.

This above list adds qualitative elements to the quantitative evaluation of resilience proposed by Bruneau et al. (2003), which focused on only four measures: robustness, redundancy, resourcefulness, and rapidity. In critical infrastructure literature, scholars additionally posit the importance of evaluating resilience qualities according to the interdependence of lifeline systems across technical, organizational, social, and economic dimensions, influencing each other which is an iterative evolution (O'Rourke 2007). Based on the same logic, this study tries to draw an urban river ideal matrix of system resilience (Appendix 2) according to six critical feedback loops specified in the healthy urban river SD prototype (Fig. 5.4), namely, 1a/1b for feedback between the resource system and the RU; 2a/2b for RU and the PIP; 3a/3b for PIP and public infrastructure; 4a/4b for PI and RS; 5a for PI-RS-RU intervention; and 6a/6b for PI-RU. Each feedback loop is reflected independently in the table, yet their interactive effect should not be discounted. The totality of feedback loops should be considered as a cause-effect chain between fluvial dynamics, habitat, ecology (Schiemer et al. 2007), and social community. The list of descriptions included in Table 5.1 is not comprehensive but aims to exemplify what can possibly be done to improve the system of urban river resilience with exemplified descriptions and samples from related research from the past.

5.3.3.4 Step 4: Comparing Case Studies Based on System Thinking Approach

To reveal the macro system behavior and identify systemic fit/misfit in the two case studies, we create their respective mental models based on the in-depth interviews and compiled archival data (Appendix 1). Then, we conducted two types of comparative analysis: First, to understand the macro system behavior, we compare the two robustness mappings against the healthy urban dynamics mental prototype discussed earlier in Fig. 5.4, where ideally all feedback loops are solid lines with positive effects to improve UESs (denoted in a green color). Second, we also compare the matrix of system resilience for both cases against the ideal matrix (Appendix 2) and determine the most vulnerable part of the system as a barrier to fully implement BGI and as areas for future improvement.

5.4 System Thinking Findings Discussion

5.4.1 Macro System Behavior

In a cursory view, the macro system behaviors of these two distinct urban river restoration cases with BGI intervention are remarkably similar. Both of the right-hand half of the mental model in Fig. 5.5 (green lines between RU-PI-PIP) exhibit all positive feedbacks generating an enhanced river ecosystem service as the balancing loop results. In other words, the logic behind these interconnected balancing loops is that the more local government's investment in blue and green (3a) infrastructure, the more ecosystem services (6a) are generated for resource users (human) and the

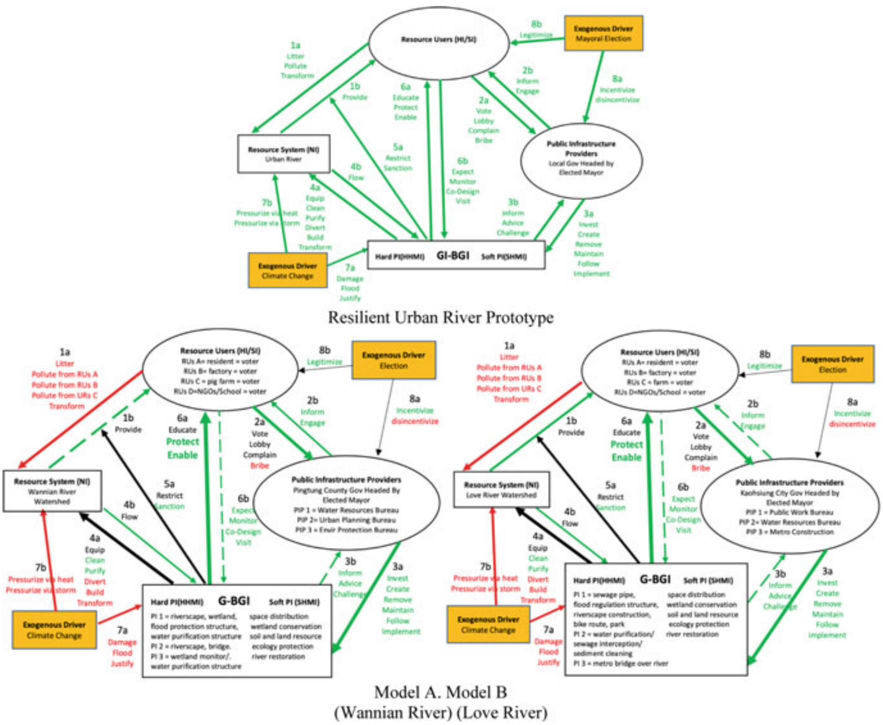


Fig. 5.5 Urban river model robustness comparison. *The green verbs or lines represent positive flow potentially enhancing river ecosystem services; red verbs or lines represent negative flow potentially hindering river ecosystem services; black verbs or lines represent neutral, potentially canceled, or unknown effects. **The thickness of arrows depends on the number of verbs or the degree of impact. ***The dashed line represents a missing link

more positive feedbacks and support provided by voters (2a) to the local government as the PIP.

Yet in the left-hand half of the mental model (PI-RU-RS), both cases again unexpectedly exhibit similar balancing loops with more negative or neutral feedbacks—degrading ecosystem services (red line) and unknown or canceled effects (black line). In particular, 1a shows a BGI sustainability problem from a system thinking perspective because more investment in PI including BGI did not deter resource users from repeatedly polluting the urban river (1a in red), i.e., recursively degrading ecosystem service provisioning capability of the urban river as RS (nature). This negatively balancing loop (1a) did not perform in isolation but is connected to how our PI such as a bridge or law often “restricts” (5a in black) the direct contact or interaction between the urban river and resource users such as resident or school. For example, school kids cannot kayak or swim in the urban river without government’s special permission in both cities. Thus, the more “restriction” imposed by PI, the more distance is created systematically between urban citizen and nature (missing or weak 1b link) and less urban citizen would pay attention or notice the pollution in the urban river, not generating sufficient public pressure to deter river pollution activities.

Finally, we also did not observe a clear positive feedback loop between the installation of BGI and the quality of the urban river (4a in black) in both cases. Although both local governments made a great effort to install different blue and green infrastructures such as man-made wetlands to purify urban river water or increase green coverage in riverscape hoping to “restore” urban rivers, the water quality of urban rivers was not adequately improved. It is unclear how different public infrastructures create conflicting consequences to the well-being of the urban river (nature). For example, the purposeful diversion of wastewater as a method to improve water quality in rivers results in insufficient inflow and the sudden increase of algae in the river, turning the river into brown or even green color[10] in the summer or dry season. This changing color problem of the urban river can potentially further deter citizens from being close to the urban river and benefiting directly from the urban river’s service (1b), indirectly sending the wrong message to factory or pig farm as RU to pollute (1a) this already “unclean” river. The vicious cycle of degrading nature is thus produced for the benefit of human beings.

In brief, the macro system behavior of the two cases demonstrates that the so-called urban river “restoration” endeavor in southern Taiwan, including the installation of BGI by the two local governments, fits more to the “Nature for Society” scenario proposed by the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) (Pereira et al. 2020). This means that the river restoration effort creates more utilitarian benefits to people and societies, and does not “restore” the urban river back to its natural status. To establish a more balanced human-nature relationship, in the long run, policymakers might need to

[10] Changing Color of Love River News June 3, 2020. https://udn.com/news/story/7327/4611421 (accessed on April 20, 2021).

consider how to design a “Nature as Culture” scenario to improve the relational values of nature to promote nature and human in harmony, or even “Nature for Nature” scenarios to rehabilitate the natural habitats for the diversity of species and nature’s ability to function autonomously.

5.4.2 Three Social-Ecological System Misfits

Besides the macro system behavior of urban river cases, there are additional three social-ecological misfits that inhibit the successful implementation of the BGI for the long-term goal of increasing UESs and urban resilience: (1) the problem of missing feedbacks; (2) the problem of trade-offs, and (3) the lack of system resilience strategies.

5.4.2.1 Problem of Missing Feedback

In a close examination of the SD of Models A and B in Fig. 5.5, we can identify three missing links in both models, albeit between different feedbacks. In Model A, feedbacks 1b, 6b, and 3b are missing, and in Model B, the missing links involve 2b, 3b, and 6b. These links, if not fixed, would compromise the robustness of the system and make the system vulnerable to any change or interruption to the system, such as climate change or election. In particular, the first major difference between Models A and B lies in the relationship between the RU (humans) and the RS (nature) where in the current setting, the Wannian River did not “provide” any material or direct service to the residents, factories, or farms in Pingtung City such as edible fish, drinking water, boating, or swimming services. This lack of a direct functional relationship between urban rivers and users reduces awareness as well as the likelihood of users demanding higher river water quality. To fix this problem, nine cities in industrialized countries, such as Boston, Paris, New York City, have initiated “reclaiming river” projects[11] to make polluted waterways into swimming venues. This is similar to what we have observed in Model B, in which Love River hosted triathlons for more than a decade, creating a solid green line between RU and RS. Yet this link is still weak, for numerous individuals were complaining about skin rashes and diarrhea after swimming in the polluted river water.[12]

Secondly, the PIP in Case A, the Pingtung County Government, made comparatively more effort to engage the local community and civil society to implement the Wannian River restoration projects (the solid line of 2b in Model A versus the dashed line of 2b in Model B). According to our interviewees, the Pingtung County Government, under the leadership of Mayor Tsao, had first successfully encouraged the establishment of a nongovernmental organization dedicated to Wannian River

[11] https://www.curbed.com/2017/8/3/16089352/city-rivers-swimming-safe (accessed on July 22, 2020).

[12] March 22, 2018. News on Love River Triathlon, https://news.pts.org.tw/article/389048 (accessed on July 22, 2020).

restoration (the Wannian River Conservation Association 2009) and then in 2012 further pushed for a Wannian River Protection Family, bringing together up to 37 public and private institutions. Such intentional efforts by the Pingtung local government had strengthened the feedback of 2b between RU and PIP, which is a vital component for bottom-up governance (Girard et al. 2015; Wicaksono 2020) of shared resource management, which was argued to have increased the adaptive capacity toward climate change. This is currently what was missing in the case of Love River, resulting in a missing link on the mapping in 2b.

Lastly, the SD mappings for both cases show missing feedbacks in 6b (RU-PI) and 3b (PIP-PI). 6b describes the ability of the RU to "expect," "monitor," "co-design," or "visit" the PI, including gray and BGI. In Pingtung City and Kaohsiung City, there is no existing large-scale mechanism to voice the expectations of residents toward the various infrastructures installed by the local governments, such as riverbend bike routes or the quality and maintenance of sewage pipes. As for the design of hard or SHMI, such as river conservation acts, opinions of resource users were seldom consulted. The exception might be the hosting of public hearings, which is required by Taiwan law, yet in practice often reflects the expert opinion and does not include enough general user perspective into the policymaking process (Tu 2010)—in other words, the "co-designing" (including "visiting"[13] to better understand our infrastructures) process of involving multiple stakeholders. Furthermore, RU, which is recommended by ICLEI (Local Governments for Sustainability) as a guideline[14] to ensure urban sustainability, is currently absent in both cities. As for 3b, the feedback between PIP and PI is considered to be missing in both cases since there is no evidence of an innovative mechanism for the actors of public infrastructure to "inform," "advise," or even "challenge" the elected mayor's policy decision, which is usually top-down in nature.

5.4.2.2 Problem of Trade-Offs

In the mapping (Fig. 5.5), the two feedback lines are colored as black in both cases, indicating unknown effects or potential trade-off effects between impacts caused by adding gray and BGI to the resource system (4a, RS-PI; 5a, PI-RS-RU). Regarding feedback 4a, since the utilization of BGI or ecosystem-based solutions is a novel practice adopted by local governments in Taiwan, how it can offset the negative impact created by gray infrastructure installed decades ago is still unknown and requires further scientific investigation. Yet, based on the ecological performance of urban rivers in the two cases, scientists and local residents noticed some trade-off problems of GI. The most common trade-off is the positive impact of sewage diversion to lower effluent discharge into rivers, which nevertheless affects the

[13] To enhance citizen's knowledge on wastewater interception facilities, Kaohsiung City Government built ten sewer display centers along Love River (Case B). See example in http://mmweb.tw/36512; http://wrb.kcg.gov.tw/loveriver/rebuild.aspx#4 (accessed on July 22, 2020).

[14] Guidelines for co-designing and co-implementing green infrastructure in urban regeneration processes. https://progireg.eu/fileadmin/user_upload/Deliverables/D2.10_Co-design_Guidelines_proGIreg_ICLEI_18-06-20.pdf (accessed on July 22, 2020).

quantity and quality of urban rivers (Huang 2014), especially during seasonal changes with higher temperatures or rain. Historically, during several summers, there have been numerous citizen complaints about the change of Love River water to white, green, or brown[15] colors, as well as large quantities of dead fish in the Wannian River.[16] Despite the Kaohsiung City Government's recent effort to set up information notices explaining the cause of the color change,[17] there might still be room for improvement and reconsidering trade-offs between different PIs. Elsewhere, another trade-off was pointed out by a Kaohsiung City councilor warning of the increased health risk of dengue fever from detention ponds during the dry season[18] when it is not performing its flood risk mitigation function.

Pertaining to feedback 5a, in the relationship between PI, RS, and RU, actors of PI by law issue penalties ("sanctions") on the pollution emitter to discourage pollution. Meanwhile, one of the purposes of PI is to keep RU away (i.e., to "restrict" it) from the river, which would further alienate people from nature (Morgan 2017) for the sake of security (trade-offs) or floodplain regulation-related concerns. Although both local governments have been hosting several "water-familiar activities," most activities were restricted to riverfront areas such as annual lantern festivals hosted in Pingtung City and Kaohsiung City[19] or involved the appreciation of riverscapes, which are considered blue-green or gray infrastructure in this study, rather than directly engaging the RS (i.e., the urban river itself).

5.4.2.3 Lack of System Resilience Strategies

The last systematic governance-ecological misfit observed in the two cases surrounds the deficit of system resilience strategies (Tables 5.2 and 5.3), which is not unusual due to the fact that the resilience principle itself is novel and is only beginning to be experimented upon in recent years.[20] It has therefore not been utilized enough in cities.

In Case A, the most deficient area of resilience strategies involves the relationship between RS and RU (1a/1b) mainly due to the lack of dependence on urban rivers for major services such as fish, irrigation, drinking, or cooling water, resulting in a lack of resource input to try innovative mechanisms or improve responsiveness for demand and supply (red box in Table 5.2). Resilience strategy number 4, safe failure

---

[15] https://news.ltn.com.tw/news/life/breakingnews/2801087 (accessed on July 24, 2020).

[16] https://news.housefun.com.tw/news/article/29703768453.html (accessed on July 24, 2020).

[17] https://udn.com/news/story/7327/4611421 (accessed on July 24, 2020).

[18] February 19, 2020, news on change of Love River upstream color into white. https://udn.com/news/story/7327/4356432 (accessed on July 24, 2020).

[19] 2020 Kaohsiung Lantern Festival (https://www.2020khl.com/) hosted in Case B; 2020 Pingtung Lantern Festival featuring animals, https://www.pthg.gov.tw/newyear/cp.aspx?n=BD366C990800F1D0 (accessed on July 24, 2020).

[20] Asian Cities Climate Change Resilience Network (ACCCRN) is one example that was founded in 2008 yet only completed its legacy portfolio of urban climate change resilience (UCCR) in 2016. See more in http://www.acccrn.net/about-acccrn/history (accessed on July 24, 2020).

Table 5.2 Case A system resilience comparison

Case A Quality/Feedback Loop	RS-RU 1a/1b	RU-PIP 2a/2b	PIP-PI 3a/3b	PI-RS 4a/4b	PI-RS-RU 5a	PI-RU 6a/6b
1) flexibility	○	◉	◉	◉	○	○
2) redundancy	○	◉	○	◉	○	○
3) resourcefulness	○	◉	◉	◉	◉	◉
4) safe failure	○	○	○	○	○	○
5) responsiveness	○	◉	○	○	◉	○
6) capacity to learn	○	◉	○	◉	○	○
7) dependency on the local ecosystem	○	◉	○	○	○	○

●, action in place; ◉, partial action in place; ○, future action required

(gray area in Table 5.2), is also lacking throughout all feedbacks in Case A. Although the city of Pingtung joined ICLEI in 2009 and endeavored to expand its capacity to learn (PI-RS 6: capacity to learn) through abundant international visits and climate change and urban resilience best practice exchanges, the focus of Pingtung has focused more on renewable energy[21] rather than ecosystem restoration. The main resilience strategy for Pingtung County involves transforming the city into a low-carbon exemplary site for Taiwan by completing the carbon disclosure report via CDP cities and developing alternative clean energy solutions. Future effort can be invested into exploring options for ensuring that the urban river system is safe to fail and can recover fast enough from disruption to be resilient. Monitoring the current river quality of the Wannian River, the RPI average showed a surprising trend of continuous degradation from an average of 4.38 during Mayor Tsao's 2009–2014 administration to 4.58 and 5[22] for Mayor Pan's 2014–2018 term. This data indirectly hints that there is no resilience for the system or safe-to-fail mechanism in place that functions well.

A similar continuous degradation of Love River water quality (RPI average 4.73 for Mayor Hsieh's 2002–2006 administration; 4.12 for Mayor Chen's 2006–2010 term; 5.61 for Mayor Chen's 2010–2014 term; 5.50 for Mayor Chen's 2014–2017 administration) and the inability to recover from disruption is observed in Case B where the resilient strategy of "safe failure" (Table 5.3: safe failure for all feedbacks) can also be strengthened in the future. Nevertheless, Kaohsiung City had been flexible enough to adopt innovative BGI, create redundancy such as multiple

[21] ICLEI programs for Pingtung County, https://lcss.epa.gov.tw/LcssViewPage/Responsive/AreaDoc.aspx?CityID=10013&ActDocId=7a6f193e-0ee2-45a1-b6f1-8297aac07ecf (accessed on July 24, 2020).

[22] Based on data collection gathered by this study based on Pingtung County Government data.

Table 5.3 Case B system resilience comparison

Case B Quality/Feedback Loop	RS-RU 1a/1b	RU-PIP 2a/2b	PIP-PI 3a/3b	PI-RS 4a/4b	PI-RS-RU 5a	PI-RU 6a/6b
1) flexibility	○	○	◉	◉	○	○
2) redundancy	○	○	○	◉	○	○
3) resourcefulness	◉	○	◉	◉	◉	◉
4) safe failure	○	○	○	○	○	○
5) responsiveness	○	○	○	○	◉	○
6) capacity to learn	○	○	○	◉	○	○
7) dependency on local ecosystem	◉	◉	○	○	○	○

●, action in place; ◉, partial action in place; ○, future action required

detention ponds, invest abundant financial resources, and demonstrate a willingness to learn to achieve the goal of a resilient city. In particular, in 2012, Kaohsiung City collaborated with ICLEI Europe to establish the ICLEI Kaohsiung Capacity Center (ICLEI KCC)[23] as the first East Asian regional training center. As for responsiveness, several Love River patrol groups have been organized and managed by the Environmental Protection Bureau of local governments and have even developed a smoke-free zone by organizing a smoke-free Love River patrol group under the health bureau of the Kaohsiung City Government in 2008.[24]

5.5 Conclusion

This study begins by asking a question in the title: how do we ensure sustainable implementation of BGI? Through adopting a system thinking perspective of analysis, this chapter argues that the success or failure of BGI should not be analyzed in isolation from the social, economic, and political environment it is embedded in. The system dynamics triggers feedback loop effects and shapes and reshapes the problems of SESs, such as the loss of open green and blue space in compact cities and how urban river restoration can be regarded as a window of opportunity to experiment with resilient strategies and BGI-based solutions.

[23] http://kcc.iclei.org; ICLEI KCC website (accessed on July 24, 2020).

[24] Smoke-free Love River news 2008, https://tw.appledaily.com/headline/20080531/7JV62TFX56ZHGZP6CPGA3PLC2Y/ (accessed on July 24, 2020).

To understand the macro system behavior and identify systemic misfit that promotes or impedes the provisioning of UESs based on BGI applications in urban river restoration, this study bases our analytical findings on two urban river cases in southern Taiwan. Apart from uncovering the Nature for Society macro system behavior, three social-ecological misfit problems are identified and discussed pertaining to contextual attributes that can improve BGI-induced urban sustainability in the long run: (1) the problem of missing feedback; (2) the problem of trade-off; and (3) the lack of systematic resilience strategies. We recognize that most of our empirical work is from specific cities, and they are contingent on local contexts. However, we also believe that their propositions can generate lessons to build urban resilience for other compact cities around the world.

In short, the two empirical cases, albeit different, unexpectedly point to a common problem—the decoupling of humans and nature. This human-nature decoupling includes the lack of direct relationships between urban rivers and resource users (link 1, Fig. 5.5) and the biased emphasis on ecosystem services for human needs such as flood prevention or cultural services (link 6), similar to the Nature for Society scenario proposed by IPBES. It also marginalizes the need for "nature" to be "restored" to its original condition (links 4 and 5), namely, the Nature for Nature scenario in IPBES's conceptualization. The next question we should ask ourselves is "what are we restoring?" and "why are we restoring it?" Recognizing this human versus nature gap in restoration strategies might also have useful applications in cases worldwide. Topics including how to reconnect cities to the biosphere (Andersson et al. 2014) (PI-RS feedback), reclaiming and recirculating urban nature (Yates and Gutberlet 2011) (RU-RS feedback), how to reconcile the temporal difference between changes in political systems, and the frequency of climate change[25] versus the ability of cities to recover from shocks (Richard and David 2018) (RU-PIP-PI feedback), either man-made or natural, are all worthy of our future scholarly attention.

Conflict of Interest Statement The authors report no conflict of interest for this publication.

[25] Climate change mapping database, https://www.carbonbrief.org/mapped-how-climate-change-affects-extreme-weather-around-the-world (accessed on July 24, 2020).

Appendix 1: Technical Note on Data Collection

Case Study	A: Wannian River[a]	B: Love River
Data collection period	November 2019–January 2020	January 2020–March 2020
Method 1	13 in-depth interviews with local government officials and civil society stakeholders were conducted to provide background information for CIS-UES prototype model building	1 visit to water engineering bureau to understand the background and problems of Love River with several staff in march of 2019 to assess the case selection and data collection process 1 in-depth interview with senior staff at Kaohsiung. Bird association who assists to manage Jungdu wetland in march of 2019 to assess the case selection and data collection process
Method 2	Government archival data systematic collection – Local government's periodical reports to city council 2006–2019 for 100 entries – Public procurement data 2006–2019 for 123 entries – River water quality monitoring data 2010–2019 for 121 entries – Regulation data – Other technical reports provided by local governments or downloaded from website, such as wetland biodiversity reports or lantern festival data summary	Government archival data collection systematic collection – Local government's periodical reports to civil council 2006–2019 for 803 entries – Public procurement data 2001–2019 for 399 entries – River water quality monitoring data – Regulation data 1999–2019 for 1765 entries – Other technical reports provided by local governments or downloaded from website, such as wetland biodiversity reports and flood regulation reports
Method 3	Social/news data systematic collection – Citizen report news archive 2009–2019; search keywords: Wannian River = 100 news – Google search for Wannian River-related events/organizations mentioned in the above reports	Social/news data systematic collection – Citizen report news archive 2007–2019; search keywords: Love River = 83 news – Google search for Love River-related events/organizations mentioned in the above reports

[a]More in-depth interviews were planned for Wannian River as prototype of CIS-UES model

Appendix 2: Urban River Ideal Matrix of System Resilience

Feedback loop quality	RS-RU 1a/1b	RU-PIP 2a/2b	PIP-PI 3a/3b	PI-RS 4a/4b	PI-RS-RU 5a	PI-RU 6a/6b
1. Flexibility	Identify and try new solutions to treat or dilute wastewater and to enjoy river (Gambhir et al. 2012)	Identify and try new ways of open data/ engage citizen (Petts 2006)	Identify and try new combination of gray infrastructure and BGI (Mulligan et al. 2020)	Identify and try new ways of purifying (Edmundnt 2000), transforming urban river, and feeding back monitoring data (Baird and Hajibabaei 2012)	Relax law to enable citizen benefiting more ecosystem services provided by urban river (Robbins 2018)	Identify and try new ways to educate, protect, enable, expect (Sakamoto et al. 2018), monitor, co-design (Bradford et al. 2018), and visit
2. Redundancy	Various options to litter, pollute, provide	Multiple channels to complain/ lobby/ inform/ engage citizen/ prevent rent seeking	Various options to inform/ advice/ challenge/ invest/create/ remove/ maintain	Various options to equip/clean/ purify/diver/ build/ transform/ inform	Various options to ensure safety of using and benefiting ecosystem services provided by urban river	Various options to educate, protect, enable, expect, monitor, co-design, and visit
3. Resourceful-ness	Provide technique to process waste and benefit from river's resource	Provide funding/ leverage ICT to vote/ lobby/ complain/ inform/ engage/ prevent rent seeking	Provide funding to monitor performance of BGI	Assemble team to monitor urban river and its associated ecosystem	Provide infrastructure and technique to enable services of urban river to human	Have laws and policies ready to educate, protect, enable, expect, monitor, co-design, and visit
4. Safe failure	Ability of regulate rate of waste discharge and equip river to absorb waste at slower pace	Respond to part of complaints/ inform and engage part of citizen/ lower probability of rent seeking	Accept minor damage of BGI	Minimize trade-off impact caused by gray infrastructure and BGI on urban river	Control of GI and BGI to absorb waste at slower pace	Ability of system to allow minor mistakes and experiment made by co-designing
5. Responsive-ness	Rapidity to restore river's services after disruption, i.e., pollution and transformation	Rapidity to inform/ engage/ lobby/ complain	Rapidity to fix and recover damage of BGI (Fekete 2019)	Rapidity to report (Cairns Jr et al. 1970) and fix problems associated with ecosystem of urban river	Rapidity to punish polluter and to permit services to human when available	Rapidity to fix minor mistakes made by co-designing experiment
6. Capacity to learn	Best practices and failures of living with urban river and benefiting from urban water[a]	Best practices and failures of open governance (Bingham 2006)	Best practices and failures of BGI and PPP (Takahasi 2004)	Systematic record of urban river ecosystem performance/ best practices and failures of urban river ecosystem restoration	Maintain record of polluters and learn to enable ecosystem services of urban river to human	Best practice and failure sharing to educate, protect, enable, expect, monitor, co-design, visit

(continued)

Feedback loop quality	RS-RU 1a/1b	RU-PIP 2a/2b	PIP-PI 3a/3b	PI-RS 4a/4b	PI-RS-RU 5a	PI-RU 6a/6b
7. Dependency on local ecosystems	Increase value and invest to maintain healthiness of river ecosystem	Promote perceived value of local ecosystems among citizen and elected mayors (Andersson et al. 2014)	Ensure different offices appreciate multiple values of local ecosystems	Ensure actors of PI recognize multiple ecosystem services provided by urban river and their trade-off and synergy (Han et al. 2017)	Ensure actors of PI recognize importance of sanctioning polluter and a healthy ecosystem to lower need to restrict use of urban river	Facilitate RU's recognition of multiple ecosystem services by BGI and encourage co-design of BGI to ensure healthiness of local ecosystem

[a]See best practice examples in http://www.ecrr.org/River-Restoration/Urban-River-Restoration (accessed on July 19, 2020)

References

Ahmad S, Hills Z (2008) Grey water use as a water management option in Las Vegas, Nevada. In: World Environmental and Water Resources Congress 2008. American Society of Civil Engineers, Reston, VA, pp 1–10

Ahmed S, Meenar M, Alam A (2019) Designing a blue-green infrastructure (BGI) network: toward water-sensitive urban growth planning in Dhaka, Bangladesh. Land 8:138. https://doi.org/10.3390/land8090138

Alves A, Gersonius B, Kapelan Z et al (2019) Assessing the co-benefits of green-blue-grey infrastructure for sustainable urban flood risk management. J Environ Manag 239:244–254. https://doi.org/10.1016/j.jenvman.2019.03.036

Anderies JM, Janssen MA, Schlager E (2016) Institutions and the performance of coupled infrastructure systems. Int J Commons 10:495–516. https://doi.org/10.18352/ijc.651

Anderies JM, Barreteau O, Brady U (2019) Refining the robustness of social-ecological systems framework for comparative analysis of coastal system adaptation to global change. Reg Environ Chang 19:1891–1908. https://doi.org/10.1007/s10113-019-01529-0

Andersson E, Barthel S, Borgström S et al (2014) Reconnecting cities to the biosphere: stewardship of green infrastructure and urban ecosystem services. Ambio 43:445–453. https://doi.org/10.1007/s13280-014-0506-y

Baird DJ, Hajibabaei M (2012) Biomonitoring 2.0: a new paradigm in ecosystem assessment made possible by next-generation DNA sequencing. Mol Ecol 21:2039–2044

Bingham LB (2006) The new urban governance: processes for engaging citizens and stakeholders. Rev Policy Res 23:815–826. https://doi.org/10.1111/j.1541-1338.2006.00234.x

Bradford LEA, Vogel T, Lindenschmidt KE et al (2018) Co-design of water services and infrastructure for indigenous Canada: a scoping review. Facets 3:487–511

Brears RC (2018) Blue and green cities: the role of blue-green infrastructure in managing urban water resources. Palgrave Macmillan, London

Bruneau M, Chang SE, Eguchi RT et al (2003) A framework to quantitatively assess and enhance the seismic resilience of communities. Earthquake Spectra 19:733–752. https://doi.org/10.1193/1.1623497

Cairns J Jr, Dickson KL, Sparks RE, Waller WT (1970) A preliminary report on rapid biological information systems for water pollution control. J Water Pollut Control Fed 42:685–703

Carruthers JI, Ulfarsson GF (2003) Urban sprawl and the cost of public services. Environ Plan B Plan Des 30:503–522. https://doi.org/10.1068/b12847

Cumming GS, Epstein G, Anderies JM et al (2020) Advancing understanding of natural resource governance: a post-Ostrom research agenda. Curr Opin Environ Sustain 44:26–34
Da Silva JMC, Wheeler E (2017) Ecosystems as infrastructure. Perspect Ecol Conserv 15:32–35
Da Silva J, Kernaghan S, Luque A (2012) A systems approach to meeting the challenges of urban climate change a systems approach to meeting the challenges of urban climate change. Int J Urban Sustain Dev 4:125–145. https://doi.org/10.1080/19463138.2012.718279
De Moor T, Laborda-Pemán M, Lana-Berasain JM et al (2016) Ruling the commons. Introducing a new methodology for the analysis of historical commons. Int J Commons 10:529–588. https://doi.org/10.18352/ijc.760
Edmundnt O (2000) Building a hybrid landscape to purify the Ruhr region, 1890-1935. In: Hollister-Short G (ed) History of technology. Bloomsbury Academic, London, pp 25–42
Evans AJ, Firth LB, Hawkins SJ et al (2019) From ocean sprawl to blue-green infrastructure – a UK perspective on an issue of global significance. Environ Sci Pol 91:60–69. https://doi.org/10.1016/j.envsci.2018.09.008
Fekete A (2019) Critical infrastructure and flood resilience: cascading effects beyond water. Wiley Interdiscip Rev Water 6:e1370. https://doi.org/10.1002/wat2.1370
Flynn CD, Davidson CI (2016) Adapting the social-ecological system framework for urban stormwater management: the case of green infrastructure adoption. Ecol Soc 21:19. https://doi.org/10.5751/ES-08756-210419
Forrester JW (1961) Industrial dynamics. Pegasus, Waltham, MA
Friedmann J, Sorensen A (2019) City unbound: emerging mega-conurbations in Asia. Int Plan Stud 24:1–12. https://doi.org/10.1080/13563475.2019.1555314
Gambhir RS, Kapoor V, Nirola A et al (2012) Water pollution: impact of pollutants and new promising techniques in purification process. J Hum Ecol 37:103–109. https://doi.org/10.1080/09709274.2012.11906453
Ghofrani Z, Sposito V, Faggian R (2017) A comprehensive review of blue-green infrastructure concepts. Int J Environ Sustain 6:15–36. https://doi.org/10.24102/ijes.v6i1.728
Girard C, Pulido-Velazquez M, Rinaudo JD et al (2015) Integrating top-down and bottom-up approaches to design global change adaptation at the river basin scale. Glob Environ Chang 34:132–146. https://doi.org/10.1016/j.gloenvcha.2015.07.002
Godschalk DR (2003) Urban hazard mitigation: creating resilient cities. Nat Hazards Rev 4:136–143
Gómez-Antonio M, Hortas-Rico M, Li L (2016) The causes of urban sprawl in Spanish urban areas: a spatial approach. Spat Econ Anal 11:219–247. https://doi.org/10.1080/17421772.2016.1126674
Guerrero AM, Bodin Ö, McAllister RR, Wilson KA (2015) Achieving social-ecological fit through bottomup collaborative governance: an empirical investigation. Ecol Soc 20(4):41. https://doi.org/10.5751/ES-08035-200441
Gunderson LH, Allen CR, Holling CS (2012) Foundations of ecological resilience. Island Press, Washington, DC
Han Z, Song W, Deng X, Xu X (2017) Trade-offs and synergies in ecosystem service within the three-Rivers headwater region, China. Water 9:588. https://doi.org/10.3390/w9080588
Hansen R, Pauleit S (2014) From multifunctionality to multiple ecosystem services? A conceptual framework for multifunctionality in green infrastructure planning for urban areas. Ambio 43:516–529. https://doi.org/10.1007/s13280-014-0510-2
Haraldsson H (2004) Introduction to system thinking and causal loop diagrams. Department of Chemical Engineering, Lund University
Hjorth P, Bagheri A (2006) Navigating towards sustainable development: a system dynamics approach. Futures 38:74–92. https://doi.org/10.1016/j.futures.2005.04.005
Huang H-H (2014) Modeling nutrient dynamics in Love River and Kaohsiung Harbor due to sewerage diversion. National Sun Yat-sen University

Ioją IC, Osaci-Costache G, Breuste J et al (2018) Integrating urban blue and green areas based on historical evidence. Urban For Urban Green 34:217–225. https://doi.org/10.1016/j.ufug.2018.07.001
Janssen MA, Anderies JM, Baeza A et al (2019) Highways as coupled infrastructure systems: an integrated approach to address sustainability challenges. Sustain Resilient Infrastruct. https://doi.org/10.1080/23789689.2019.1708181
Journals.elsevier.com (2017) Special issue on "the future of urban sustainability: smart, efficient, green or just?". Sustain Cities Soc 51:101761
Kaur H, Garg P (2019) Urban sustainability assessment tools: a review. J Clean Prod 210:146–158
Kofinas GP, Chapin FS (2009) Livelihoods and human well-being during social-ecological change. In: Principles of ecosystem stewardship: resilience-based natural resource management in a changing World. Springer, New York, pp 55–75
Lawson E, Thorne C, Ahilan S et al (2014) Delivering and evaluating the multiple flood risk benefits in blue-green cities: an interdisciplinary approach. WIT Trans Ecol Environ 184:113–124. https://doi.org/10.2495/FRIAR140101
Liao K-H (2019) The socio-ecological practice of building blue-green infrastructure in high-density cities: what does the ABC waters program in Singapore tell us? Socio-Ecological Pract Res 1:67–81. https://doi.org/10.1007/s42532-019-00009-3
Liao K-H, Deng S, Tan PY (2017) Blue-green infrastructure: new frontier for sustainable urban stormwater management. In: Tan P, Jim C (eds) Greening cities. Springer Singapore, Singapore, pp 203–226
McDonald RI (2015) Conservation for cities. How to plan and build natural infrastructure. Island Press, Washington, DC
Moench M, Tyler S, Lage J (2011) Catalyzing urban climate resilience: applying resilience concepts to planning practice in the ACCCRN program (2009–2011). Institute for Social and Environmental Transition-International, Boulder, CO
Morgan T (2017) Alienated nature, reified culture: understanding the limits to climate change responses under existing socio-ecological formations. Polit Econ Commun 5:30–50
Mui Y, Ballard E, Lopatin E et al (2019) A community-based system dynamics approach suggests solutions for improving healthy food access in a low-income urban environment. PLoS One 14:e0216985. https://doi.org/10.1371/journal.pone.0216985
Mulligan J, Bukachi V, Clause JC et al (2020) Hybrid infrastructures, hybrid governance: new evidence from Nairobi (Kenya) on green-blue-grey infrastructure in informal settlements: "Urban hydroclimatic risks in the 21st century: integrating engineering, natural, physical and social sciences to build resilience". Anthropocene 29:100227. https://doi.org/10.1016/j.ancene.2019.100227
O'Brien L, De Vreese R, Kern M et al (2017) Cultural ecosystem benefits of urban and peri-urban green infrastructure across different European countries. Urban For Urban Green 24:236–248
O'Donnell EC, Lamond JE, Thorne CR (2017) Recognising barriers to implementation of blue-green infrastructure: a Newcastle case study. Urban Water J 14:964–971. https://doi.org/10.1080/1573062X.2017.1279190
O'Rourke TD (2007) Critical infrastructure, interdependencies, and resilience. Bridges 37:22–29
Ostrom E (2005) Understanding institutional diversity. Princeton University Press, Princeton, NJ
Ostrom E, Gardner R, Walker J (1994) Rules, games, and common-pool resources. University of Michigan Press, Ann Arbor, MI
Pereira LM, Davies KK, Belder E et al (2020) Developing multiscale and integrative nature–people scenarios using the nature futures framework. People Nat 2:1172–1195. https://doi.org/10.1002/pan3.10146
Petts J (2006) Managing public engagement to optimize learning: reflections from urban river restoration. Hum Ecol Rev 13:172–181
Putri M, Lou C-H, Syai'in M et al (2018) Long-term river water quality trends and pollution source apportionment in Taiwan. Water 10:1394. https://doi.org/10.3390/w10101394

Richard E, David LF (2018) The future of citizen engagement in cities—the council of citizen engagement in sustainable urban strategies (ConCensus). Futures 101:80–91. https://doi.org/10.1016/j.futures.2018.06.012
Robbins K (2018) Allocating property interests in ecosystem services: from chaos to flowing rivers. Harvard Environ Law Rev 42:197
Sakamoto T, Shinozaki Y, Shirakawa N (2018) Nationwide investigation of citizen-based river groups in Japan: their potential for sustainable river management. Int J River Basin Manag 16:203–217. https://doi.org/10.1080/15715124.2017.1394314
Schiemer F, Hein T, Reckendorfer W (2007) Ecohydrology, key-concept for large river restoration. Ecohydrol Hydrobiol 7(2):101–111
Seto KC (2011) Exploring the dynamics of migration to mega-delta cities in Asia and Africa: contemporary drivers and future scenarios. Glob Environ Chang 21:S94–S107. https://doi.org/10.1016/j.gloenvcha.2011.08.005
Shen Q, Chen Q, Tang BS et al (2009) A system dynamics model for the sustainable land use planning and development. Habitat Int 33:15–25. https://doi.org/10.1016/j.habitatint.2008.02.004
Sterman JD (2000) Business dynamics: systems thinking and modeling for a complex world. McGraw-Hill, Boston, MA
Svendsen E, Northridge M, Metcalf S (2012) Integrating grey and green infrastructure to improve the health and Well-being of urban populations. Cities Environ 5:Article 3
Takahasi Y (2004) Public–private partnership as an example of flood control measures in Japan. Int J Water Resour Dev 20:97–106. https://doi.org/10.1080/0790062031000l635638
Tan Y, Jiao L, Shuai C, Shen L (2018) A system dynamics model for simulating urban sustainability performance: a China case study. J Clean Prod 199:1107–1115. https://doi.org/10.1016/j.jclepro.2018.07.154
Tekwa EW, Fenichel EP, Levin SA, Pinsky ML (2019) Path-dependent institutions drive alternative stable states in conservation. Proc Natl Acad Sci U S A 116:689–694. https://doi.org/10.1073/pnas.1806852116
Tellman B, Bausch JC, Eakin H et al (2018) Adaptive pathways and coupled infrastructure: seven centuries of adaptation to water risk and the production of vulnerability in Mexico city. Ecol Soc 23:1. https://doi.org/10.5751/ES-09712-230101
Thorne CR, Lawson EC, Ozawa C et al (2018) Overcoming uncertainty and barriers to adoption of blue-green infrastructure for urban flood risk management. J Flood Risk Manag 11:S960–S972. https://doi.org/10.1111/jfr3.12218
Tu W-L (2010) Environmental impact assessment: environmental disputes over the 3(superscript rd) stage of Central Taiwan science park development. J Public Adm 35:29–60
Voskamp IM, Van de Ven FHM (2015) Planning support system for climate adaptation: composing effective sets of blue-green measures to reduce urban vulnerability to extreme weather events. Build Environ 83:159–167. https://doi.org/10.1016/j.buildenv.2014.07.018
Von Bertalanffy L (1968) General system theory. Braziller, New York, NY
Walker BH, Carpenter SR, Rockstrom J et al (2012) Drivers, slow variables, fast variables, shocks, and resilience. Ecol Soc 17:30. https://doi.org/10.5751/ES-05063-170330
Wan C, Shen GQ (2015) Salient attributes of urban green spaces in high density cities: the case of Hong Kong. Habitat Int 49:92–99. https://doi.org/10.1016/j.habitatint.2015.05.016
Wicaksono A (2020) Urban river governance through community movement to increase the adaptive capacity to climate change of the poor: a case study of Yogyakarta. IOP Conf Ser Earth Environ Sci 402:012003
World Bank Group (2015) East Asia's changing urban landscape: measuring a decade of spatial growth, Washington, DC
Yates JS, Gutberlet J (2011) Reclaiming and recirculating urban natures: integrated organic waste management in Diadema, Brazil. Environ Plan A Econ Sp 43:2109–2124. https://doi.org/10.1068/a4439

Herlin Chien is an Associate Professor at National Pingtung University of Science and Technology (NPUST) in Taiwan.

Osamu Saito is a Principal Policy Researcher at the Institute for Global Environmental Strategies (IGES), Kanagawa, Japan.

Kensuke Fukushi is an Academic Programme Officer and Academic Director at the United Nations University Institute for the Advanced Study of Sustainability (UNU-IAS). He is also Professor and Vice Director of the Institute for Future Initiatives, the University of Tokyo (UTokyo), Japan.

Understanding Blue-Green Infrastructure Through Spatial Maps: Contribution of Remote Sensing and GIS Technology

6

Akhil Francis Thekkan, Anjaly George, P. Rama Chandra Prasad, and Shijo Joseph

Abstract

Understanding the spatiotemporal distribution of blue-green infrastructures in urban environment is a critical element in the landscape-level planning. Asian cities, which are rapidly undergoing transformational changes in its land cover, predominantly feature urban signatures at the expenses of natural ecosystems. The rapid urbanization in conjunction with mega developmental projects and industrialization requires sophisticated analytical tools in the synoptic assessments and impact measurements. Remote sensing together with geographical information system (GIS) and Global Positioning Systems (GPS) plays an important role in developing the spatial maps and assessing the dynamics of land cover in the urban environment. This chapter reviews various remote sensing instruments available to characterize vegetation and water in complex urban environments. The progress with respect to diverse instruments such as panchromatic, multispectral, hyperspectral, radar, and LiDAR in mapping the blue-green infrastructures is reviewed in this chapter. The chapter helps in understanding the

A. F. Thekkan
Department of Remote Sensing and GIS, Kerala University of Fisheries and Ocean Studies (KUFOS), Kochi, Kerala, India

Lab for Spatial Informatics, International Institute of Information Technology (IIIT), Hyderabad, India

A. George · S. Joseph (✉)
Department of Remote Sensing and GIS, Kerala University of Fisheries and Ocean Studies (KUFOS), Kochi, Kerala, India
e-mail: shijo@kufos.ac.in

P. R. C. Prasad
Lab for Spatial Informatics, International Institute of Information Technology (IIIT), Hyderabad, India

S. Dhyani et al. (eds.), *Blue-Green Infrastructure Across Asian Countries*,
https://doi.org/10.1007/978-981-16-7128-9_6

diverse initiatives and instruments in mapping the extent and quality of blue-green infrastructures which are vital for the spatial planning of urban landscapes.

Keywords

Urban environment · Vegetation cover · Water bodies · Spatial planning · Geoinformatics

6.1 Introduction

The world is witnessing an unprecedented growth of urban population and expansion of urban areas. The World Urbanization Prospects of the United Nations (UN) highlights that nearly 55 percent of the world's population lives in urban areas (UNDESA 2019). As urban areas are increasingly the home of the majority of the population and centers of economic growth, it poses new challenges for sustainable development. Studies conducted worldwide point out that rapid urbanization leads to environmental, economic, and social problems (Grimm et al. 2008; Li et al. 2012). Asia is one of the fast urbanizing continents with a population density of 150 per km^2 spread across an area of 31 M km^2 (Worldometers 2021). The urban population in this region has increased more than ninefold from 246 million in 1950 to 2.3 billion in 2018 (UNFPA 2020). Seven out of ten most populated cities in the world are located in Asia. The studies also show that the population of Delhi, India, is projected to increase by more than ten million inhabitants and will become the most populated city in the world by overtaking Tokyo, Japan, before 2030. Out of 36 cities with 500,000 inhabitants with a 2.4 or more percent of annual average urbanization, 28 are in Asia (UNDESA 2019). The urbanization trends from 1950 to 2050 show that Asia marks the highest compared to Africa, Europe, Latin America and the Caribbean, Northern America, and Oceania.

The process of urbanization requires a large number of buildings and manufacturing plants to meet the requirements of the urban population. Urbanization and urban sprawl change land use and replace vegetation and water bodies with impervious constructions. This leads to loss of agricultural land and open green areas, depletion of surface water and groundwater resources, degradation of air quality and pollution, and changes in the meteorological variables including the formation of urban heat islands (UHI). With the ever-increasing expansion of city areas, the traffic congestion, waste treatment and disposal, public distribution systems, and providing utility facilities for urban dwellers are increasingly challenging in urban environment. Besides, urban safety is also a matter of concern with the increased rates of crime and violence, terrorist attacks, epidemics, and proneness to natural and man-made disasters.

BGI is an interconnected network of natural resources and designed landscape components, including green vegetation and water resources of that area, which provide crucial functions such as (i) urban heat island mitigation, (ii) water storage, (iii) flood control, (iv) increasing groundwater recharge, (v) reduction of air and water pollution, and many others (Ghofrani et al. 2017). The blue infrastructure includes lakes, water reservoirs, rivers, wetlands, swamps, water engineering facilities, and rain gardens, while the green includes forests, arable fields, non-urbanized areas, grasslands, woodlands, lawns, parks, private gardens, sports facilities, green roofs, green walls, and other facilities (Antoszewski et al. 2020). BGI can be applied to various geographic areas like urban, rural, river basin, and functions across jurisdictional boundaries. Strategies such as BGI can increase resilience across a range of possible future climates while helping to improve human health, social and economic wellbeing, environmental quality, and livelihoods (Ghofrani et al. 2017).

While BGI is a relatively new term, the idea and practice are not new. Historically BGI is closely related to the concept of “green infrastructure” (Ahmed et al. 2019). In recent years, BGI is increasingly embraced through diverse initiatives globally, for making long-term and effective solutions for different local challenges (Liao et al. 2017; Baker et al. 2021). The number of BGI projects that have been successfully carried out and still in progress is comparatively small. But it is expected that this number will increase in the future. United Nations Environment Programme (UNEP) together with UN-Habitat (United Nations Human Settlements Programme) is running a special program called “Sustainable Cities Programme” to make sustainable cities in Asia (SCP-Asia). The program bases the contributions of urban areas on society’s social and economic development and helps cities to respond to sustainability challenges. Singapore launched the Active, Beautiful, Clean (ABC) Waters Programme indenting to increase the water quality, recreational value, and physical appearance of waters in Singapore by 2030 (Liao 2019). It aims to integrate vegetation and water along with local participants to develop community spaces in and around the water (Finlay 2018). In India, the Future Proofing Indian Cities program helps the cities to develop action plans to respond to climate challenges and promote transitioning toward a low carbon economy while addressing poverty and economic development (Atkins 2014).

6.2 Mapping BGI Using Remote Sensing and GIS

Knowledge about the patterns of land use/land cover (LULC) of an area is important not only to assess the current status but also to plan future challenges under changing environmental conditions (Vani and Prasad 2020). Geoinformatics which is the combination of remote sensing, geographical information systems (GIS), and Global Positioning Systems (GPS) is an emerging technology to characterize an area synoptically and to assess the changes in land cover spatially and temporally (Joseph et al. 2011). In remote sensing, the light reflected from the surface of the Earth is measured to locate the type of land cover it represents. GIS tools are useful in spatial analysis, modelling, and visualization (Wang and Xie 2018; Sebastian et al. 2019). Remote sensing and GIS tools help to estimate the rates, directions, and patterns of urban sprawling and to map the changes in blue-green infrastructures in the urban ecosystem.

6.2.1 Panchromatic and Multispectral Remote Sensing

Panchromatic (PAN) remote sensing produces images in a single-band gray scale with high spatial resolution. Sensors combine the information from the visible R (red), G (green), and B (blue) bands to a single band without any wavelength-specific information (Filchev et al. 2020). PAN data have the potential for accurate and detailed mapping of the urban vegetation and water, but at the same time, the amount of information it can hold is limited due to its single-band imaging. The multispectral (MS) remote sensing systems record energy in the visible and near-infrared region (NIR) of the EMR spectrum in several separate wavelength ranges at various spectral resolutions (Govender et al. 2007). Multispectral imagery from airborne and satellite systems has been used from the early 1960s for water and land observations (McGwire et al. 2000; Joseph et al. 2009; Krishnaswamy et al. 2014; DeVries et al. 2015; Thayamkottu and Joseph 2018).

WorldView-4 is a multispectral, high-resolution commercial satellite that is capable of discriminating objects on the Earth's surface as small as 31 cm in the PAN band and 1.0 m in MS. IKONOS operated by DigitalGlobe provides 0.82 m panchromatic and 3.2 m multispectral resolution, while the QuickBird-2 offers commercial imagery at 0.61 m panchromatic and 2.4 m multispectral resolution. The SPOT (from French "Satellite pour l'Observation de la Terre") satellite series has been supplying high-resolution, wide-area optical imagery since 1986. Table 6.1 shows the various studies conducted using panchromatic and multispectral imageries in mapping the blue and green infrastructures in different urban ecosystems in the world. Majorities of these studies are conducted in the developed countries while a few only in the Asian region. Kanniah and Kang (2014) studied the role of green and blue infrastructure in reducing the temperature in Iskandar, Malaysia, using Landsat Thematic Mapper (TM) data. Tuan et al. (2019) assessed the green space, blue space, and green infrastructure in Can Tho City, Vietnam, using Sentinel-2, Landsat 5, and Landsat 8 satellites. The result indicated a declining trend in the blue-green infrastructures of the Can Tho City from 1990 to 2018. Rafiee et al. (2009) assessed changes in urban green areas of Mashad city using Landsat TM and IRS LISS-III sensors. Mukherjee et al. (2018) mapped impacts of LULC changes on urban water security of Kolkata, India. They analyzed the LULC changes between 1980 and 2014 with satellite data from IRS LISS-III, Landsat TM, and Landsat ETM+ and found that rapid urbanization and population growth are significantly impacting the water bodies in the city.

6.2.2 Hyperspectral Remote Sensing

Hyperspectral remote sensing acquires images in many narrow and contiguous bands throughout the visible and near-, mid-, and far-infrared portions of the EMR spectrum (Govender et al. 2007). Each object on the surface has a unique spectral reflectance corresponding to the electromagnetic waves interacting with them. The characteristics of hyperspectral images help to distinguish each object on the Earth's

Table 6.1 Major panchromatic and multispectral remote sensing instruments used for blue-green infrastructure mapping in various urban ecosystems in the world

Satellite	Resolution				Data period	Reference
	Spatial	Spectral	Temporal	Radiometric		
WorldView-2	1.84 m MS0.41 m PAN	9 bands	1 day	11 bits	2009–present	Santos et al. (2016), Gašparović et al. (2018), Furberg et al. (2020)
QuickBird-2	2.4 m MS0.6 m PAN	5 bands	3 days	11 bits	2001–2015	Furberg et al. (2020)
Landsat 7	30 m MS15 m PAN60 m TIR	8 bands	16 days	8 bits	1999–present	Farrugia et al. (2013), Kanniah and Kang (2014), Wu et al. (2019)
Landsat 8	30 m MS15 m PAN 100 m TIR	9 bands	16 days	12 bits	2013–present	Venter et al. (2020), Di Leo et al. (2016), Labib and Harris (2018), Yang et al. (2020)
Sentinel-2	10–60 m	13 bands	5 days	12 bits	2015–present	Tuan et al. (2019), Labib and Harris (2018), Vatseva et al. (2016)
Landsat 5	30 m MS 15 m PAN 120 m TIR	7 bands	16 days	8 bits	1984–2013	Di Leo et al. (2016), Tuan et al. (2019)
SPOT 5	10 m MS 5 m PAN	5 bands	2–3 days	8 bits	2002–2015	Calderón-Contreras and Quiroz-Rosas (2017)
RapidEye	6.5 m	5 bands	1 day	8 bits	2008–2020	Gašparović et al. (2018)
PlanetScope	3.9 m	5 bands	1 day	8 bits	2016–present	Gašparović et al. (2018)
LISS-IV	5.8 m	4 bands	5 days	10 bits	2011–present	ThiLoi et al. (2015) Rajesh et al. (2020)
WorldView-3	0.31 mPAN 1.24 m MS3.7 m SWIR	29 bands	1 day	11 bits	2014–present	Hartling et al. (2019)

surface by extracting the spectral reflectance of that particular object. Hyperspectral data are used for many applications in water resource management, agriculture, and environmental monitoring (McGwire et al. 2000). Hyperion (EO-1 platform) was the first spaceborne hyperspectral satellite launched in 2000 which captures the data with a 30 m spatial resolution and 400–2500 nm spectral range. It records data in 220 unique spectral channels with a 10 nm bandwidth. HySIS is another hyperspectral Earth observation satellite system developed by ISRO. It employs a hyperspectral imager to take images in visible and near-infrared (VNIR) and short-wave infrared (SWIR) bands (ISRO 2018). The Environmental Mapping and Analysis Program (EnMAP) is a German hyperspectral satellite mission that aims to collect the data in the spectral range of 420–2450 nm at 5–12 nm sampling intervals and a ground sampling distance of 30 m. EnMAP provides high-spectral resolution observations of biophysical, biochemical, and geochemical variables that suit a wide range of ecosystem parameters of agriculture, forestry, and inland waters.

Näsi et al. (2018) studied the damages in urban forests by bark beetle at individual tree level using Fabry-Pérot interferometer (FPI) hyperspectral camera. The study was conducted in the city of Lahti, in southern Finland. Tree health was evaluated at the individual level, and they developed a tree health monitoring method for small-scale areas. Luo et al. (2017) extracted urban surface water using airborne hyperspectral images in the Lujiazui, the inner city of Shanghai. Pushbroom Hyperspectral Imaging II (PHI-2) sensor was used to extract the water-covered areas in the city. Zhang et al. (2020) mapped urban river quality in Zhongshan City, China, using GaiaSky mini sensor which was attached to a small unmanned aerial vehicle (UAV). A Self-Adapting Selection of Multiple Artificial Neural Networks (SSNN) method was used for linking the spectral properties obtained from the hyperspectral imager to that of water quality parameters measured at the ground.

6.2.3 Vegetation and Water Indices

The analysis of panchromatic, multispectral, and hyperspectral data heavily relies on the vegetation and water indices that are applied on the specific spectral bands in the electromagnetic spectrum. Spectral reflectance from different vegetation types varies according to plant type, stage of growth, water content, health conditions, nutrient status, and other intrinsic factors (Liu et al. 2016). Chlorophyll pigment in plant leaves absorbs most of the red (630–690 nm) region, while near-infrared (NIR) (760–900 nm) region is strongly reflected. By combining these, it is possible to differentiate vegetation area from others (Bannari et al. 1995). Normalized Differential Vegetation Index (NDVI) is the most widely used vegetation index which is based on the spectral reflectances in the NIR and red regions of the EMR spectrum.

Table 6.2 NDVI-based assessment of green infrastructure in the urban landscapes in Asia

Source	Satellite sensor	Study region	Focus of the study
Yue et al. (2007)	Landsat 7	Shanghai, China	Land surface temperature and NDVI
Sun et al. (2011)	MODIS	Pan China	NDVI-based vegetation cover change
Gorgani et al. (2013)	Landsat 5 and 7	Mashhad, Iran	NDVI and land surface temperature
Shetty and Somashekar (2014)	QuickBird	Bangalore, India	Vegetation cover assessment using NDVI
Grover and Singh (2015)	Landsat 5	Delhi and Mumbai, India	Urban heat island (UHI) and NDVI
Huang and Ye (2015)	Landsat 7	Beijing, China	Urban vegetation and land surface temperature
Son et al. (2016)	MODIS	Seoul, Korea	Urban vegetation and heat-related mortality
Ren et al. (2017)	Landsat TM	Changchun, China	Vegetation structural attributes and field measurements
Wong et al. (2019)	Sentinel-2	Pearl River Delta, China	Vegetation fraction for urban climate model parameterization

$$\mathrm{NDVI} = \frac{\rho_{\mathrm{nir}} - \rho_{\mathrm{red}}}{\rho_{\mathrm{nir}} + \rho_{\mathrm{red}}} \tag{6.1}$$

NDVI value ranges from −1 to +1, positive for vegetated areas due to high visible light absorption together with high near-infrared reflectance by plants. Other portions like soil, rock, snow, and clouds show NDVI value near 0, while water shows a negative value (Neigh et al. 2008) due to its strong absorbance of near-infrared radiation. NDVI is widely used in estimating the vegetation fraction in the urban landscapes, and temporal changes in the vegetation cover, and to measure the relationship between the vegetation cover and land surface temperature (LST) in the urban landscapes. Table 6.2 summarizes the major studies conducted in the urban landscapes in Asia using Normalized Differential Vegetation Index (Fig. 6.1).

Water strongly absorbs most of the visible, NIR, and SWIR radiations (Jones and Vaughan 2010), while absorbance varies with the purity of water. Normalized Difference Water Index (NDWI) developed by McFeeters is the most fundamental and widely used index for the identification of water (McFeeters 1996). The index is calculated by the formula:

$$\mathrm{NDWI} = \frac{\rho_{\mathrm{green}} - \rho_{\mathrm{nir}}}{\rho_{\mathrm{green}} + \rho_{\mathrm{nir}}} \tag{6.1}$$

Results of NDWI value vary from −1 to +1, positive water bodies, while areas with vegetation show negative values. The green band is selected to maximize the reflectance of water, while the NIR band is selected to minimize the reflectance of water and to maximize the reflectance of vegetation and soil factors (McFeeters

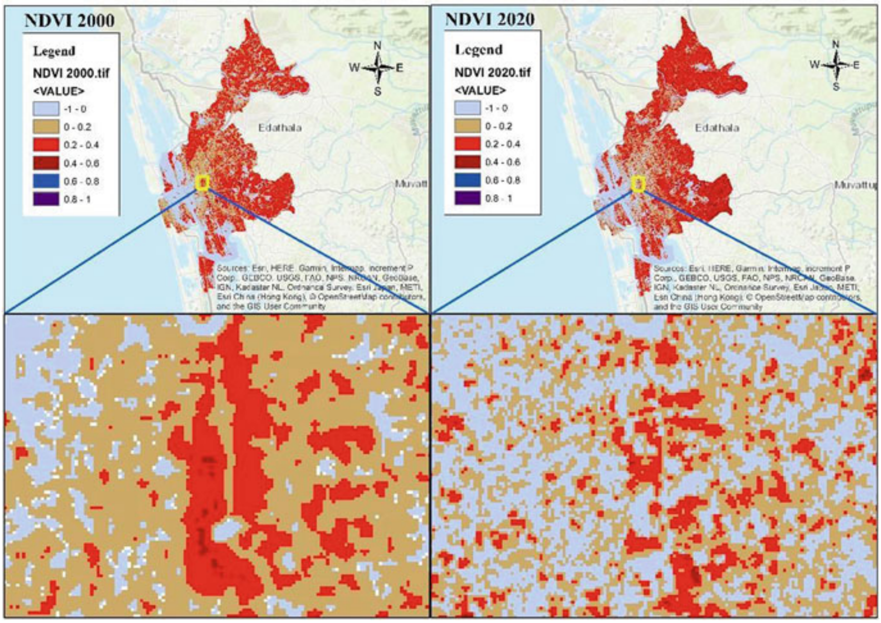


Fig. 6.1 The Normalized Differential Vegetation Index-based time series analysis of green infrastructure in the Cochin city of Kerala, India. The results show that the area covered under vegetation in 2000 got fragmented and the extent is reduced by the year 2020 (Source: Francis 2021)

1996). NDWI has been widely used in mapping the surface water bodies in urban landscapes, to analyze the changes in the extent of water bodies and to link with other biophysical measurements. Table 6.3 summarizes the major studies conducted in the urban landscapes in Asia using Normalized Differential Water Index (Fig. 6.2).

6.2.4 Radar Remote Sensing

Radio detection and ranging (radar) is an active microwave remote sensing with its electromagnetic energy source to illuminate the terrain (Gandhi and Sarkar 2016). Active microwave remote sensing offers cloud penetration and day-night imaging capability. It can also provide data in all weather conditions which can be used for the analysis of water and vegetation in extreme weather events. A satellite-based synthetic aperture radar (SAR) scans the Earth's surface using microwave radiation. The SAR antenna transmits microwave pulses and receives the backscattered radiation from the surface. The pulse duration and the length of the radar antenna decide the spatial resolution of the radar images; therefore the longer the antenna, the finer the resolution. There are several imaging radar systems on spaceborne platforms. The RADARSAT-2 and RADARSAT Constellation Mission (RCM) are Canada's

Table 6.3 NDWI-based assessment of blue infrastructure in the urban landscapes in Asia

Source	Satellite sensor	Study region	Focus of the study
Li et al. (2013)	ALI, Landsat 5 and 8	Hubei province, China	Comparison of NDWI in TM, ETM+, and ALI products
Gautam et al. (2015)	Landsat 7	Bangalore, India	Surface water mapping using various water indices
Mukherjee and Samuel (2016)	Landsat MSS, TM, and OLI	Chennai, India	Temporal variations of surface water bodies
Yang et al. (2017a)	ZiYuan-3	Beijing, Guangzhou, and Wuhan	Automated extraction of urban water bodies
Yang et al. (2017b)	Sentinel-2	Beijing and Yantai	Mapping of urban surface water bodies
Chen et al. (2018)	ZiYuan-3 and Gaofeng-2	Beijing, Tianjin, and Chengdu	Extraction of urban water bodies using deep learning
Ali et al. (2019)	Landsat 8	Makassar, Indonesia	Mapping surface water using NDWI and MNDWI
Guha et al. (2020)	Landsat 8	Raipur, India	Seasonal variability between LST and NDWI

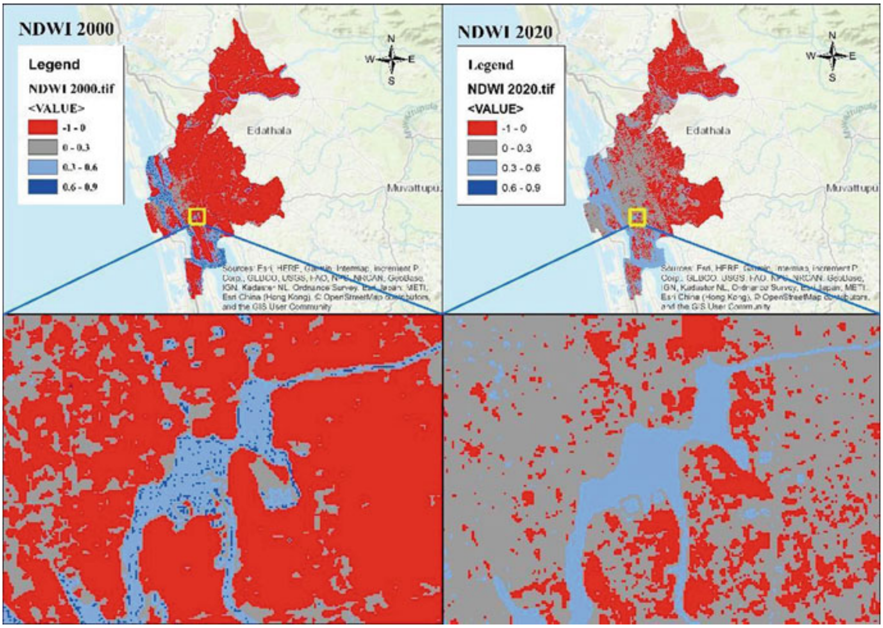


Fig. 6.2 The Normalized Differential Water Index-based time series analysis of blue infrastructure in the Cochin city of Kerala, India. The results indicated the shrinkage in water bodies across the city in the last two decades (Source: Francis 2021)

new generation of Earth observation satellites that produce radar images for geographical applications in oceanography, agriculture, forestry, hydrology, and geology. Sentinel 1 and ALOS PALSAR are two other prominent missions by the European Union and Japan, respectively. RISAT is microwave platform operated by the Indian Space Research Organization (ISRO 2012). ISRO is also developing another microwave system called NISAR (NASA-ISRO SAR Mission) jointly with the National Aeronautics and Space Administration (NASA) to measure the causes and consequences of land cover changes. One of the major uses of radar remote sensing is its capacity to develop terrain models including Digital Elevation Models (DEM) and Digital Surface Models (DSM). Soergel (2010) explains the use of radar remote sensing in urban studies. Water bodies reflect low backscatter which translates into a homogeneous, nearly featureless, and textureless region in the water-covered area in a SAR image. Treuhaft et al. (1996) explain methods to extract vegetation and underlying ground surface topography from radar data. Although radar is a promising tool, its applications in the urban environment are limited due to its inability to provide high spatial resolution datasets. Also the number of operational SAR missions is limited to a few or negligible compared to satellite missions in the optical region of the electromagnetic spectrum. However, these limitations may be overcome in the future as the investment and technology develops.

6.2.5 LiDAR

Light detection and ranging (LiDAR), also known as optical radar, is an advanced active remote sensing technique that uses electromagnetic energy in the optical range. It is used to detect an object, to measure the distance between the target and the instrument, and to understand the physical properties of the object by measuring the interaction of the radiation with the target through interacting phenomena such as reflection, scattering, absorption, and fluorescence (Fernandez-Diaz et al. 2013). LiDAR detects the backscattered light from the atmosphere and surfaces and records the target characteristics from the changes in the received and transmitted signals. LiDAR remote sensing systems allow researchers and mapping professionals to study both natural and man-made environments with accuracy and precision (Meñaca et al. 2015). Geoscience Laser Altimeter System (GLAS) is the first LiDAR instrument for continuous global observations of the Earth. Although the primary purpose of GLAS was to assess the mass balance of the polar ice sheets, it has been widely used for developing ecosystem structure models across the globe. The Global Ecosystem Dynamics Investigation (GEDI) produces high-resolution laser ranging observations of the 3D structure of the Earth. The GEDI contributes to the analysis of ecosystem structure and dynamics fundamental to the carbon cycle. The ATLAS is another LiDAR instrument launched on September 15, 2018, by NASA. Other than spaceborne platforms, there are several ground-based and airborne platforms which can be used for the blue-green feature extraction in the urban environment.

Pyszny et al. (2020) used LiDAR remote sensing data from airborne platforms to estimate the density of greenery in the city of Gorzów Wielkopolski located in Poland. Lafortezza and Giannico (2019) studied the structure and spatial arrangement of green spaces in relation to built-up areas and other infrastructures in Bari city in Italy. They used high-resolution WorldView-2 satellite images and LiDAR point cloud data, acquired using RIEGL LMSQ680i laser scanner (RiPROCESS, RIEGL Laser Measurement Systems, Austria), to map the green and built-up areas in the city. Jonassen et al. (2019) studied urban blue-green factor estimation in Fredrikstad, Norway, from hyperspectral and LiDAR data fusion. Bartesaghi-Koc et al. (2019) mapped green infrastructure typologies for climate-related studies in Sydney, Australia, synergizing the different data products including thermal infrared (TIR), hyperspectral, LiDAR, and cadastral data. Herrero-Huerta et al. (2018) estimated tree relevant individual structural parameters of urban trees using a mobile LiDAR system named Fugro Drive-map system, which has two high-performance Riegl VQ250 laser scanners and a navigation system. Zhang and Qiu (2012) mapped individual urban tree species in Texas using airborne hyperspectral and LiDAR data. AISA Dual hyperspectral sensor along with Lightwave Model 110 whisk-broom scanning LiDAR system was used to collect fine resolution data. The study also developed an algorithm for automatically inventorying urban tree forest from hyperspectral and LiDAR point cloud data.

6.3 Conclusion

Blue-green infrastructures contribute vital functions to the maintenance of ecosystem services in the urban landscapes. Remote sensing and GIS play a significant role in delineating the blue and green infrastructures in the city, assessing its spatiotemporal changes, and surrogate the biophysical environment. A wide range of remote sensing instruments are available to characterize the water and vegetation in the urban environment including panchromatic and multispectral, hyperspectral, radar, and LiDAR. However, extracting the vegetation and water signatures in the urban environment is quite complex as these land covers are sparsely distributed and sandwiched in the predominant urban signature. Multi-sensor fusion especially integration with LiDAR data is being recently developed to overcome such situations, though they are mostly done in the developed countries. It is important that these multi-sensor fusion products should be brought and tested in the densely populated Asian cities to develop high fidelity maps that are able to unveil complex structures of the water and vegetation in the urban environment.

Acknowledgments The authors would like to thank Hon'ble Vice Chancellor of Kerala University of Fisheries and Ocean Studies (KUFOS), Dean of Faculty of Ocean Sciences and Technology, and Head of the Department of Climate Variability and Aquatic Ecosystems, KUFOS, for permitting and providing facilities to conduct the study. Constructive evaluation by two anonymous reviewers greatly helped us to improve the quality of the manuscript.

Conflict of Interest Statement The authors report no conflict of interest for this publication.

References

Ahmed S, Meenar M, Alam A (2019) Designing a blue-green infrastructure (BGI) network: toward water-sensitive urban growth planning in Dhaka, Bangladesh. Land 8(9):138

Ali MI, Dirawan GD, Hasim AH, Abidin MR (2019) Detection of changes in surface water bodies urban area with NDWI and MNDWI methods. Int J Adv Sci Eng Inf Technol 9(3):946–951

Antoszewski P, Świerk D, Krzyżaniak M (2020) Statistical review of quality parameters of blue-green infrastructure elements important in mitigating the effect of the urban heat island in the temperate climate (C) zone. Int J Environ Res Public Health 17(19):7093

Atkins (2014). Future proofing Indian cities: Madurai action plan for blue-green infrastructure. http://www.indiaenvironmentportal.org.in/content/404086/future-proofing-indian-cities-madurai-action-plan-for-blue-green-infrastructure/. Accessed 20 Feb 2021

Baker F, Smith GR, Marsden SJ, Cavan G (2021) Mapping regulating ecosystem service deprivation in urban areas: a transferable high-spatial resolution uncertainty aware approach. Ecol Indic 121:107058

Bannari A, Morin D, Bonn F, Huete AR (1995) A review of vegetation indices. Remote Sens Rev 13(1–2):95–120

Bartesaghi-Koc C, Osmond P, Peters A (2019) Spatio-temporal patterns in green infrastructure as driver of land surface temperature variability: the case of Sydney. Int J Appl Earth Obs Geoinf 83:101903

Calderón-Contreras R, Quiroz-Rosas LE (2017) Analysing scale, quality and diversity of green infrastructure and the provision of urban ecosystem services: a case from Mexico City. Ecosyst Serv 23:127–137

Chen Y, Fan R, Yang X, Wang J, Latif A (2018) Extraction of urban water bodies from high-resolution remote-sensing imagery using deep learning. Water 10(5):585

DeVries B, Decuyper M, Verbesselt J, Zeileis A, Herold M, Joseph S (2015) Tracking disturbance-regrowth dynamics in tropical forests using structural change detection and Landsat time series. Remote Sens Environ 169:320–334

Di Leo NS, Escobedo FJ, Dubbeling M (2016) The role of urban green infrastructure in mitigating land surface temperature in Bobo-Dioulasso, Burkina Faso. Environ Dev Sustain 18:373–392

Farrugia S, Hudson MD, McCulloch L (2013) An evaluation of flood control and urban cooling ecosystem services delivered by urban green infrastructure. Int J Biodivers Sci Ecosyst Serv Manage 9(2):136–145

Fernandez-Diaz JC, Carter WE, Shrestha RL, Glennie CL (2013) Lidar remote sensing. In: Pelton JN, Madry S, Camacho-Lara S (eds) Handbook of satellite applications. Springer, New York, pp 757–808

Filchev L, Pashova L, Kolev V, Frye S (2020) Surveys, catalogues, databases/archives, and state-of-the-art methods for geoscience data processing. In: Skoda P, Adam F (eds) Knowledge discovery in big data from astronomy and earth observation. Elsevier, Amsterdam, pp 103–136

Finlay M (2018) Active, beautiful, clean waters design guidelines, PUB Singapore's National Water Agency, 4th edn. https://www.pub.gov.sg/abcwaters/designguidelines. Accessed 20 Feb 2021

Francis AT (2021) Mapping blue-green infrastructures in a rapidly expanding coastal city in the South West Coast of India. MSc Dissertation submitted to Kerala University of Fisheries and Ocean Studies, Kochi, India (unpublished)

Furberg D, Ban Y, Mörtberg U (2020) Monitoring urban green infrastructure changes and impact on habitat connectivity using high-resolution satellite data. Remote Sensing 12(18):3072

Gandhi SM, Sarkar BC (2016) Essentials of mineral exploration and evaluation. Elsevier, London

Gašparović M, Dobrinić D, Medak D (2018) Urban vegetation detection based on the land-cover classification of Planet scope, RapidEye and Worldview-2 Satellite Imagery. In: Proceedings of the 18th International Multidisciplinary Scientific Geo-Conference SGEM2018, Albena, Bulgaria, pp. 249–256

Gautam VK, Gaurav PK, Murugan P, Annadurai M (2015) Assessment of surface water dynamics in Bangalore using WRI, NDWI, MNDWI, supervised classification and KT transformation. Aquatic Procedia 4:739–746

Ghofrani Z, Sposito V, Faggian R (2017) A comprehensive review of blue-green infrastructure concepts. Int J Environ Sustain 6(1):15–36

Gorgani SA, Panahi M, Rezaie F (2013) The Relationship between NDVI and LST in the urban area of Mashhad, Iran. In: International Conference on Civil Engineering Architecture & Urban Sustainable Development. 27–28 November 2013

Govender M, Chetty K, Bulcock H (2007) A review of hyperspectral remote sensing and its application in vegetation and water resource studies. Water SA 33(2):49049

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

Grover A, Singh RB (2015) Analysis of urban heat island (UHI) in relation to normalized difference vegetation index (NDVI): a comparative study of Delhi and Mumbai. Environments 2(2):125–138

Guha S, Govil H, Besoya M (2020) An investigation on seasonal variability between LST and NDWI in an urban environment using Landsat satellite data. Geomat Nat Haz Risk 11(1):1319–1345

Hartling S, Sagan V, Sidike P, Maimaitijiang M, Carron J (2019) Urban tree species classification using a WorldView-2/3 and LiDAR data fusion approach and deep learning. Sensors19(6) 1284

Herrero-Huerta M, Lindenbergh R, Rodríguez-Gonzálvez P (2018) Automatic tree parameter extraction by a Mobile LiDAR system in an urban context. PLoS One 13(4):e0196004

Huang C, Ye X (2015) Spatial modeling of urban vegetation and land surface temperature: a case study of Beijing. Sustainability 7(7):9478–9504

ISRO (2012) RISAT-1. https://www.isro.gov.in/Spacecraft/risat-1. Accessed on 23 Feb 2021

ISRO (2018) PSLV-C43 / HySIS Mission Brochure. https://www.isro.gov.in/pslv-c43-hysis-mission/pslv-c43-hysis-mission-brochure. Accessed 23 Feb 2021

Jonassen VO, Aarsten D, Kailainathan J, Maalen-Johansen I (2019) Urban blue-green factor estimation in Fredrikstad, Norway from hyperspectral and lidar remote sensing data fusion-a concept study. In: 2019 10th Workshop on Hyperspectral Imaging and Signal Processing: Evolution in Remote Sensing (WHISPERS) (pp. 1–5). IEEE. Amsterdam

Jones HG, Vaughan RA (2010) Remote sensing of vegetation: principles, techniques, and applications. Oxford University Press, Oxford

Joseph S, Blackburn GA, Gharai B, Sudhakar S, Thomas AP, Murthy MSR (2009) Monitoring conservation effectiveness in a global biodiversity hotspot: the contribution of land cover change assessment. Environ Monit Assess 158:169–179

Joseph S, Murthy MSR, Thomas AP (2011) The progress on remote sensing technology in identifying tropical forest degradation: a synthesis of the present knowledge and future perspectives. Environ Earth Sci 64(3):731–741

Kanniah KD, Kang CS (2014) Exploring the role of green and blue infrastructure in reducing temperature in Iskandar Malaysia using remote sensing approach. IOP Conf Ser: Earth Environ Sci 18:012156

Krishnaswamy J, John R, Joseph S (2014) Consistent response of vegetation dynamics to recent climate change in tropical mountain regions. Glob Chang Biol 20:203–215

Labib SM, Harris A (2018) The potentials of Sentinel-2 and LandSat-8 data in green infrastructure extraction, using object based image analysis (OBIA) method. Eur J Remote Sensing 51(1):231–240

Lafortezza R, Giannico V (2019) Combining high-resolution images and LiDAR data to model ecosystem services perception in compact urban systems. Ecol Indic 96:87–98

Li J, Liu Q, Sang Y (2012) Several issues about urbanization and urban safety. Procedia Eng 43: 615–621

Li W, Du Z, Ling F, Zhou D, Wang H, Gui Y, Sun B, Zhang X (2013) A comparison of land surface water mapping using the normalized difference water index from TM, ETM+ and ALI. Remote Sens 5(11):5530–5549

Liao KH (2019) The socio-ecological practice of building blue-green infrastructure in high-density cities: what does the ABC waters program in Singapore tell us? Socio-Ecol Pract Res 1(1):67–81

Liao KH, Deng S, Tan PY (2017) Blue-green infrastructure: new frontier for sustainable urban stormwater management. In: Tan P, Jim C (eds) Greening cities. Advances in 21st century human settlements. Springer, Singapore, pp 203–226

Liu C, Sun PS, Liu SR (2016) A review of plant spectral reflectance response to water physiological changes. Chin J Plant Ecol 40(1):80–91

Luo X, Xie H, Tong X, Pan H (2017) A water extraction method based on airborne hyperspectral images in highly complex urban area. In: 2017 IEEE International Workshop on Remote Sensing with Intelligent Processing (RSIP) pp. 1–4, doi: https://doi.org/10.1109/RSIP.2017.7958812

McFeeters SK (1996) The use of the normalized difference water index (NDWI) in the delineation of open water features. Int J Remote Sens 17(7):1425–1432

McGwire K, Minor T, Fenstermaker L (2000) Hyperspectral mixture modeling for quantifying sparse vegetation cover in arid environments. Remote Sens Environ 72(3):360–374

Meñaca JGDT, Bartholomeus HM, Joseph S, Herold M, Avitabile V, Goodman RM, Raumonen P, Burt A (2015) Terrestrial LiDAR and 3D tree Quantitative Structure Model for quantification of aboveground biomass loss from selective logging in a tropical rainforest of Peru. In: Proceedings of SilviLaser 2015: 14th conference on Lidar applications for assessing and managing Forest ecosystems, La Grande motte, France, pp 119–121

Mukherjee NR, Samuel C (2016) Assessment of the temporal variations of surface water bodies in and around Chennai using Landsat imagery. Indian J Sci Technol 9(18):1–7

Mukherjee S, Bebermeier W, Schütt B (2018) An overview of the impacts of land use land cover changes (1980–2014) on urban water security of Kolkata. Land 7(3):91. https://doi.org/10.3390/land7030091

Näsi R, Honkavaara E, Blomqvist M, Lyytikäinen-Saarenmaa P, Hakala T, Viljanen N, Kantola T, Holopainen M (2018) Remote sensing of bark beetle damage in urban forests at individual tree level using a novel hyperspectral camera from UAV and aircraft. Urban For Urban Green 30: 72–83

Neigh CS, Tucker CJ, Townshend JR (2008) North American vegetation dynamics observed with multi-resolution satellite data. Remote Sens Environ 112(4):1749–1772

Pyszny K, Sojka M, Wróżyński R (2020) LiDAR based urban vegetation mapping as a basis of green infrastructure planning. In: E3S Web of Conferences: The 9th International Scientific-Technical Conference on Environmental Engineering, Photogrammetry, Geoinformatics – Modern Technologies and Development Perspectives, 171: 02008 https://doi.org/10.1051/e3sconf/202017102008

Rafiee R, Mahiny AS, Khorasani N (2009) Assessment of changes in urban green spaces of Mashad city using satellite data. Int J Appl Earth Obs Geoinf 11(6):431–438

Rajesh S, Nisia TG, Arivazhagan S, Abisekaraj R (2020) Land cover/land use mapping of LISS IV imagery using object-based convolutional neural network with deep features. J Indian Soc Remote Sensing 48:145–154

Ren Z, Pu R, Zheng H, Zhang D, He X (2017) Spatiotemporal analyses of urban vegetation structural attributes using multitemporal Landsat TM data and field measurements. Ann For Sci 74(3):1–14

Santos T, Tenedório JA, Gonçalves JA (2016) Quantifying the city's green area potential gain using remote sensing data. Sustainability 8(12):1247

Sebastian A, Joseph S, Khalam AA, Reddy CS (2019) Development of high resolution wetland database and web interface in the Ernakulam and Thrissur districts in Kerala, India. Climate Change Environ Sustain 7(1):25–31

Shetty M, Somashekar RK (2014) Multispectral monitoring of vegetation cover of Bangalore metropolitan area. Global J Biochem Biotechnol 2(1):27–32

Soergel U (2010) Radar remote sensing of urban areas. Springer, Netherlands, p 277

Son JY, Lane KJ, Lee JT, Bell ML (2016) Urban vegetation and heat-related mortality in Seoul, Korea. Environ Res 151:728–733

Sun J, Wang X, Chen A, Ma Y, Cui M, Piao S (2011) NDVI indicated characteristics of vegetation cover change in China's metropolises over the last three decades. Environ Monit Assess 179(1):1–14

Thayamkottu S, Joseph S (2018) Tropical forest cover dynamics and carbon emissions - contribution of remote sensing and data mining techniques. Trop Ecol 59:555–563

ThiLoi D, Tuan PA, Gupta K (2015) Development of an index for assessment of urban green Spacesat city level. Int J Remote Sensing Appl 5:78–88

Treuhaft RN, Moghaddam M, van Zyl JJ (1996) Vegetation characteristics and underlying topography from interferometric radar. Radio Sci 31(6):1449–1485

Tuan VQ, Trung NH, Nguyen M (2019) An assessment of green space, blue space and green infrastructure using remote sensing approach. Research Report No. DMI-0111/2019, DRAGON–Mekong Institute of Climate Change Research, Can Tho University, Vietnam

UNDESA (United Nations, Department of Economic and Social Affairs, Population Division) (2019) World urbanization prospects: the 2018 revision (ST/ESA/SER.A/420). New York

UNFPA (United Nations Population Fund) (2020). Asia and the Pacific: Population trends. https://asiapacific.unfpa.org/en/node/15207. Accessed 10 Feb 2021

Vani M, Prasad PRC (2020) Assessment of spatio-temporal changes in land use and land cover, urban sprawl, and land surface temperature in and around Vijayawada city, India. Environ Dev Sustain 22(4):3079–3095

Vatseva R, Kopecka M, Otahel J, Rosina K, Kitev A, Genchev S (2016) Mapping urban green spaces based on remote sensing data: case studies in Bulgaria and Slovakia. In: Proceedings of 6th International Conference on Cartography and GIS (pp. 569–578). 13–17 June 2016, Albena, Bulgaria

Venter ZS, Krog NH, Barton DN (2020) Linking green infrastructure to urban heat and human health risk mitigation in Oslo, Norway. Sci Total Environ 709:136193

Wang X, Xie H (2018) A review on applications of remote sensing and geographic information systems (GIS) in water resources and flood risk management. Water 10(5):608

Wong MMF, Fung JCH, Yeung PPS (2019) High-resolution calculation of the urban vegetation fraction in the Pearl River Delta from the Sentinel-2 NDVI for urban climate model parameterization. Geosci Lett 6(1):1–10

Worldometers (2021) Asia population. https://www.worldometers.info/world-population/asia-population/. Accessed 19 Feb 2021

Wu C, Li J, Wang C, Song C, Chen Y, Finka M, La Rosa D (2019) Understanding the relationship between urban blue infrastructure and land surface temperature. Sci Total Environ 694:133742

Yang F, Guo J, Tan H, Wang J (2017a) Automated extraction of urban water bodies from ZY-3 multi-spectral imagery. Water 9(2):144

Yang X, Zhao S, Qin X, Zhao N, Liang L (2017b) Mapping of urban surface water bodies from Sentinel-2 MSI imagery at 10 m resolution via NDWI-based image sharpening. Remote Sens 9(6):596

Yang G, Yu Z, Jørgensen G, Vejre H (2020) How can urban blue-green space be planned for climate adaption in high-latitude cities? A seasonal perspective. Sustain Cities Soc 53:101932

Yue W, Xu J, Tan W, Xu L (2007) The relationship between land surface temperature and NDVI with remote sensing: application to Shanghai Landsat 7 ETM+ data. Int J Remote Sens 28(15):3205–3226

Zhang C, Qiu F (2012) Mapping individual tree species in an urban forest using airborne lidar data and hyperspectral imagery. Photogramm Eng Remote Sens 78:1079–1087

Zhang Y, Wu L, Ren H, Liu Y, Zheng Y, Liu Y, Dong J (2020) Mapping water quality parameters in urban rivers from hyperspectral images using a new self-adapting selection of multiple artificial neural networks. Remote Sens 12(2):336

Akhil Francis Thekkan is a graduate student in Environmental Sciences from the Kerala University of Fisheries and Ocean Studies, Kerala, India.

Anjaly George is a PhD scholar at the Kerala University of Fisheries and Ocean Studies, Kerala, India.

P. Rama Chandra Prasad works as an Associate Professor at the International Institute of Information Technology, Hyderabad.

Shijo Joseph is an Assistant Professor in Remote Sensing at the Kerala University of Fisheries and Ocean Studies, Kerala, India.

Part II

Challenges and Constraints

7 Cities and Biodiversity: Hidden Connections Between the Built Form and Life

Radha Gopalan and Sindhu Radhakrishna

Abstract

Urbanisation is perhaps the most crucial factor affecting the environment in the Anthropocene. Not only does urban development directly impact the biotic elements in the environment by causing changes in land cover and degradation of natural habitat, it also indirectly affects the living environment by altering abiotic components such as temperature, rainfall, soil conditions, humidity, etc. The biodiversity that exists within the contours of built environments emerges from the complex interactions between anthropogenic actions and the surrounding environment. While some floral and faunal species gain from human interventions, others decline in response to human-caused alterations to the habitat. The evolution of cities, and the biodiversity that they shape, is not only impacted by the geography and climate of the region, but is also affected by sociopolitical changes in the human communities that reside within the cities. Using a historical lens, and the examples of three Asian cities, this chapter examines how urban biodiversity evolved and was produced in different ecogeographic zones in the continent at different time periods. Drawing insights from these different patterns of urban biodiversity, the chapter explores the multitudinous ways in which cities and biodiversity have interacted over the years, the changing conceptualisations of urban biodiversity and the many challenges that face sustainable urban biodiversity.

R. Gopalan
School of Development, Azim Premji University, Bengaluru, India

S. Radhakrishna (✉)
National Institute of Advanced Studies, Bengaluru, India

S. Dhyani et al. (eds.), *Blue-Green Infrastructure Across Asian Countries*,
https://doi.org/10.1007/978-981-16-7128-9_7

Keywords

Cities · Urban biodiversity · Synurbanisation · Telecoupling · CHANS · Governance · Sustainability

Whether one looks at the city morphologically or functionally, one cannot understand its development without taking in its relationship to earlier forms of cohabitation that go back to non-human species. One must remember not only the obvious homologies of the anthill and the beehive but also the nature of fixed seasonal habitations in protected sites, like the breeding grounds of many species of birds.— Lewis Mumford (Mumford 1956). The Natural History of Urbanization.

7.1 Urbanisation and The Evolution of Cities

Urbanisation is a process that shapes the structure, form, nature and function of cities. Defining this process has been a challenge because the criteria for what is urban vary across countries (Deuskar 2015). Researchers argue that there is no uniform or single process or pattern of urbanisation that has evolved over time. Smith and Lobo (2019) identify that the variation in the "spatial and social forms of cities, their size, functions, activities, and growth patterns" has made this difficult. Urbanisation is most often used to describe the transition of people, change in land use, economic activity and culture from a rural to urban setting (McGranahan and Satterthwaite 2014). While sociologists define urbanisation on the basis of demographical characteristics such as density, size and heterogeneity of population, anthropologists, historians and archaeologists find this limiting and define it with respect to the relationship of a city with its hinterland (Smith and Lobo 2019). Biologists, environmental scientists and ecologists define urbanisation from the perspective of changes in the environment and associated impacts. It is described as a growing threat to the Earth's ecosystems causing degradation of biodiversity and fragmentation of habitats and disturbing ecosystem services (Santangelo et al. 2018).

An urban ecological perspective of cities sees them as "emergent phenomena in which each component contributes to but does not control the form and behavior of the whole" (Alberti et al. 2003). Cities are seen as evolving from complex interactions between "human agents" (e.g. individuals, communities, the state, commerce) and "biophysical agents" (e.g. local geology, climate and other natural forces). Diverse development and land use patterns emerging from these interactions impact the ecosystems in and around the city, both directly and indirectly. Human health and well-being, in turn, is affected by these changes. More recent research explores how urbanisation affects species' evolution stemming from these changes to the environment (Johnson and Munshi-South 2017). As the Dutch biologist and ecologist Menno Schilthuizen puts it, "human actions are the world's single most influential ecological force," and the site of a lot of this change appears to be "the city's underbelly where the artificial and the natural meet and engage in ecological relations" (Schilthuizen 2018).

The phenomenon or rather the process of urbanisation can be traced to Neolithic times when the ancestor of a city, as described by Lewis Mumford, was a "tendency toward formal cohabitation and fixed residence" (Mumford 1956) in contrast to the peripatetic existence of hunters-gatherers in their quest for food and nomadic pastoralists. Mumford (1956) uses a natural history lens to discuss the history and evolution of cities. According to this perspective, early cities and urbanisation were characterised by a symbiotic relationship between human settlements and fertile agricultural land and pastures to cultivate food as well as rear animals. Urban growth was primarily along rivers to draw on these aquatic sources for food. Technological development, changes in transportation and the ability to store and process food, brought about by changes in access to, control of and transformation of energy sources, led to a shift from a symbiotic relationship to one of control over environmental resources. Security and protection from potential aggression led to another dimension of urbanisation: walled cities from as early as seventh to eighth millennium. Walled cities "retained some portion of the land within their walls for gardens and the harboring of animals for food in case of military siege."

As cities grew, urbanisation was accompanied by large-scale transformation of the environment. Paved surfaces and filling of water bodies to increase land availability changed the hydrology and microclimate of urban areas. There was a shift in the availability and choice of building materials: manufactured steel, cement, glass and composites taking over from materials sourced from the immediate local environment, e.g. stone, mud, wood, reed, bamboo, etc. Urbanisation therefore is seen as leading to transformation of the relationship of the city with its surroundings from a symbiotic one to a parasitic one and then to one of control leading to an intensive takeover of land and water resources of the surrounding areas to form an urban agglomeration rather than just a city, "the transformation of eopolis into megalopolis" (Mumford 1956).

As cities are growing, at various rates and in diverse ways across the planet, there is a sense of urgency to examine, understand and "manage" the process of urbanisation. There is increased recognition of how planetary processes such as global warming, biodiversity loss and threats to freshwater resources are inextricably linked with deepening socio-economic inequalities, threats to freedom, peace and justice (Steffen et al. 2015; Raworth 2012). This is pushing for a systemic and cohesive examination of how cities transform the environment, and how they in turn are transformed by the environment (Kondratyeva et al. 2020; Kowarik et al. 2020; Santangelo et al. 2018). Against this background, the present chapter attempts to understand the relationship between cities and biodiversity.

7.2 Urbanisation and Impacts on Biodiversity

Many studies have documented the varied effects of urbanisation on biodiversity. Urban development is regarded as one of the biggest threats to biodiversity, as it brings about fragmentation and loss of natural habitat. Scholars have pointed out that, unlike other anthropogenic drivers of habitat loss like logging and farming, the fallouts of urbanisation tend to be more permanent in nature (Stein et al. 2000) and that the impacts of urbanisation are not only due to the overall area effect but also because of the sprawl involved, i.e. the scattered and widespread nature of urban growth (Concepción et al. 2016). Urban expansion has direct and indirect effects on the ecosystem and biodiversity. Some of the direct impacts include vegetation loss and/or degradation, modified soil and microclimatic conditions and local extinction of species inhabiting the original natural habitat. The more indirect impacts are altered water and nutrient availability, increase in the abundance of non-native species and changes in herbivory and predation levels (Pickett and Cadenasso 2009). Urbanised regions often witness what is referred to as biotic homogenisation, wherein local native species are replaced by non-native species, resulting in a rich but homogenised urban diversity (McKinney 2006). The replacement of native organisms by non-native species in urbanised areas occurs due to two reasons: because (i) they are introduced through human activities intentionally or accidentally and (ii) human settlements offer environmental conditions that favour the establishment of non-native species (McKinney 2006). Novel, human-altered/human-created habitats often prove disadvantageous for native species, while they provide a competitive edge for non-native species (Byers 2002).

Organisms vary in their response to urbanisation and the changes it brings about both in the physical environment (e.g. presence of tall buildings as potential roosting sites, urban heat island effect, high alkalinity of urban soils) and the biotic environment (access to anthropogenic food resources, reduction in predation and competition levels, etc.). While some specialist/sensitive species (variously called non-synanthropes, avoiders or urbanophobes) show an avoidance response and disappear from urban habitats, some species (casual synanthropes, adapters, moderately urbanophilics) are able to adapt to urban settlements by utilising some elements of these habitats and natural resources (Johnston 2001). Yet others (exploiters, urbanophiles, full synanthropes) exploit the advantages offered by urban habitats to the extent that their numbers show high densities in urban areas and they become almost dependent on human food resources (Marzluff 2001). Highly urbanised ecosystems tend to have some common characteristics such as high human population densities, impervious sealed surface areas, built physical infrastructure, fragmented vegetation patches, soil alkalinity, average ambient temperatures and light and air pollution (Collins et al. 2000; Pickett et al. 2001), due to which cities in different regions tend be more similar to each other than to the environments that surround them (Savard et al. 2000; Clergeau et al. 2001). This homogenisation in the physical environment is also reflected in the biotic environment; species assemblages in cities are more similar to each other than to species communities in their surrounding areas (Clergeau et al. 2001; Blair 2001). Full synanthropes and exploiter species such as house mouse (*Mus musculus*), Norway rat (*Rattus norvegicus*), house gecko (*Hemidactylus mabouia*), house cricket (*Acheta domestica*), rock dove (*Columba livia*), peregrine falcon (*Falco peregrinus*), house sparrow (*Passer domesticus*), barn owl (*Tyto alba*) and chimney swift (*Chaetura pelagica*) attain their greatest densities in highly urbanised habitats, while the population sizes of casual synanthropes and adapter species like burrowing owl (*Athene cunicularia*), dandelion (*Taraxacum officinale*) and Chinese privet (*Ligustrum sinense*) peak in moderately urbanised or suburban environments (McKinney 2006).

The paradox of urbanisation is that it results in increased local biodiversity but reduced global biodiversity. This is because regional or local species richness in urbanised areas is augmented by the introduction of non-native or invasive species whereas the disappearance of locally endemic species diminishes global biodiversity (McKinney 2002; Kowarik 2011; Elmqvist et al. 2016). Specialisation in resource use, mobility and their interaction has been shown to affect species' adaptation to urbanisation, although different taxonomic groups varied in their responses (Concepción et al. 2015). For example, specialist and highly mobile plants increased in species richness in response to urbanisation, while the species richness of highly mobile specialist birds and butterflies showed decreases with increasing urbanisation levels (Concepción et al. 2015). Other studies also attest that animal taxonomic groups vary widely in their responses to urbanisation. While bird abundances generally increase in cities, often due to the increase in numbers of non-native species, bird diversity and richness tend to decrease (Chase and Walsh 2006; McKinney 2008; Shochat et al. 2010). Similarly arthropod abundance also increases (or shows no response) to urbanisation, while arthropod richness decreases (or shows no change) (Faeth et al. 2011). However, much of this data about species responses to urbanisation is drawn from studies conducted in temperate cities, which may therefore represent a skewed view of global urban biodiversity patterns. The few studies conducted in tropical cities show that species richness and abundances tend to decline in response to urbanisation, while the handful of studies conducted in cities with arid climates show that species abundances increase while species richness may increase or decrease due to urbanisation (Faeth et al. 2011). Clearly there is an urgent need for more studies in cities with different climates to achieve a more holistic understanding of urban biodiversity patterns and mechanisms.

7.3 Theorising Urbanisation-Biodiversity Interactions

Studies on ecological phenomena in urban environments reflect certain theoretical transitions in thought that occurred over the years, and it is useful to understand these conceptual phases to comprehend the current status of research in urban ecology. The initial set of studies on biodiversity in urban habitat patches compared species richness between various kinds of urban habitat patches and forest patches to understand differences between rural and urban ecosystems (Trepl 1995; Walbridge 1997), effect of patch size on species composition and richness (Klausnitzer 1993), invasion and extinction in urban ecosystems (Rebele 1994) and scale of variation in urban landscapes (Spence 1990; Blair and Launer 1997). These studies largely drew upon classical theories in ecology such as island biogeography theory (MacArthur and Wilson 1967), metapopulation theory (Hanski and Simberloff 1997) and intermediate disturbance hypothesis (Connell 1978) to use as frameworks to explain the processes occurring in urban ecosystems (Niemelä 1999). During this phase, environmental variables such as microclimatic factors, soil quality, rainfall, temperature and landscape factors were considered as the primary drivers for processes within urban ecosystems (Grimm et al. 2000). The second phase of studies in urban ecology is characterised by the emergence of the concept that human-induced impacts on the environment are long-standing and extensive and that urban ecosystems cannot be studied without considering human activities as an important driver for ecosystem dynamics. Vitousek et al. (1997), for example, state that "most aspects of the structure and functioning of Earth's ecosystems cannot be understood without accounting for the strong, often dominant influence of humanity." The "constellation" of studies (to use Mugerauer's (2010) term) in this phase variously acknowledge the role of human influence on ecosystem functioning and call for more extensive investigations into the way human beings interact with their environment, due to the inadequacy of classical ecological theory to capture all aspects of these interactions, and the need for a more integrative socioecological approach to address the coupling between anthropogenic components and environmental processes in urban ecosystems (Collins et al. 2000; Grimm et al. 2000; Pickett et al. 2001, 2008). The most recent phase of studies in urban ecology has pushed forwards the call for a more integrative socioecological approach in urban ecology to present urban ecosystems as coupled human-natural systems (CHANS approach—Liu et al. 2007) and focuses on the feedback mechanisms between human social process and the environment for a better understanding of eco-evolutionary dynamics and human-wildlife interactions in cities (Strohbach et al. 2014; Alberti et al. 2020; Des Roches et al. 2021).

While the large body of literature on urban ecology has addressed at length the role of human influences in driving biodiversity dynamics in urban ecosystems, there is relatively little work on how animal species may actuate urbanisation-biodiversity interactions. As described above, urban ecologists recognise that some species adapt well and even thrive in urban ecosystems, and based on the degree of adaptation displayed, they categorise such species as full or casual synanthropes (Johnston 2001). Ethologists refer to this phenomenon as synurbanisation and explain it in terms of the adjustments that animals make to alterations in their natural habitat (Luniak 2004). In contrast to this view that presents animals as "passive victims of changes in their habitats" (Radhakrishna and Sengupta 2020), animal studies scholars suggest that animals are *agents* in that they "actively engage with the environment" for improved chances of their survival and reproduction (Spinka and Wemelsfelder 2011; Špinka 2019). From this perspective, domestication is also interpreted as resulting from an act of animal agency; some animal species voluntarily moved towards human settlements for food or shelter and began to be utilised by humans for their domiciliary purposes (Budiansky 1992, 1994; Clutton-Brock

1994). A similar view of animal agency was proposed by Richard et al. (1989) when they characterised some Old World monkeys as "weed macaques" to explain their distributional spread and adaptive success. The authors suggested that these monkey species' dependence on human resources should not be seen as a "fall from grace" brought about by habitat destruction; instead it should be seen as an adaptive strategy that allows them to flourish near human settlements. "In short, like weed plants, weed macaques can be construed as human camp followers that may even occupy some habitats only because human disturbance is present" (Richard et al. 1989). Although scarce, ethological approaches that admit the notion of animal agency via observations on animal decision-making lend enormous insights into the dynamics of human-wildlife interactions in urban areas (Goulart et al. 2010; Beisner et al. 2015; Maibeche et al. 2015).

7.4 Socioecological Interactions in Cities

Geography, ecology, age and geopolitical position are some of the many factors that have influenced the evolution of cities and urban centres. Among the many biogeophysical factors that impact urban biodiversity, temporal dynamics is of particular import. Although well-accepted in the field of ecology, the importance of a temporal perspective is less acknowledged in studies on cities (Ramalho and Hobbs 2012). Urban biodiversity is shaped by the age of cities, as species diversity and abundance occur in response to climatic conditions, fragmentation intensities, disturbance regimes and the interactions of these various human and ecological elements. However, the rate of evolution of cities, urban sprawl and governance policies also crucially determine the continuing existence of biological communities in urban patches (Helm et al. 2006; Luck et al. 2009; Blaustein 2013). In the following sections, we examine three Asian cities from different ecoregions, at different periods of their history, to illustrate the uniqueness and universality that is involved in urbanisation processes worldwide and the nature of urban biodiversity generated by these processes. The rationale behind the selection of these particular cities was their diversity in geography, climate, age and ecology.

7.4.1 Ancient Jerusalem: Biodiversity Shaped by Religion and Geography

The earliest archaeological evidence of Jerusalem as an urban centre points to between 4500 and 3500 BCE (Slavik 2001). Present-day Jerusalem is characterised by the old "walled" city and the more "modern" new city that was built after 1948 (Slavik 2001). The natural systems from which the urban centre of Jerusalem emerged and grew are defined by mountainous regions with valleys and ridges on either side of the watershed line between the Mediterranean and the Dead Sea. The significant difference in precipitation across the city as well as exposure to the sun shapes the natural landscape of the city. The area around the watershed line forms a relatively narrow strip around which the ancient city of Jerusalem developed. This was a relatively protected area with natural springs serving as a good source of water for the population. The geology of the area dominated by diverse limestone formations was conducive for agriculture and yielded the prized building stones used in the city's construction (Avnimelech 1966). These geological and hydrological factors shape the quality of the soils in the area which in turn influences the natural biodiversity, as well as what is cultivated and how the latter modifies the native biodiversity.

Historical political events and ancient Jewish traditions have played a unique role in shaping the flora of Jerusalem; the biodiversity of the ancient (and the modern) city is a product of the intersecting forces of geography, geology and religion. Drawing from literary and archaeological sources, Shemesh (2018) found that during the Second Temple period between 560 BCE and 70 CE, the natural and cultivated vegetation within and around the city was strictly regulated by religious practices. In the inner urban space, "special ecological regulations" permitted only the growth of roses and cinnamon trees since they were fragrant, enhancing the religious and spiritual significance of ancient Jerusalem. Agriculture (local crops included vines, figs, olives and palm trees) was only practised in the hinterland outside the city, and the uncultivated area outside the city walls supported natural vegetation characteristic of the region (e.g. trees such as oak, pines, almond and hawthorns and several shrub and bush species). These species were harvested for heating, cooking and building and the areas used as grazing grounds for sheep (Shemesh 2018). Human processes thus influenced the growth, abundance and diversity of floral and, indirectly, faunal species. The study also showed that this biodiversity was significantly transformed by the Great Revolt (66–70 CE) when the Romans uprooted trees, cleared the agricultural land and destroyed the local vegetation. Cinnamon and acacia trees disappeared from the landscape.

Palynological studies from Jerusalem provide evidence of the role of palace gardens in influencing the city's biodiversity between the seventh and fourth centuries BCE. For instance, Persian rulers during that period imported tree species into the palace gardens of Ramat Rahel from other parts of their empire. This also led to introduction of the shrubby citron tree into the region. Other imported trees grown in the gardens were the cedar, birch and Persian walnut. Native fruit trees and ornamentals that were grown include the fig, grape, olive, willow, poplar, myrtle and water lily (Langgut et al. 2013). This study indicates the nature of biodiversity in Jerusalem during that period and also provides a glimpse into ways by which native flora was adapted and finally disseminated throughout the world. Creation of water features such as garden pools brought in aquatic plant diversity. Local and exotic shrub and tree species, ornamental plants and aquatic plants shaped the biodiversity of the area.

The building materials used and architectural style also shaped the urban ecosystems. Jerusalem stone used for construction (various types of limestone, dolomite and dolomitic limestone) characterises most parts of the old and new city. This stone was quarried from the surrounding limestone and dolomite hills. Centuries-old stone walls with their nooks and crannies, reservoirs and rooftops have interacted with natural systems in very dense areas and transformed into habitats for diverse local and migratory fauna and flora. This includes wet habitats, mature trees, nesting sites, refuge for molluscs, reptiles, insects and mammals. The most notable example is how the stones of the Western Wall provide close to 88 nesting spaces housing the migratory common swift nesting communities for over 2500 years (SPNI 2013). Historically the walls of the old city "constituted the point of encounter between nature and the city." But with the development of the new city, these walls are considered to have fragmented habitats and passage of wildlife and flora (City of Jerusalem's Biodiversity Report 2013).

A large part of modern Jerusalem is built on land that was used for agriculture until the nineteenth century. Vineyards, orchards and olive groves, which characterised the hinterland of the Second Temple period, are found in private and public gardens, open spaces around the city as well as monasteries. Rapid and dense urban development in the new city has displaced natural habitats and agricultural land, fragmented wildlife habitats leading to reduction in their population and eliminated several ecological corridors permanently (ICLEI 2017). On the other hand, a mosaic of new public and private green spaces in the form of orchards, groves, parks, gardens and agricultural sites have also been created leading to formation of new habitats in the built environment for diverse floral and faunal species. Conflicts of the twentieth century have created separation fences leading to physical fragmentation of the city that impacts ecosystem functions. For example, the enclosure of habitats of large mammal populations reduces the chances of their survival. Other human-natural systems interactions that are exerting selection pressure and shaping the city include efforts at mainstreaming biodiversity governance into urban planning, periodic urban nature infrastructure surveys that provide information needed to plan effectively and the active role of citizen groups in conserving open spaces (City Biodiversity Report 2013).

Human activities that have transformed the Jerusalem landscape for over close to 5000 years include nomadic pastoralism, settled agriculture, traditional orchard and grove farming, religious traditions, Jerusalem's place as a pilgrim centre for the Abrahamic religions, invasions by the Roman and Persian empires, modern agriculture practices, changing patterns of urban planning, several years of conflict and strong collective actions by citizen groups and civil society to conserve its biodiversity. Varying degrees of selection pressure have been created by grazing, traditional agriculture, planting forests of select species of trees, construction of roads and other infrastructure and, more recently, artificial lighting at night (Amichai and Kronfeld-Schon 2019). The modern city of Jerusalem has been shaped through interactions with the natural systems over centuries that have altered the hydrology, temperature and microclimate of the area, created transitions and gradients between the old and new city and with the hinterland and contributed to the emergence of the current urban socioecological system.

7.4.2 Modern Bengaluru: Colonial Production of Biodiversity

Bengaluru, a megacity in southern India, is the largest city in the country (741 km^2) and the third most populous (about seven million in 2007) (Sudhira et al. 2007). Built in 1537 by Kempe Gowda, a chieftain from the Yelahanka Nadu Prabhu dynasty, as a fortress town, Bengaluru has gone through many transformations in structure and governance over its history. Captured by British troops led by Lord Cornwallis in 1791, the city saw the development of a new Civil and Military Station (the cantonment town) just outside the old city area in 1809. Following India's independence in 1947, the two urban settlements were merged into a single urban centre, and what is now considered the city of Bengaluru, in 1949 (Sudhira et al. 2007; Kamath 2008; Pani et al. 2010).

Bengaluru is often referred to as the Garden City, due to large green spaces within the city (now fast disappearing) and its many public parks (Nagendra and Gopal 2011). Yet, the history of Bengaluru establishes that this urban biodiversity was to large extent produced and created by various regimes that built and governed the city. The British Cantonment was established in 1809 as separate from the old city (pete), in the plains towards the east, and historical maps from 1791 depict this area as largely open and semiarid, with intermittent scrub vegetation and a smattering of tall trees (Nagendra 2016). Narrative accounts from travelers who passed through the region then describe the area as open, treeless and stark (Buchanan 1807). Over the next few decades, persistent greening efforts by the administrators of the cantonment transformed this landscape. Importance was placed on the cultivation of home gardens, and British sepoys received small parcels of land for cultivation. With a focus on garnering income from their home gardens, British soldiers tended to grow fruit-bearing trees, while the officers' bungalows displayed a profusion of ornamental trees and plants (Rees 1891; Arthur 1847). In 1865, the picture that emerges of the cantonment is of considerable greenery in the home gardens and campuses of educational institutions, but "little or no jungle" outside of these private spaces (Ellis 1865). The efforts to intensively plant trees in areas "populated by British officers" continued apace, and a map of Bengaluru in 1885 "depicts trees distributed widely across the cantonment, and in lesser density across the native pete areas as well" (Nagendra 2016).

Planted vegetation in the pete and the cantonment subscribed to the differing aesthetics of the resident populations. According to Nagendra (2016), "while sacrality and productivity were the lens through which nature seems to have been viewed in the pete, recreation played a major role in shaping the cantonment's view of nature." For example, while the trees in the old city were largely native fruiting trees and sacred plants like jackfruit, mangoes, tamarind, coconut and tulsi, most of the trees planted in the public parks and along roads were exotic trees, chosen for their large flowering canopies and seasonal blooming (Issar 1998). The *Casuarina* tree, introduced primarily as a fuelwood, was grown so extensively that it "visibly altered the landscape in some parts" (Rice 1878). The wildlife populations in Bengaluru also reflected the differing biodiversities of the pete and the cantonment. While the deciduous forests around the old city harboured elephants, tigers, leopards and bear, the grasslands around the cantonment abounded in blackbuck populations, bustards and snipes (Pollock 1894). The landscape of the new cantonment area was remade not only through the assiduous planting of trees and shrubs but also by the construction of new reservoirs to meet the needs of the new immigrants and the draining of existing lakes to accommodate their recreational requirements (Nair 2005; Unnikrishnan and Nagendra 2014; Nagendra 2016). While much of the wildlife around the city and the cantonment was decimated due to hunting practices of the colonial era, the ecologically fragile grasslands around the cantonment area also disappeared over the course of that era, in response to the demands of the built environment as well as the recently planted exotic and invasive flora. Within the cantonment, the presence of smaller wildlife and domestic animals like large fruit bats, snakes, monkeys and cattle prevailed by adapting to the new habitats (Hoole 1844; Arthur 1847).

The legacy of this colonial production of biodiversity makes its presence felt to this day in contemporary Bengaluru. Over the years since the colonial era, more lakes have been drained and the lake beds converted to sports stadiums, markets, golf club, football grounds and bus stations. Small remnant grassland patches on the outskirts of the city and their fauna are threatened with destruction to make way for a film city. Amidst these changes, some wildlife like the bonnet monkey, the slender loris and fruit bats continue to persist in the ever-decreasing green patches within Bengaluru city. The existing green patches and the fauna and flora within the city are a reminder of how biodiversity can be created and destroyed due to the constantly changing goals of urbanisation.

7.4.3 Contemporary Singapore: A Biodiversity Paradox

Singapore, an island city-state in Southeast Asia, is a highly developed nation, with 392 species of birds, over 50% vegetation cover and a score of 80 out of 100 on the City Biodiversity Index. Contemporary Singapore is often held up as an example of exemplary urban biodiversity. However, with its high population density (over five million in total land area of 714 km^2), rapid rate of urban development and extensive loss of forest cover (the city lost more than 99% of its original lowland tropical rainforest within a century of its founding in 1819), the city appeared as a poor case prognosis for biodiversity even a few decades ago (Corlett 1992). Singapore's remarkable attempts to recover the loss of its native fauna and flora and overcome the effects of fragmented landscapes within the city not only offer insights into the resilience of urban biodiversity but also speak of the success of focused governance efforts. Post-independence in the 1960s, urban ecosystem development was included as a national developmental goal to promote the nation as a Garden City (Blaustein 2013). The strategies for this were multipronged: (i) 22 nature areas were set up that sustain about "255 hard coral species, 50 species of intertidal sea anemones, more than 2000 species of native vascular plants, 57 mammal species, 364 bird species, 301 butterfly species, and over 400 spider species"; (ii) the quality of nature parks were improved by adding other green patches to them as buffer parks; (iii) diverse microhabitats were inserted into nature sites to improve the complexity of the habitat and attract higher species diversity; (iv) diversified land management techniques were employed such as avoiding insecticides, reusing leaf litter, changing concretised canals to naturalised waterways to encourage growth of greenery along the sides; (v) making incremental additions to green habitat patches to improve their attractiveness to wildlife; (vi) planning interventions that accommodate urban developmental goals alongside urban greenery; (vii) designing structural barriers that maintain distance between people and wildlife yet permit visual access to biodiverse landscapes; (viii) establishing landscape connectivity measures that permit movement of fauna between fragmented landscapes, such as the tree-top overpasses, overhead bridges and underpasses below elevated highways; and (ix) implementing environmental education programmes that increase citizens' awareness of and value for urban biodiversity (Chan and Toh 2017; Tan 2017; An et al. 2020; Low 2020; NParks 2020; Jain et al. 2020; Hwang and Jain 2021).

Going forward, Singapore needs to balance the constructed biodiversity, which dominates the urban landscape, with trying to retain native species and accommodating rapid economic growth. Yu and Makoto (2017) point out that the biodiversity conservation approaches adopted by Singapore are characterised by manicured landscapes and green corridors which have been modelled on urban biodiversity planning in temperate regions. This approach has also changed the relationship of the people of Singapore with nature. While most of them support nature conservation, they identify it as manicured landscapes which have a lower conservation potential as shown from comparative biodiversity surveys (Yu and Makoto 2017). Any efforts at regenerating native biodiversity needs to consider this aspect. Moreover as tropical biodiversity has very different habitat requirements and adapts differently from temperate biodiversity, sustaining the constructed biodiversity may be a challenge as climate uncertainties increase. The historical top-down approach to urban biodiversity conservation is also raising some challenges for Singapore's future conservation efforts due to increasing inequalities and demands for more democratic governance (Hamel 2020). A more balanced, democratic, less top-down governance approach is recommended to promote urbanisation that benefits both human and natural systems.

7.5 The Urbanisation Benefits for Biodiversity

Research and discourse around urban biodiversity interactions is largely focused on the impacts of pollution on natural systems, effects of invasive species on native biodiversity, erosion of biodiversity and human-wildlife conflict. It is only more recently that some studies have begun to highlight other dimensions of human-nature interactions in urban environments such as understanding the emergence of novel ecosystems and examining human activity as a driver of evolution (Alberti et al. 2003; Johnson and Munshi-South 2017) wherein some species "are actually adapting to habitats that were originally created by humans for humans" (Schilthuizen 2018). Some researchers like Johnson and Munshi-South (2017)

Pathways		*Importance in the city when the city is surrounded by...* Agriculture/ plantations	Wildlands
1. Provide release from pressures faced in the surrounding landscape	Interspecific interactions (predation, competition, herbivory, and parasitism)	Low	High
	Prey abundance	Low	High
	Net primary productivity (arid)	High	Low
	Net primary productivity (temperate)	Low	High
	Chemical inputs	High	Low
	Length of growing season	High	High
	Human food subsides	High	High
2. Increase regional habitat heterogeneity	Habitat heterogeneity	High	Variable
	Rare habitats	High	Variable
3. Provide stopover locations for migratory species	Stopover habitat	High	Low
4. Contribute to species genetic diversity and preadaptation to climate change	Genetic diversity and pre adaptation to climate change	High	Variable
5. Enable and bolster intensive engagement and stewardship	Opportunities for engagement in biodiversity conservation	High	Low

Fig. 7.1 Benefits provided by cities to various species (Source: Spotswood et al. 2021)

consider that "urbanization represents the best and largest-scale unintended evolution experiment." Cities and urban areas thus offer opportunities to understand the nuances of the mechanisms that are driving evolution.

Spotswood et al. (2021) draw upon examples from various locations to illustrate what they call the "biological deserts fallacy." As discussed earlier in this chapter (Sect. 7.2), rather than seeing urbanisation only as destroying native biodiversity, it is useful to recognise that urban areas can also provide benefits, support various species and create novel ecosystems. The study identifies five primary categories of benefits (Fig. 7.1). The examples used illustrate that urban biodiversity interactions in cities can lead to increase in abundance of some species by making conducive habitats available; create refuges during periods of food or water stress for animals living outside the urban areas; provide habitats that serve to release threats from predators of some species thus promoting greater survival of the latter; provide easy access to food for some species through vegetable gardens and availability of waste;

serve as stopovers for migratory birds due to presence of urban parks, forested areas and water features; and support species through diverse and heterogenous habitats such as rooftops, windows, various kinds of green spaces, empty lots, gardens, water features, etc. While considering the benefits of cities to species, it is important to understand that urbanisation-biodiversity interactions are highly species-specific. The emergent effect on species is context specific: characteristics of the species, the actions of the urban system and the nature and responses of the surrounding environment together influence the adaptation of the species to urbanised habitats. This is important to understand in the context of urban planning and biodiversity conservation.

Urban conservation biology studies on the impact of urbanisation on native species of an area provide evidence of cities supporting both biodiversity and people. For example, Aronson et al. (2014) found that while cities retained most of their native species, the abundance of the plants reduced by 75% and that of the birds by 92% compared to their pre-urban density. The authors also point out that "retaining these connections requires sustainable urban planning, conservation and education focused on each city's unique natural resources." Anthropogenic features such as land cover and city age were found to be greater determinants of the density of species in the cities studied compared to geography, climate and topography.

The role of human systems as drivers of "microevolutionary change" through application of selection pressures, particularly in urbanised environments, is well-documented. However it is only recently that evidence points to significant evolutionary change occurring over a short time scale (Alberti 2015). While evolution was considered to be too slow a process to study in the context of urbanisation, more and more evidence is emerging that evolution can be rapid. Studies are reporting observable evolutionary change even in two generations (Johnson and Munshi-South 2017). It is also being recognised that urbanisation is a unique anthropogenic activity and studies on evolutionary processes in non-urban environments are distinct and may not be relevant for understanding these processes in urban areas. More recent studies present evidence of urbanisation affecting both adaptive (natural and sexual selection) and nonadaptive (genetic drift and gene flow) evolutionary processes in diverse organisms (microbes, plants, insects, fish, mammals and birds) (Johnson and Munshi-South 2017; Alberti et al. 2017).

Alberti et al. (2017) report more than 1600 cases of distinct "signatures" of phenotypic changes across species (animals, plants, fungi and microorganisms). Based on an analysis of drivers of change, it was found that the changes were higher and faster in urbanising compared to non-urbanising and natural systems. The study also found that the strongest drivers were interactions between organisms and humans or with other organisms brought into the city by humans (Alberti et al. 2017; Schilthuizen 2018). Urban ecologists are also reporting evidence of a convergence of species of soil microbes, plants and animals across cities and natural areas in various continents: similar species of these organisms playing similar roles are being reported in various cities (Schilthuizen 2018).

Globalisation and advances in communication technology facilitate rapid spread between cities of innovations and technology in transportation, infrastructure construction, architecture, building materials, urban planning, etc. These provide the selection pressure for evolutionary changes in species leading to better adaptation by some to the new conditions and disappearance of others who are not able to adapt. While, in non-human-dominated ecosystems, evolution is driven by natural drivers, in cities evolutionary change appears to be driven by human decisions and interactions. This extract from Menno Schilthuizen's book *Darwin Comes to Town* (2018) summarises the role of human-natural systems interactions in cities well:

> *We build cities full of novel structures made of glass and steel. We irrigate, pollute, and dam waterways; mow, spray, and fertilize fields. We pump greenhouse gases into the air that alter the climate; we release non-native plants and animals, and harvest fish, game, and trees for our food and other needs. Every non-human life form on earth will come across humans, either directly or indirectly. And, mostly, such encounters are not inconsequential for the organism in question…So what does nature do when it meets challenges and opportunities? It evolves. If at all possible, it changes and adapts. The greater the pressure, the faster and more pervasive it does so.*

7.6 Sustainable Urban Biodiversity and Its Challenges

Urbanisation has been with us since Neolithic times, but what is new is the scale, rate and intensity of the process. As centres of economic growth, cities and urban areas are becoming more and more powerful drivers of environmental change. Urban processes of the present and future and urban living are being seen as "shaping planetary dynamics" (UN Habitat 2020). Asian and African cities are projected to be at the epicentre of urban growth. Studies report that 96% of urban growth is projected to take place in Asia and Africa with the level of urbanisation in Asia set to increase from 37.5% in 2000 to 59.2% in 2035. At a country level, India, China and Nigeria are projected to account for 35% of the increase in global urban population by 2035 (UN Habitat 2020).

Asia has cities at various stages of urbanisation. While Singapore, Seoul, most cities in Japan and larger cities in China are witnessing a slowing of population growth, smaller cities in China and cities in other Asian countries including India are exploding with increasing in-migration from rural areas. Comparisons of today's Asian cities with cities of the Global North note that they exhibit much higher densities. This is attributed to geographical constraints (e.g. Tokyo, Hong Kong and Mumbai), rates of infrastructure development not being proportionate to rate of spatial expansion and population growth. Some of the main challenges that emerge from this include affordable housing, increased densification of cities, rising water and sanitation needs, solid waste management, transportation and, underpinning all this, high energy demands which are predominantly met by fossil fuels (Yue-man 2011; UNESCAP 2013). Other features characteristic of modern Asian cities are incentives for economic growth through creation of special economic zones, industrial corridors where infrastructure is provided and labour and environmental regulations are relaxed. This results in a spillover into pressure on land and water resources which transcends the administrative boundaries of cities and has regional impacts. Apart from cities drawing on resources from their immediate surroundings, studies report that multiple urban areas may also depend on the same regions for their resource requirements. This has implications for urban planning which needs to go beyond city to regional planning taking cognisance of the finitude of resources and limits of planetary boundaries (Seitzinger et al. 2012).

It is projected that by 2025 half the world's expansion in urban land will occur in Asia, primarily in largely rural countries. Studies on impact of urbanisation in 41 tropical countries document significant increase in pressure on resources in rural areas as a result of rise in deforestation accompanying changes in land use and land cover (Hughes 2017). Resource extraction, waste disposal and changes in land use and land cover from and in these surrounding areas can lead to fragmentation, erosion and loss of habitats of living species in these areas (ADB 2014). As discussed in Sect. 7.4 and 7.5 the urbanisation-biodiversity relationships and interactions are complex and multidimensional. The interactions lead to transformations both within and beyond the city. In some cases, as discussed earlier, cities see a rise in species richness and abundance of non-native species including habitats conducive for species considered invasive. At the same time, it has potential impacts on species dispersal as a result of habitat fragmentation. In this context an important distinction is made by Güneralp and Seto (2013): impact on biodiversity is determined not just by size of urban areas but also by the spatial configuration and heterogeneity in urban land use. As demand for land increases, it is accompanied by deforestation with implications for biodiversity loss, release of greenhouse gases, changes in rainfall patterns and effect on ground and surface water resources. Urbanisation is also accompanied by contamination of water bodies by wastes from cities, providing conditions for thriving of potentially invasive species. Compared to cities of the Global North, a large part of the urban areas in Asia, particularly South and Southeast Asia, fall within biodiversity hotspots. This not only drives a direct loss in biodiversity in areas where land use and land cover undergoes changes, but it also potentially impacts biodiversity in surrounding areas and in the region as a whole.

Emphasis on the need for urban planning that integrates biodiversity conservation and regeneration is widely being called for by civil society, citizen groups, the scientific community, UN agencies and international NGOs such as ICLEI—Local Governments for Sustainability as well as UN agencies (UN 2019; ICLEI). Exemplars of these are presented from Asian cities considered as well-planned and managed (e.g. Singapore, Seoul), in the form of creating new green spaces, maintenance and regeneration of existing urban green spaces, promoting food forests, home and kitchen gardens, living roofs, etc. While they enhance urban biodiversity and cause evapotranspiration-based cooling of the urban heat islands, they can be a serious challenge in cities where density of population is increasing and there are serious spatial constraints on land. Mega coastal cities like Mumbai, Dhaka, Singapore and others are particularly vulnerable in this regard. Projected sea-level rise, effects of intense monsoons and unpredictable extreme weather events add to the challenges of these cities (UN Habitat 2012).

A number of approaches and solutions are being proposed to find ways to integrate ecological principles into urban planning, e.g. nature-based solutions in some cities in China, Vietnam, Laos and India (Lechner et al. 2020; ICLEI) and maintaining provision of ecosystem services within cities (Hughes 2017). In Kochi, Panjim and Mangaluru which are non-metro cities in India, projects are underway with a focus on improving ecosystem services through urban forestry and wetland restoration efforts and mainstreaming biodiversity conservation in urban policy and planning (ICLEI—INTERACT-Bio). Some critics argue that most of the urban planning and management in Asian cities is top-down, and does not recognise or accommodate ground realities -, "way of life" of most people and communities in the city and the unique identity of each city; an identity built by historical, cultural and ecological diversity. The technology focus and requirements of many of these plans are complex and cost intensive which deepens the inequalities in most Asian cities. Lack of adequate public consultation of the plans makes them incompatible with the culture, values and priorities of local communities (UN Habitat 2012).

The future of urbanisation in Asian cities has significant implications for biodiversity regeneration and sustainability. Urban planning, approaches to land use, architectural styles and construction practices will all need to be aligned to the geography, climate and deeply unequal socio-economic-ecological realities of each city and region. A democratic, participatory and bottom-up approach to planning is almost an imperative to ensure that these realities are incorporated in the planning and actions in these urban areas. Above all, there cannot be a uniform "model" of addressing urban biodiversity interactions. It has to emerge from the sociocultural and ecological understanding of the place.

Building socioecological resilience of the linked human-natural system in urban centres for a climate-uncertain future needs adaptive capacity. In thinking and planning for the future of human-natural systems and their resilience, two points merit particular consideration—some of the changes that human systems are creating in this process of urbanisation are irreversible and, the adaptations by life on Earth to this "selection pressure" and its impact for the future of life on the planet.

Conflict of Interest Statement The authors report no conflict of interest for this publication.

References

ADB (2014) Urban metabolism of six Asian cities. Asian Development Bank, Mandaluyong City, Philippines. https://www.adb.org/sites/default/files/publication/59693/urban-metabolism-six-asian-cities.pdf

Alberti M (2015) Eco-evolutionary dynamics in an urbanizing planet. Trends Ecol Evol 30(2):2015. https://doi.org/10.1016/j.tree.2014.11.007

Alberti M, Marzluff JM, Shulenberger E et al (2003) Integrating humans into ecology: opportunities and challenges for studying urban ecosystems. Bioscience 53:1169–1179

Alberti, M., Correa, C., Marzluff, J.M., Hendry, A.P., Palkovacs, E. P., Gotanda, K.M., Hunt, VM, Apgar, T.M., Zhou, Y (2017), Global urban signatures of phenotypic change in animal and plant

populations. PNAS, 114, 34:8951–8956. https://www.pnas.org/content/pnas/114/34/8951.full.pdf
Alberti M, Palkovacs EP, Des Roches S et al (2020) The complexity of urban eco-evolutionary dynamics. Bioscience 70:772–793
Amichai E, Kronfeld-Schon N (2019) Artificial light at night promotes activity throughout the night in nesting common swifts (*Apus apus*). Sci Rep 9:11052. https://doi.org/10.1038/s41598-019-47544-3
An Z, Chen Q, Li J (2020) Ecological strategies of urban ecological parks – a case of Bishan Ang Mo Kio park and Kallang river in Singapore. E3S Web of Conf 194:05060
Aronson MF, La Sorte FA, Charles H et al (2014) A global analysis of the impacts of urbanization on bird and plant diversity reveals key anthropogenic drivers. Proc R Soc B 281(1780): 20133330. https://doi.org/10.1098/rspb.2013.3330
Arthur W (1847) Reminiscences of a mission to the Mysore. Wesleyan-Methodist Mag 3:40–47
Avnimelech M (1966) Influence of geological conditions on the development of Jerusalem bulletin of the American schools of oriental. Research 181:24–31
Beisner BA, Heagerty A, Seil SK et al (2015) Human–wildlife conflict: proximate predictors of aggression between humans and rhesus macaques in India. Am J Phys Anthropol 156:286–294
Blair RB (2001) Birds and butterflies along urban gradients in two ecoregions of the U.S. In: Lockwood JL, McKinney ML (eds) Biotic homogenization. Kluwer Academic Publishers, Norwell, MA, pp 33–56
Blair RB, Launer AE (1997) Butterfly diversity and human land use: species assemblages along an urban gradient. Biol Conserv 80:113–125
Blaustein R (2013) Urban biodiversity gains new converts: cities around the world are conserving species and restoring habitat. Bioscience 63:72–77
Buchanan FH (1807) A journey from Madras through the countries of Mysore, Canara, and Malabar. Performed under the orders of the most noble the Marquis Wellesley, Governor General of India, vol 1. Cadell, London
Budiansky S (1992) The covenant of the wild: why animals chose domestication. Yale University Press, New Haven
Budiansky S (1994) A special relationship: the coevolution of human beings and domesticated animals. J Am Vet Med Assoc 204:365–368
Byers JE (2002) Impact of non-indigenous species on natives enhanced by anthropogenic alteration of selection regimes. Oikos 97:449–458
Chase JF, Walsh JJ (2006) Urban effects on native avifauna: a review. Landsc Urban Plan 74:46–69
Chan S, Toh YH (2017) Windsor Nature Park, CITYGREEN 15: 6. https://www.nparks.gov.sg/-/media/cuge/ebook/citygreen/cg15/cg15_12.pdf
City of Jerusalem's Biodiversity Report 2013, https://cbc.iclei.org/wp-content/uploads/2016/09/Jerusalem-Biodiversity-Report_2013.pdf
Clergeau P, Jokimaki J, Savard JPL (2001) Are urban bird communities influenced by the bird diversity of adjacent landscapes? J Appl Ecol 38:1122–1134
Clutton-Brock J (1994) The unnatural world: Behavioural aspects of humans and animals in the process of domestication. In: Manning A, Serpell J (eds) Animals and human society: changing perspectives. Routledge, New York, pp 23–35
Collins JP, Kinzig A, Grimm NB et al (2000) A new urban ecology. Am Sci 88:416–425
Concepción E, Moretti M, Altermatt F, Nobis M, Obrist M (2015) Impacts of urbanisation on biodiversity: the role of species mobility, degree of specialisation and spatial scale. Oikos 124. https://doi.org/10.1111/oik.02166
Concepción ED, Obrist MK, Moretti M et al (2016) Impacts of urban sprawl on species richness of plants, butterflies, gastropods and birds: not only built-up area matters. Urban Ecosyst 19:225–242
Connell JH (1978) Diversity in tropical rainforests and coral reefs. Science 199:1302–1310
Corlett RT (1992) The ecological transformation of Singapore, 1819-1990. J Biogeogr:411–420

Des Roches S, Brans KI, Lambert MR et al (2021) Socio-eco-evolutionary dynamics in cities. Evol Appl 14:248–267

Deuskar C (2015) What does urban mean? https://blogs.worldbank.org/sustainablecities/what-does-urban-mean

Elmqvist T, Zipperer W, Güneralp B (2016) Urbanization, habitat loss, biodiversity decline: solution pathways to break the cycle. In: Karen S, William DS, Griffith CA (eds) Routledge handbook of urbanization and global environmental change. Routledge, London, pp 139–151

Faeth SH, Bang C, Saari S (2011) Urban biodiversity: patterns and mechanisms. Ann N Y Acad Sci 1223:69–81

Goulart VD, Teixeira CP, Young RJ (2010) Analysis of callouts made in relation to wild urban marmosets (Callithrix penicillata) and their implications for urban species management. Eur J Wildlife Res 56:641–649

Grimm NB, Grove JM, Pickett STA, Redman CL (2000) Integrated approaches to long-term studies of urban ecological systems. Bioscience 50:571–584

Güneralp B, Seto KC (2013) Futures of global urban expansion: uncertainties and implications for biodiversity conservation. Environ Res Lett 8:014025

Hamel P (2020), The place of nature in cities: taking inspiration from Singapore. https://www.thenatureofcities.com/2020/07/24/the-place-of-nature-in-cities-taking-inspiration-from-singapore/

Hanski I, Simberloff D (1997) The metapopulation approach, its history, conceptual domain, and application to conservation. In: Hanski I, Gilpin M (eds) Metapopulation biology, ecology. Genetics and Evolution. Academic Press, San Diego, CA, pp 5–26

Helm A, Hanski I, Pärtel M (2006) Slow response of plant species richness to habitat loss and fragmentation. Ecol Lett 9:72–77

Hoole E (1844) Madras, Mysore, and the South of India: or a personal narrative of a mission to those countries from 1820-1827. Longman, Brown, Green, and Longmans, London

Hughes AC (2017) Understanding the drivers of Southeast Asian biodiversity loss. Ecosphere 8: e01624. https://doi.org/10.1002/ecs2.1624. https://esajournals.onlinelibrary.wiley.com/doi/10.1002/ecs2.1624

Hwang YH, Jain A (2021) Landscape design approaches to enhance human–wildlife interactions in a compact tropical city. J Urban Ecol 7:juab007

ICLEI (2017) Interact-bio – integrated action on biodiversity. https://cbc.iclei.org/project/interact-bio/

Issar TP (1998) The city beautiful: Bangalore. Bangalore Urban Arts Commission, Bangalore

Jain A, Chan SKM, Vlasanek P et al (2020) Impacts of habitat on butterfly dispersal in tropical forests, parks and grassland patches embedded in an urban landscape. Biotropica 52:404–409

Johnson M, Munshi-South J (2017) Evolution of life in urban environments. Science 358: eaam8327. https://doi.org/10.1126/science.aam8327

Johnston RF (2001) Synanthropic birds of North America. In: Marzluff JM, Bowman R, Donnelly R (eds) Avian ecology in an urbanizing world. Kluwer Academic Publishers, Norwell, MA, pp 49–67

Kamath SU (2008) A city yet unborn. In: De A (ed) Multiple city: writings on Bangalore. Penguin Books, New Delhi, pp 6–9

Klausnitzer B (1993) Ökologie der Großstadtfauna. 2. Auflage. Gustav Fischer, Stuttgart

Kondratyeva A, Knapp S, Durka W et al (2020) Urbanization effects on biodiversity revealed by a two-scale analysis of species functional uniqueness vs. redundancy. Front Ecol Evol 8:73. https://doi.org/10.3389/fevo.2020.00073

Kowarik L (2011) Novel urban ecosystems, biodiversity, and conservation. Environ Pollut 159: 1974–1983

Kowarik I, Fischer LK, Kendal D (2020) Biodiversity conservation and sustainable urban development. Sustainability 12:4964. https://doi.org/10.3390/su12124964. www.mdpi.com/journal/sustainability

Langgut D, Gadot Y, Porat N, Lipschits O (2013) Fossil pollen reveals the secrets of the Royal Persian Garden at Ramat Rahel, Jerusalem. Palynology 37(1):115–129. https://doi.org/10.1080/01916122.2012.736418

Lechner A, Gomes RL, Rodrigues L et al (2020) Challenges and considerations of applying nature-based solutions in low- and middle-income countries in Southeast and East Asia. Blue-Green Syst 2:331–351

Liu J, Dietz T, Carpenter SR et al (2007) Coupled human and natural systems. Ambio 36:639–649

Liu J, Hull V, Batistella M et al (2013) Framing sustainability in a telecoupled world. Ecol Soc 18: 26. https://doi.org/10.5751/ES-05873-180226

Low SP (2020) Explore phase 1 of Singapore's first National Garden in the Heartlands. https://wwwdesignandarchitecturecom/article/lakeside-garden-ramboll-studio-dreiseitlhtml. Accessed 15 Jan 2021

Luck GW, Smallbone LT, O'Brien R (2009) Socio-economics and vegetation change in urban ecosystems: patterns in space and time. Ecosystems 12:604–620

Luniak M (2004) Synurbanization: adaptation of animal wildlife to urban development. Proc Int Urban Wildlife Symp 4:50–55

MacArthur RH, Wilson EO (1967) The theory of island biogeography. Princeton University Press, Princeton, NJ

Maibeche Y, Moali A, Yahi N et al (2015) Is diet flexibility an adaptive life trait for relictual and peri-urban populations of the endangered primate *Macaca sylvanus*? PLoS One 10(2):e0118596

Marzluff JM (2001) Worldwide urbanization and its effects on birds. In: Marzluff JM, Bowman R, Donnelly R (eds) Avian Ecology in an Urbanizing World. Kluwer Academic Publishers, Norwell, MA, pp 19–47

McGranahan G, Satterthwaite D (2014) Urbanisation concepts and trends. IIED Working Paper. IIED, London. http://pubs.iied.org/10709IIED

McKinney ML (2002) Urbanization, biodiversity, and conservation. Bioscience 52:883–890

McKinney ML (2006) Urbanization as a major cause of biotic homogenization. Biol Conserv 127: 247–260

McKinney ML (2008) Effects of urbanization on species richness: a review of plants and animals. Urban Ecosyst 11:161–176

Mugerauer R (2010) Toward a theory of integrated urban ecology: complementing Pickett et al. Ecol Soc 15:31

Mumford L (1956) The natural history of urbanization. http://habitat.aq.upm.es/boletin/n21/almum.en.Html#Piepag1

Nagendra H (2016) Nature in the City: Bengaluru in the past, present, and future. Oxford University Press, New Delhi

Nagendra H, Gopal D (2011) Tree diversity, distribution, history and change in urban parks: studies in Bangalore, India. Urban Ecosyst 14:211–223

Nair J (2005) The promise of the metropolis: Bangalore's twentieth century. Oxford University Press, New Delhi

Niemelä J (1999) Is there a need for a theory of urban ecology? Urban Ecosyst 3:57–65

NParks (2020) Community in nature schools awards. https://www.nparks.gov.sg/biodiversity/community-in-nature-initiative/cin-schools-award. Accessed 10 Nov 2020

Pani N, Radhakrishna S, Bhat KG (2010) Bengaluru, Bangalore, Bengaluru: Imaginations and their Times. Sage Publications, New Delhi

Pickett ST, Cadenasso ML (2009) Altered resources, disturbance, and heterogeneity: a framework for comparing urban and non-urban soils. Urban Ecosyst 12:23–44

Pickett STA, Cadenasso ML, Grove JM et al (2001) Urban ecological systems: linking terrestrial ecological, physical, and socioeconomic components of metropolitan areas. Ann Rev Ecol Syst 32:127–157

Pickett STA, Cadenasso ML, Grove JM et al (2008) Beyond urban legends: an emerging framework of urban ecology, as illustrated by the Baltimore ecosystem study. Bioscience 58:139–150

Pollock A (1894) Sporting days in southern India: being reminiscences of twenty trips in pursuit of big game, chiefly in the Madras presidency. H. Cox, London
Radhakrishna S, Sengupta A (2020) What does human-animal studies have to offer ethology? Acta Ethol 23:193–199
Ramalho CE, Hobbs RJ (2012) Time for a change: dynamic urban ecology. Trends Ecol Evol 27: 179–188
Raworth K (2012) A safe and just space for humanity. Oxfam Discussion Paper. https://www-cdn.oxfam.org/s3fs-public/file_attachments/dp-a-safe-and-just-space-for-humanity-130212-en_5.pdf
Rebele F (1994) Urban ecology and special features of urban ecosystems. Glob Ecol Biogeogr Lett 4:173–187
Rees JD (1891) Narratives of tours in India made by his excellency lord connemara, G.C.I.E., governor of Madras 1886-1890. Government Press, Madras
Rice BL (1878) Mysore and Coorg: a gazetteer compiled for the government of India. Mysore Government Press, Mysore
Richard AF, Goldstein SJ, Dewar RE (1989) Weed macaques: the evolutionary implications of macaque feeding ecology. Int J Primatol 10:569–594
Santangelo JS, Rivkin LR, Johnson MTJ (2018) The evolution of city life. Proc R Soc B285: 20181529. https://doi.org/10.1098/rspb.2018.1529
Savard JPL, Clergeau P, Mennechez G (2000) Biodiversity concepts and urban ecosystems. Landsc Urban Plan 48:131–142
Schilthuizen M (2018) Darwin comes to town: how the urban jungle drives evolution. Picador, New York
Seitzinger SP, Svedin U, Crumley CL (2012) Planetary stewardship in an urbanizing world: beyond city limits. Ambio 41:787–794. https://doi.org/10.1007/s13280-012-0353-7
Seitzinger SP, Svedin U, Crumley CL et al (2020) Planetary stewardship in an urbanizing world: beyond city limits. Ambio 41:787–794
Shemesh AO (2018) Holiness, war, and peace: ancient Jewish traditions concerning the landscape and ecology of Jerusalem and its environs in the second temple period. Religions 9:241. https://doi.org/10.3390/rel9080241
Shochat E, Lerman SB, Anderies JM et al (2010) Invasion, competition, and biodiversity loss in urban ecosystems. Bioscience 60:199–208
Slavik D (2001) Cities through time: daily life in ancient and modern Jerusalem. Runestone Press, Geneva
Smith ME, Lobo J (2019), Cities through the ages: one thing or many? Frontiers in digital humanities, Vol 6, https://www.frontiersin.org/article/10.3389/fdigh.2019.00012
Spence JR (1990) Success of European carabid species: preadaptation for synanthropy. In: Stork N (ed) Ground beetles: their role in ecological and environmental studies. Intercept Publications, Andover, pp 129–141
Špinka M (2019) Animal agency, animal awareness and animal welfare. Anim Welf 28:11–20
Spinka M, Wemelsfelder F (2011) Environmental challenge and animal agency. In: Appleby MC, Mench JA, Olsson IAS et al (eds) Animal welfare. CABI International, Wallingford, pp 27–43
SPNI (2013) Jerusalem welcomes the return of the Swift. https://natureisrael.org/News/Jerusalem-welcomes-the-return-of-the-Swift
Spotswood EN, Beller EE, Grossinger R et al (2021) The biological deserts fallacy: cities in their landscapes contribute more than we think to regional biodiversity. Bioscience 71:148–160
Steffen W, Richardson K, Rockström J et al (2015) Planetary boundaries: guiding human development on a changing planet. Science 347:6223
Stein BA, Kutner L, Adams J (2000) Precious heritage. Oxford University Press, Oxford
Strohbach MW, Warren PS, Peterson MN (2014) Urban wildlife science in coupled human–natural systems. In: McCleery RA, Moorman C, Peterson MN (eds) Urban wildlife conservation: theory and practice. Springer, Boston, MA, pp 33–53
Sudhira HS, Ramachandra TV, Subrahmanya MB (2007) Bangalore. Cities 24:379–390

Tan A (2017) Mandai eco-link: all you need to know about the wildlife bridge. The Strait Times. https://www.straitstimes.com/singapore/environment/mandai-eco-link-how-wildlife-crossing-works. Accessed 27 Jul 2017

Trepl L (1995) Towards a theory of urban biocoenoses. In: Sukopp H, Numata M, Huber a (eds)urban ecology as the basis for urban planning. SPB Academic Publishing, The Hague, pp 3–21

UN Habitat (2012) Sustainable Urbanisation in Asia – A Sourcebook for Local Govts. UN Habitat, Nairobi. https://unhabitat.org/sites/default/files/download-manager-files/Sustainable%20Urbanization%20in%20Asia.pdf

UN Habitat (2020) World cities report 2020: the value of sustainable urbanization. United Nations Human Settlement Program, Nairobi. https://unhabitat.org/sites/default/files/2020/10/wcr_2020_report.pdf. Accessed 20 July 2021

UNESCAP (2013). https://www.unescap.org/sites/default/files/SPPS-Factsheet-urbanization-v5.pdf

United Nations (2019) The Future of Asian and Pacific Cities. https://www.unescap.org/sites/default/d8files/knowledge-products/Future%20of%20AP%20Cities%20Report%202019.pdf

Unnikrishnan H, Nagendra H (2014) Unruly commons: contestations around Sampangi lake in Bangalore, Occasional Paper, Perspectives in Indian Development Series, no 39. Nehru Memorial Museum and Library, New Delhi

Vitousek PM, Mooney HA, Lubchenco J et al (1997) Human domination of Earth's ecosystem. Science 277:494–499

Walbridge MR (1997) Urban ecosystems. Urban Ecosyst 1:1–2

Yu TJK, Makoto Y (2017) Recommendations for Urban Biodiversity Conservation in the Context of Landscape Preference in Singapore, Cities and the Environment (CATE). Vol. 10, Iss. 1, Article 4. Available at: https://digitalcommons.lmu.edu/cate/vol10/iss1/4

Yue-man Y (2011) Rethinking Asian cities and urbanization: four transformations in four decades. Asian Geogr 28:65–83

Radha Gopalan is a Visiting Faculty at the School of Development, Azim Premji University, Bengaluru.

Sindhu Radhakrishna is a Professor at the National Institute of Advanced Studies (NIAS), Bengaluru, India.

8

Assessing Ecological Risks of Urban Air and Water Environment to Analyse the Scenarios for Mainstreaming Nature-Based Solutions: A Case Study of Bengaluru City, India

S. Varshini, Kiran Hungund, Sudip Kumar Kundu, Harini Santhanam, and Shalini Dhyani

Abstract

Urban ecological risks are intricately linked to several environmental and anthropogenic factors which need closer attention to these relationships at local scales. Among factors enhancing the impacts of urbanisation, land use changes and land management frameworks, the management of the urban air quality as well as the availability of blue-green infrastructure to alleviate these risks are not well connected with each other despite their synergistic effects over the environmental and public health of urban centres as reported by several studies. Hence, quantification of the ecological risks as well as derivation of nature-based solutions as effective strategies facilitating the urban sustainability needs to be examined in detail at different spatio-temporal scales to derive the appropriate strategies and policy formulations to decrease the risks. The present study takes the case of Bengaluru city to assess and quantify the ward-wise and overall ecological risks associated with the reduction in green cover, conversion of permeable land into concreted surface as well as the increase in particulate matter in the air. Differential scenarios with respect to the combination of three factors, ratios of the extents of green-to-blue areas, percentage impervious surface area and air quality index, were studied to identify those causing summative reduction in the ecological risks for the city. The use of nature-based solutions in managing the risks is examined from the perspective of mainstreaming them in land management practices for urban areas such as the Bengaluru urban area.

S. Varshini · K. Hungund · S. K. Kundu · H. Santhanam (✉)
National Institute of Advanced Studies (NIAS), Indian Institute of Science Campus, Bangalore, India

S. Dhyani
CSIR-National Environmental Engineering Research Institute (NEERI), Nagpur, India

S. Dhyani et al. (eds.), *Blue-Green Infrastructure Across Asian Countries*,
https://doi.org/10.1007/978-981-16-7128-9_8

Keywords

Ecological risk assessment · Air quality index · Urban centres · Bengaluru

8.1 Introduction

Human activities have significant impact on ecosystem health all around the world and contribute to the ecological risks, due to the intricate links with different socioeconomic practices of a given region. Predominantly, anthropogenic activities contribute to ecological risks in urban ecosystems, including the risks posed to the biological, air, water and land environments over different scales of the impacts to the biotic and abiotic components (Tang et al. 2018) as well as the biodiversity. Urban biodiversity, as urban units, refers to the diversity of life which includes ecosystem, animals and their genes. While these 'green spaces' play vital role in cooling the cities and provide space for physical activities, for social interaction and also for recreation purpose, their roles as nature-based solutions (NbS) in the reduction of pollution and ecological risks are noteworthy. For example, trees produce oxygen and help to filter out harmful air pollutants including airborne particulates. Biodiversity of flora and fauna is viewed from standpoint of its underlying asset, regardless of their direct or indirect benefits to mankind (Swartjes et al. 2011), and has also been explored as agents alleviating urban ecological risks due to their presence in the buffer regions of the cities. Most often, complicated resource usage scenarios and decrease in the carrying capacities of the natural environments in the urban areas lead to drastic amplification of the ecological risks over the short term as well as the long-terms. Notably, structural and functional changes to the ecological units, such as parks, fields, natural meadows and wetlands, due to the accelerated pace of urbanisation can drastically reduce their ecosystem services while inducing risks (Pickett et al. 1989; Jax 2006). However, identification, assessment and management of the urban ecological risks have a lot of scope for improvement (e.g. Tang et al. 2018) owing to the local-specific definitions of the nature and the manifestations of the changes (e.g. Zhao et al. 2000; Power and McCarty 2002; Wu et al. 2004; Deng et al. 2011, etc.).

For example, ecological risks posed by urban floods to developing urban centres vary from those posed for the developed ones (Balica et al. 2009). Further, cities may be flooded predominantly due to natural changes such as acute or chronic changes to the precipitation levels and patterns or due to anthropogenically induced land use changes to areas covered by flood plains (Jha et al. 2012). This also results in land degradation due to soil erosion, further decreasing the yield capacity of the soil. However, the risks posed vary based on the land use and management policies prevailing at the respective urban centres (De et al. 2013). Such changes impact both the land and the water ecosystems of the urban centres to a large extent. Similarly, the occurrence of spontaneous fire in urban areas may be attributed to different reasons—natural disasters or anthropogenic activities such as waste fires from landfill and recycling centres (e.g. Ibrahim 2020). Large amount of heat flux and heatwaves can cause serious fires over the buildings and/or green cover region of the city (e.g. Davao City; Villa and Ceballos 2021), alongside the accelerated increase in the land surface temperatures in response to reduction in the soil permeability and moisture (Ahmed et al. 2013). These events, if single or in series over a temporal scale, can compound the ecological risks over the urban areas. The ecological risks are connected with severe pollution levels which are reflected on the public health problems, resulting in respiratory illness, bronchitis, asthma, cancer and other serious health issues. These connections are often ignored in urban policymaking leading to huge economic and social losses (e.g. Corburn 2004). In the present times and warming world, there is a growing need to find innovative solutions to solve the urban challenges because of rampant urbanisation and climate change (Sarabi et al. 2020). Nature-based solutions (NbS) have the much required potential to offer support for sustainability and resilience building for advancing the urban planning approach and finding solutions to complex and emerging global urban challenges (Frantzeskaki et al. 2019). NbS can conserve, sustainably manage as well as help in restoring the natural as well as man-made ecosystems (Oral et al. 2020). NbS requires multidisciplinary-integrated approach to solve societal and environmental challenges especially disaster risk reduction and climate change adaptations (Cohen-Shacham et al. 2019). While solving societal and environmental issues, NbS are sure sort approach to secure human well-being and provide many additional co-benefits, viz. improving water quality, conservation of biodiversity, social co-benefits, thermal stability and cooling by improving microclimate that helps in reduction of energy consumption (Dhyani et al. 2018, 2019, 2020, 2021). There are evidences that urban planning can be relevant area to support mainstreaming of NbS and address trade-offs. NbS has been clearly observed being mainstreamed in circular cities to make them self-regenerative and more resourceful (Oral et al. 2020). NbS inclusive urban planning can also help in conflict resolution and addressing the need of environmental and social justice (Bush and Doyon 2019). Despite being increasingly at the centre of discussion for mitigating urban heatwaves and flooding, there has been really slow, inconsistent as well as very limited implementation and mainstreaming of NbS in urban planning and disaster risk reduction approaches (Croeser et al. 2021). There is a growing need and international consensus on that urban planners, policymakers, practitioners and scientists to understand, acknowledge and recognise the synergies as well as trade-offs that are linked with NbS and to enable NbS for its larger benefits (Seddon et al. 2021). It is crucial that NbS to be implemented in urban areas is guided by customised or place-specific solutions and are evidence based to facilitate replication and upscaling of NbS, and the integration of NbS efforts follows the principles of social and environmental justice and transdisciplinarity (Albert et al. 2021).

The above discussion illustrates the need to integrate the ecological risks due to land use modification, air quality degradation and loss of green and blue spaces and derive the optimal strategies to adopt NbS in the long term to provide impetus for urban sustainable development. The present study is an attempt in this direction and provides a basis for a more formal discussion of quantification of the place-specific risks as well as to plan the appropriate place-specific and customised NbS strategies using the case study of Bengaluru, India.

8.2 Study Area

The Bengaluru Urban district occupies about 2196 km^2 and is located between 12° 50′ 0″ N to 13° 20′ 0″ N and 77° 10′ 0″ E to 77° 50′ 0″ E (Fig. 8.1). In the past, Bengaluru was popularly known as 'Pensioner's paradise' because of quaint cottages and pretty bungalows surrounded by lovely gardens, which attest to its long association with nature-based living. It has also known with many other names such as 'Gandu Bhoomi (i.e. Land of Heroes)' and 'Bendakaaluru (i.e. Land of boiled beans)' which popularly indicate, recognise and celebrate local scale practices that gave rise to the multi-cultural city with affinity for environmentalism. Historical documents have referred to the construction of a large number of lakes by its rulers, thus giving Bengaluru the name 'Land of Lakes', and during the same period, a large number of parks were created like Lalbagh, Cubbon Park, etc., thus getting the name as 'Garden City'. However, Bengaluru has experienced the sudden urbanisation from the past few decades due to unprecedented scales of development activities focussed more on the economic development in the area, leading to the pressures on the air and water environments.

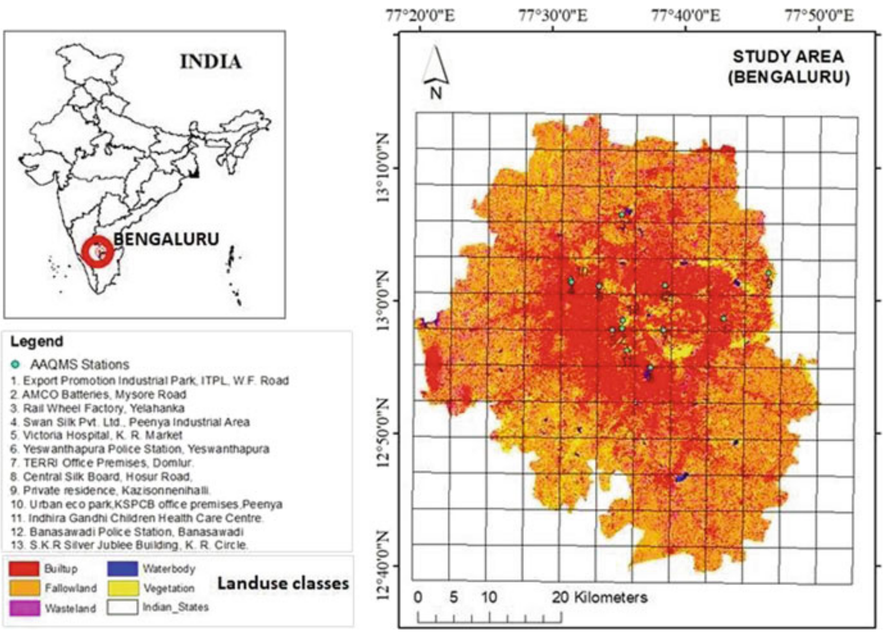


Fig. 8.1 Study area, the Bengaluru urban region showing the locations of sites where air quality is monitored and the various land use categories in existence

With increase in the developmental activities, there are some factors which affect the ecology of the city. Bengaluru city ranks the sixth among the ten cities globally in terms of the traffic congestion and volume contributing to pollution (The Times of India Report, January 2020) which led to increase in impervious layers throughout the cities. This is due to rapid urbanisation and migration of people from rural to urban areas leading to urban sprawl. Due to increase migration, the city faces major problems like decrease in the green spaces, depletion in ground water level, increase in energy consumption and increase in traffic congestion and pollution levels. The population has also increased about 154.5% in past two decades. Increase in livelihoods of urban people with better life standards, good educational opportunities and business prospects has spurred large-scale migration from the sub-urban and rural areas into the city. However, a shift from agricultural to residential and commercial land uses has been detrimental (Verma et al. 2017). These factors have led to the drastic increase in the concentrated population leading to the pressure on infrastructure development and natural resources, thus causing serious challenges such as climatic change; ecological change; traffic congestion; lack of amenities such as electricity, water and sanitation; and increase in greenhouse gas emission. This has contributed to the increase in the ecological risks for urban Bengaluru, compounded by air pollution.

As per the 2019 reports, Bengaluru is the most traffic congested city in India where drivers spend around 71% extra time on roads which is equivalent to wasting 10 days and 3 h on road every year creating more vehicular pollution (Zhou et al. 2014). The city is also experiencing different levels of pollution with areas having high level of pollutants. A study by IISc in 2016 shows Bangalore holds second position in emission of nitrogen oxides after Chennai. Agriculture, ammonium-based fertiliser application and animal husbandry are the sources of emission of ammonia to the air by chemical transformations. These gaseous pollutants also influence in formation of particulate matter and degradation in visibility. Hence predominantly the anthropogenic factors related to urbanisation such as changes in land use as well as the traffic sources for air pollutants indicate the significant contributions to ecological risks, which have not been investigated for their synergistic contributions.

The present investigation provides analyses of the ward-wise contributions to the total ecological risks for the city as well as the spatio-temporal variations between the years 2001, 2010 and 2019. The study combines the reported levels of emissions from limited air quality monitoring stations for the entire city with the changes to the land use using new indices proposed in the current study to determine the effects of the spatial variability of the impacts of land use on the differences in the risks at different parts of the city using geospatial analyses (e.g. by spatial interpolation techniques like inverse distance weighting, IDW; Chinnaswamy et al. 2016). These procedures are detailed in the subsequent sections.

8.3 Methodology

8.3.1 Derivation of LULC and NDVI

The land use changes were derived using satellite images of Landsat 4–5 TM for the years 2001 and 2010. Using the pixels of the satellite data to obtain the digital number values, the latter were converted into reflectance using the given formula:

$$\text{Reflectance} = (M\rho * Q_{\text{cal}} + A\rho)/\sin\ \gamma\text{SE} \tag{8.1}$$

where

$M\rho$ = REFLECTANCE_MULT_BAND
Q_{cal} = Quantised and calibrated pixel values
$A\rho$ = REFLECTANCE_ADD_BAND
γ_{SE} = SUN_ELEVATION

All these are obtained from Metadata file.

For the year 2019, data from the satellite Sentinel was considered which required no conversion. Later the layer stacking of the image was performed. LULC analysis refers to the categorisation of natural environment along with human activities on the land surface of a particular time frame based on statistical and scientific methods of analysis. Here the supervised classification using maximum likelihood parameter was carried out. Five land use land cover classes were considered, and accordingly the spectral signatures were created. Normalised Difference Vegetation Index (NDVI) analysis was performed to measure the state of health of plant based on how the plants reflect the light at a certain frequency. The value of NDVI lies between −1 and 1. The formula used to calculate NDVI is provided in Eq. (8.2).

$$\text{NDVI} = \frac{\text{NIR} - \text{Red}}{\text{NIR} + \text{Red}} \tag{8.2}$$

where

NIR is reflection in near-infrared spectrum.
Red is reflection in red spectrum.

For Landsat 4–5 TM satellite, data band 4 corresponding to the NIR band and band 3 corresponding to Red band were used for the analyses. In the case of Landsat 8 OLI satellite data, band 5 corresponding to NIR band and band 4 of Red band were used. In the case of Sentinel 2A satellite data, band 8 which is the NIR band and band 4 corresponding to the Red band were used for the purpose of mapping. The steps followed for analyses of LULC and NDVI are illustrated in Fig. 8.2.

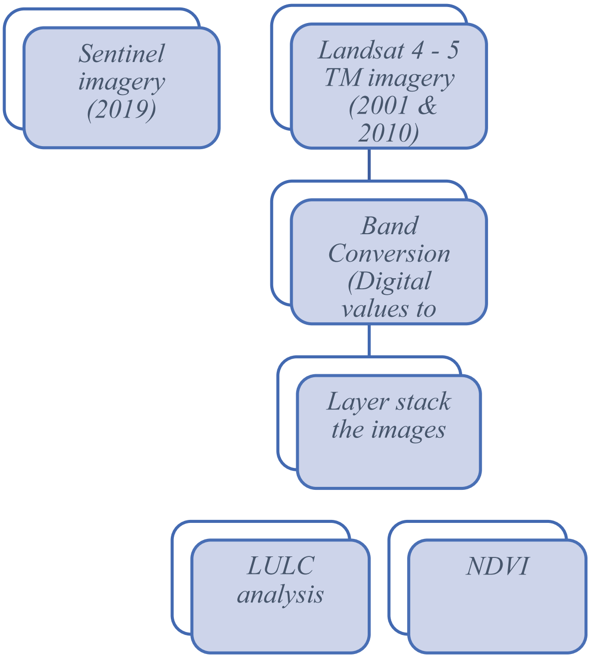


Fig. 8.2 Methodology followed for LULC and NDVI analyses

8.3.2 Derivation of Urban Expansion Index, ERI, GBR, BBA and ISA

Using the fishnet tool, the grid size of 5 × 5 km is created for the Bengaluru urban district. The lat-long values are obtained from the attribute table and are exported to the MS Excel. By using split tool, split each grids and overlay on LULC created and clip it. Then the area of each class of the grid is calculated. Once all the areas are calculated, urban expansion index, ecological risk index, green-to-blue ratio, blue by built-up area and impervious surface area are calculated for each grid. The centroid point of each grid is calculated, and inverse distance weighting interpolation is carried out for the study area. Finally, mapping is done for the same.

8.3.2.1 Urban Expansion Index

The urban expansion index represents the rate of growth of urban area. High value of the index represents the rapid growth of urban area, whereas low rate represents the slow growth of the urban area. This can be calculated using the formula provided in Eq. (8.3).

$$I_{\mathrm{ve}} = \frac{\Delta U * 100}{\mathrm{TLA} * \Delta t} \tag{8.3}$$

where

I_{ve} is urban expansion index.
ΔU is urban expansion during certain period.
TLA is total research area.
Δt is time span of certain period considered.

8.3.2.2 Ecological Risk Index

The ecological risk index is used to understand the comprehensive spatial difference in ecological risk on a particular land type. This can be obtained by the formula shown in Eq. (8.4):

$$\mathrm{ERI} = \sum\nolimits_{i=1}^{N} \left(\frac{A_i}{A} * w_i \right) \tag{8.4}$$

where

ERI is ecological risk index.
i is the land type considered.
A_i is area of land type i.
A is total area of research.
w_i is weightage assigned to each land type is calculated using AHP method.

For built-up land, weightage assigned was 0.472. In the case of vegetation and water bodies, the weightages assigned were 0.033 and 0.063, respectively. In the case of barren land and fallow up land, the weightage assigned was 0.216.

8.3.2.3 Green-to-Blue Ratio

The green-to-blue ratio is a qualitative estimate of vegetation cover over the waterbodies. The estimation can be done using the formula as shown in Eq. (8.5):

$$\mathrm{GBR} = \sum \frac{G}{B} \tag{8.5}$$

where

GBR is green-to-blue ratio.
G is sum of areas of the vegetation cover.
B is sum of areas of the waterbodies.

8.3.2.4 Blue to Built-up Area

The blue to built-up area is the ratio of waterbodies to built-up. This is calculated using the Eq. (8.6) as follows:

$$\mathrm{BBA} = \sum \frac{B}{C} \tag{8.6}$$

where

BBA is blue to built-up area.
B is sum of areas of the waterbodies.
C is sum of areas of the built-up.

8.3.2.5 Percentage Impervious Surface Area

Impervious surface area is the percentage of impervious spaces in the area. It is estimated using Eq. (8.7) as follows:

$$\mathrm{ISA} = \frac{\Sigma C}{\sum(G + C)} * 100 \quad (8.7)$$

where

ISA is percentage of impervious surface area.
C is sum of areas of the built-up.
G is sum of areas of the vegetation cover.

The overall procedure followed is summarised in Fig. 8.3.

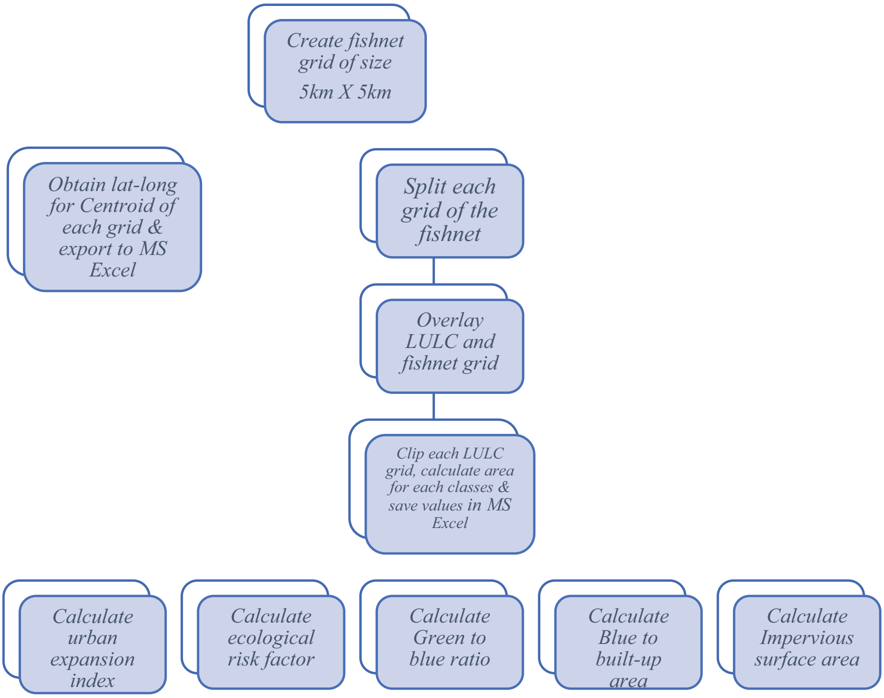


Fig. 8.3 Methodology followed for derivation of urban expansion index, ecological risk index, green-to-blue ratio, blue to built-up ratio and percentage impervious surface area

8.3.2.6 Methodology for Generating Air Pollution Maps Using Ground-Based Data

For studying the changes in the cumulative Air Quality Index (AQI), 2019 data were considered. The methodology followed for generating air pollution maps using ground-based data is shown in Fig. 8.4.

Interpolation using inverse distance weighting (Eq. 8.8) was carried out to create new data points within a distinct set of known data points to estimate unknown values by providing search distance, nearest points, power settings and barriers within a GIS environment.

$$Z_P = \frac{\sum_{i=1}^{n} \left(\frac{Z_i}{d_i} \right)}{\sum_{i=1}^{n} (1\ d_i\ )} \tag{8.8}$$

where

Z_p is value of unknown point.
Z_i is value of known point.

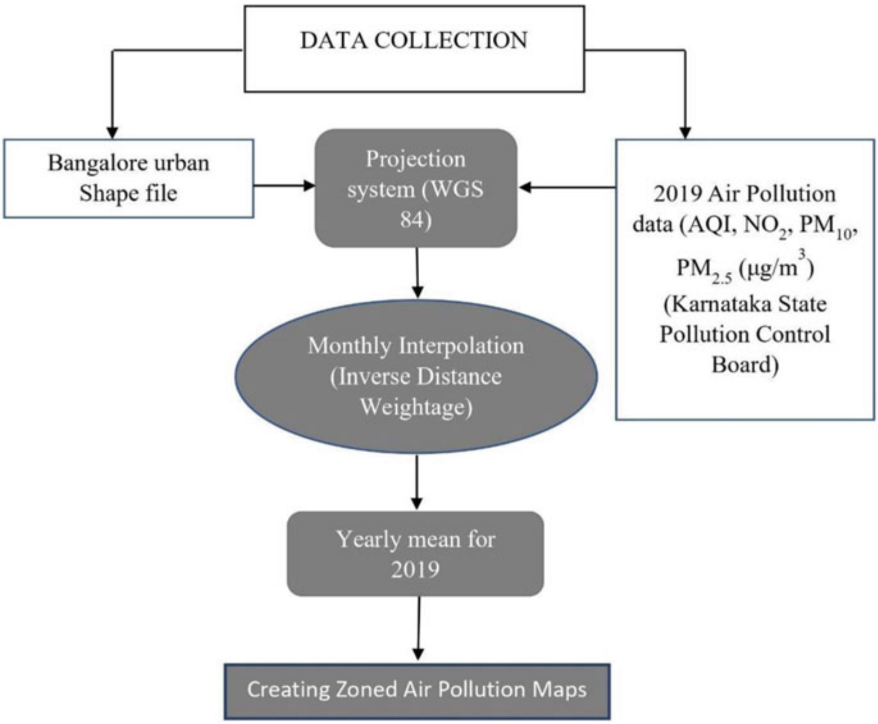


Fig. 8.4 Methodology for 3 years air pollution trend analysis using Karnataka State Pollution Control Board Data

d_i is distance of known point.
n is user picked exponent.

Overlay analyses by overlaying individual air pollutants such as nitrogen dioxide (NO_2) over Air Quality Index (AQI) and particulate matters ($PM_{2.5}$ as well as PM_{10}) over Air Quality Index (AQI) were performed as shown in Eqs. 8.9, 8.10, 8.11 and 8.12 by the addition of interpolated digital numbers (DN) of NO_2, $PM_{2.5}$, PM_{10} and ERI with and AQI in raster calculator.

$$NO_2 \text{ over AQI} = \text{DN values of } NO_2 + \text{DN values of AQI} \tag{8.9}$$

$$PM_{2.5} \text{ over AQI} = \text{DN values of } PM_{2.5} + \text{DN values of AQI} \tag{8.10}$$

$$PM_{10} \text{ over AQI} = \text{DN values of } PM_{10} + \text{DN values of AQI} \tag{8.11}$$

$$\text{ERI over AQI} = \text{DN values of ERI} + \text{DN values of AQI} \tag{8.12}$$

8.3.3 Derivation of NbS Scenarios

Based on the values of the AQI, ERI, BBA, GBR and ISA reported in the earlier sections, the scenarios of low and high ERI and AQI based on the changes to ground-based indices were performed. Using the assessment of AQI, ERI, BBA, GBR and ISA in 5 × 5 km grid analysis over the Bangalore city, the above-mentioned four major criteria have been identified to represent the NbS scenarios of the city. The values of the indices, i.e. the centroid mean values from spatial interpolation for each of the 5 × 5 km grids derived, were normalised to a value between 0 and 5 and classified into six major classes: negligible (n), very low (l), low (l), moderate (m), high (h) and very high (vh). Scores ranging between 0 and 5 (n = 0; vl = 1, l = 2, m = 3, h = 4, vh = 5) were allotted based on the ranges of the values obtained as per the classes to the ERI as well as AQI, BBA, GBR and ISA as shown in the following Table 8.1.

Summation of the scores of the yielded final scores based on four NbS scenarios which are as follows with respect to different combinations for each of the 5 × 5 km grids:

1. Scenarios causing major decrease in final score.
2. Scenarios causing major increase in final score.
3. Scenarios causing moderate decrease in final score.
4. Scenarios causing moderate increase in final score.

The scenarios were further analysed for suggesting appropriate NbS methods to be adopted.

Table 8.1 Grid-wise classification and scoring for derivation of NbS scenarios

	Values of the indices computed					Classification for scoring				
Grid ID (5 × 5 km) linked to geodatabase	AQI	ERI	BBA	GBR	ISA	AQI	ERI	BBA	GBR	ISA
7	80.51	0.18	0.27	58.36	56.33	m	m	vl	vl	m
8	79.98	0.17	0.02	242.18	71.91	m	m	n	vl	h
18	82.43	0.13	0.05	71.96	36.61	m	l	n	vl	vl
19	81.62	0.19	0.06	62.41	37.41	m	m	n	vl	l
20	80.52	0.22	0.04	115.12	49.17	m	m	n	vl	l
21	79.70	0.21	0.02	363.46	51.53	m	m	n	vl	m
29	83.06	0.18	0.03	1529.85	36.12	m	m	n	l	vl
30	83.99	0.21	0.02	597.37	53.58	m	m	n	vl	m
31	84.28	0.22	0.01	346.10	47.26	h	m	n	vl	l
32	82.57	0.25	0.02	44.42	56.62	m	h	n	vl	m
33	80.29	0.22	0.08	27.52	46.10	m	m	n	vl	l
34	79.06	0.22	0.05	179.46	45.59	m	m	n	vl	l
35	78.75	0.18	0.01	756.01	48.91	m	m	n	vl	l
40	82.04	0.10	0.01	6097.57	32.86	m	l	n	vh	vl
41	82.64	0.17	0.03	4060.34	32.52	m	m	n	m	vl
42	83.57	0.22	0.06	1203.02	45.39	m	m	n	vl	l
43	85.80	0.25	0.01	8154.70	59.65	h	h	n	vh	m
44	88.91	0.31	0.02	360.04	76.45	h	h	n	vl	h
45	83.97	0.34	0.02	38.50	79.77	m	vh	n	vl	vh
46	78.96	0.31	0.03	23.56	73.26	m	h	n	vl	h
47	77.70	0.26	0.02	59.19	58.03	m	h	n	vl	m
48	78.00	0.19	0.05	114.95	34.52	m	m	n	vl	vl
49	78.47	0.16	0.06	145.99	30.14	m	m	n	vl	vl
50	78.82	0.15	0.07	100.19	33.58	m	l	n	vl	vl

53	81.41	0.12	0.00	6404.57	45.22	m	l	n	vh	l
54	82.81	0.21	0.00	5179.61	42.48	m	m	n	h	l
55	83.69	0.23	0.01	3685.83	46.61	m	m	n	m	l
56	85.23	0.28	0.01	549.64	65.08	h	h	n	vl	h
57	92.35	0.33	0.01	290.57	73.22	vh	vh	n	vl	h
58	80.25	0.34	0.05	36.37	86.98	m	vh	n	vl	vh
59	73.81	0.37	0.14	207.07	80.93	l	vh	vl	vl	vh
60	75.63	0.32	0.01	62.94	70.45	l	vh	n	vl	h
61	77.49	0.23	0.04	47.41	46.31	m	m	n	vl	l
62	78.40	0.18	0.12	73.23	29.33	m	m	vl	vl	vl
63	78.84	0.18	0.10	96.44	33.41	m	m	n	vl	vl
67	82.51	0.21	0.00	30351.92	50.37	m	m	n	vh	l
68	85.30	0.26	0.01	1809.23	59.28	h	h	n	l	m
69	82.60	0.31	0.01	66.70	70.53	m	h	n	vl	h
70	78.92	0.34	0.02	181.62	74.93	m	vh	n	vl	h
71	69.41	0.34	0.01	507.96	74.01	vl	vh	n	vl	h
72	66.23	0.38	0.02	769.54	82.10	vl	vh	n	vl	vh
73	76.29	0.37	0.01	372.27	79.73	l	vh	n	vl	vh
74	78.49	0.30	0.02	55.37	67.73	m	h	n	vl	h
75	78.77	0.21	0.03	121.82	39.92	m	m	n	vl	l
77	79.06	0.13	0.01	622.98	40.30	m	l	n	vl	l
80	81.50	0.21	0.01	1779.21	64.04	m	m	n	l	h
81	82.21	0.26	0.02	789.37	63.00	m	h	n	vl	m
82	78.97	0.30	0.04	24.06	73.65	m	h	n	vl	h
83	72.72	0.36	0.02	280.63	82.02	l	vh	n	vl	vh
84	76.78	0.35	0.02	1103.24	76.32	l	vh	n	vl	h
85	81.30	0.34	0.01	10681.25	73.99	m	vh	n	vh	h

(continued)

Table 8.1 (continued)

Grid ID (5 × 5 km) linked to geodatabase	Values of the indices computed					Classification for scoring				
	AQI	ERI	BBA	GBR	ISA	AQI	ERI	BBA	GBR	ISA
86	88.52	0.37	0.04	530.66	83.07	h	vh	n	vl	vh
87	80.87	0.31	0.04	14.25	75.03	m	h	n	vl	h
88	79.65	0.24	0.10	29.13	52.28	m	m	vl	vl	m
89	79.36	0.24	0.03	73.70	58.77	m	h	n	vl	m
90	79.29	0.18	0.03	105.71	40.02	m	m	n	vl	l
93	80.23	0.19	0.02	1921.04	59.70	m	m	n	l	m
94	79.71	0.24	0.03	69.41	60.52	m	m	n	vl	m
95	77.95	0.26	0.02	31.72	62.70	m	h	n	vl	m
96	75.88	0.32	0.03	18.04	72.61	l	h	n	vl	h
97	80.11	0.34	0.02	588.03	73.76	m	vh	n	vl	h
98	81.97	0.30	0.06	708.92	66.88	m	h	n	vl	h
99	82.88	0.32	0.03	591.84	72.79	m	h	n	vl	h
100	81.18	0.31	0.04	207.36	76.46	m	h	n	vl	h
101	80.14	0.29	0.05	31.19	70.46	m	h	n	vl	h
102	79.71	0.24	0.16	50.29	56.46	m	m	vl	vl	m
103	79.53	0.20	0.01	204.90	42.34	m	m	n	vl	l
106	79.71	0.15	0.01	1630.19	53.85	m	l	n	l	m
107	79.52	0.19	0.02	117.61	48.29	m	m	n	vl	l
108	79.83	0.23	0.03	40.52	52.46	m	m	n	vl	m
109	81.16	0.27	0.07	18.37	62.02	m	h	n	vl	m
110	88.76	0.33	0.02	197.77	76.15	h	vh	n	vl	h
111	83.95	0.30	0.02	938.25	70.21	m	h	n	vl	h
112	81.73	0.26	0.01	4448.81	62.19	m	h	n	m	m
113	80.89	0.25	0.05	665.52	57.56	m	h	n	vl	m

114	80.29	0.25	0.08	218.96	59.41	m	h	n	vl	m
115	79.91	0.24	0.01	314.77	59.08	m	m	n	vl	m
116	79.70	0.22	0.01	435.59	51.73	m	m	n	vl	m
122	81.06	0.22	0.02	55.53	60.21	m	m	n	vl	m
123	82.82	0.23	0.02	271.22	59.29	m	m	n	vl	m
124	82.48	0.20	0.05	996.32	53.54	m	m	n	vl	m
125	81.49	0.22	0.01	4937.19	51.81	m	m	n	h	m
126	80.79	0.23	0.01	5657.56	57.13	m	m	n	h	m
127	80.33	0.22	0.01	552.87	54.18	m	m	n	vl	m
128	80.02	0.22	0.01	519.46	60.77	m	m	n	vl	m
129	79.82	0.14	0.01	769.18	41.03	m	l	n	vl	l
138	80.67	0.17	0.00	1352.26	43.13	m	m	n	vl	l

8.4 Results and Discussion

8.4.1 LULC Analysis

The land use/land cover maps are obtained by the supervised classification (Level 1; Patra et al. 2018) as per Space-Based Information Support for Decentralised Planning at Panchayat level (SIS DP). The spatio-temporal distribution of these classes for the area of Bengaluru urban district is obtained for the years 2001, 2010 and 2019. The images are shown in Fig. 8.5a–c, and the trend in changes of land use land cover classes is shown in Fig. 8.5d.

The LULC analysis maps and the graph show that the urban area has been increasing continuously from 2001 to 2019. It is found that about 15.3% (i.e. 334.61 km^2) of urban area increased from 2001 to 2010 and subsequently 8.3% (i.e. 180.44 km^2) of urban area increased from 2010 to 2019, whereas the barren land has been decreasing continuously from 2001 to 2019. It is found that about 12.1% (i.e. 265.63 km^2) of barren land decreased from 2001 to 2019, and further from 2010 to 2019, 17% (i.e. 373.24 km^2) of the barren land has decreased. Thus, it is observed that that city is experiencing large amount of urbanisation and the spread of urban area is taking place from the core of the city towards the Bengaluru north, south and east part to a major extent. And towards Anekal region, the less extent of urban expansion has taken place.

The overall accuracy of the LULC map for 2001, 2010 and 2019 is 88.24%, 80.00% and 80.00%, respectively. It is calculated by using the class values of created random points and then assigning the values to the reference using Google Earth (substitute of ground truthing).

8.4.2 NDVI Analysis

The NDVI images are obtained by processing the satellite data using ERDAS IMAGINE 2014. The spatial distribution of plant growth and its health are studied here. For the same, the NDVI images are obtained for the year 2001, 2010 and 2019 and are shown in Fig. 8.6a–c, while the changes in trends of NDVI are represented in Fig. 8.6d.

In the NDVI maps, higher value represents the good quality of vegetation, and other lower values represent the barren land and other built-up area. From the graph it is observed that the NDVI value has decreased from 2001 to 2010, whereas it has increased from 2010 to 2019. This trend in NDVI can also be justified from LULC maps where vegetation has decreased from 2001 to 2010 and increased from 2010 to 2019.

The reasons for this change in trend could be as follows:

- The decrease in NDVI values from 2001 to 2010 may be due to urbanisation and cutting of trees and utilisation of other agricultural/barren land.

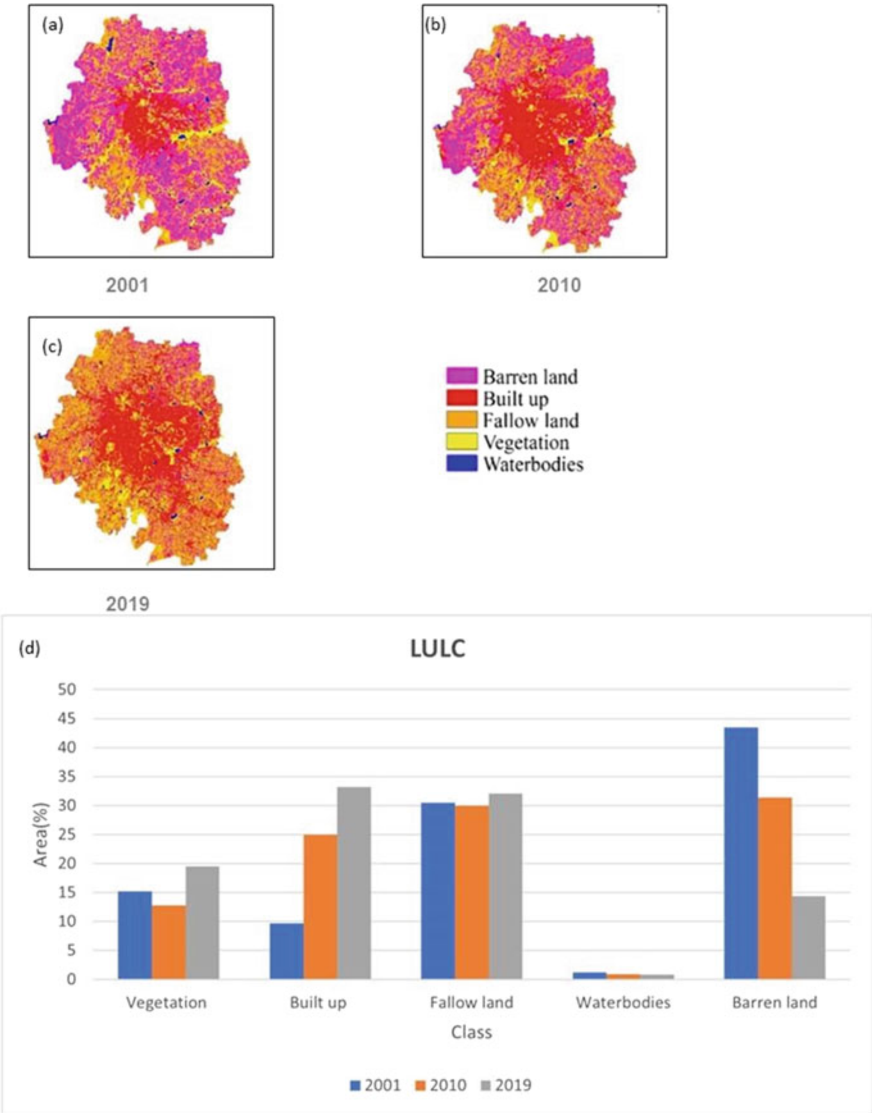


Fig. 8.5 Land-Use Land-Cover (LULC) classification for the years (**a**) 2001, (**b**) 2010, (**c**) 2019 for different parts of Bengaluru city and (**d**) illustration of the percentages of the LULC classes

- The increase in NDVI values from 2010 to 2019 may be attributed to the growth of vegetation and subsequent greenery in the layouts/IT parks.
- Nowadays the awareness about the importance of greenery among the people is improving. So, there are social campaigns, and NGOs are coming forwards to save the greenery.

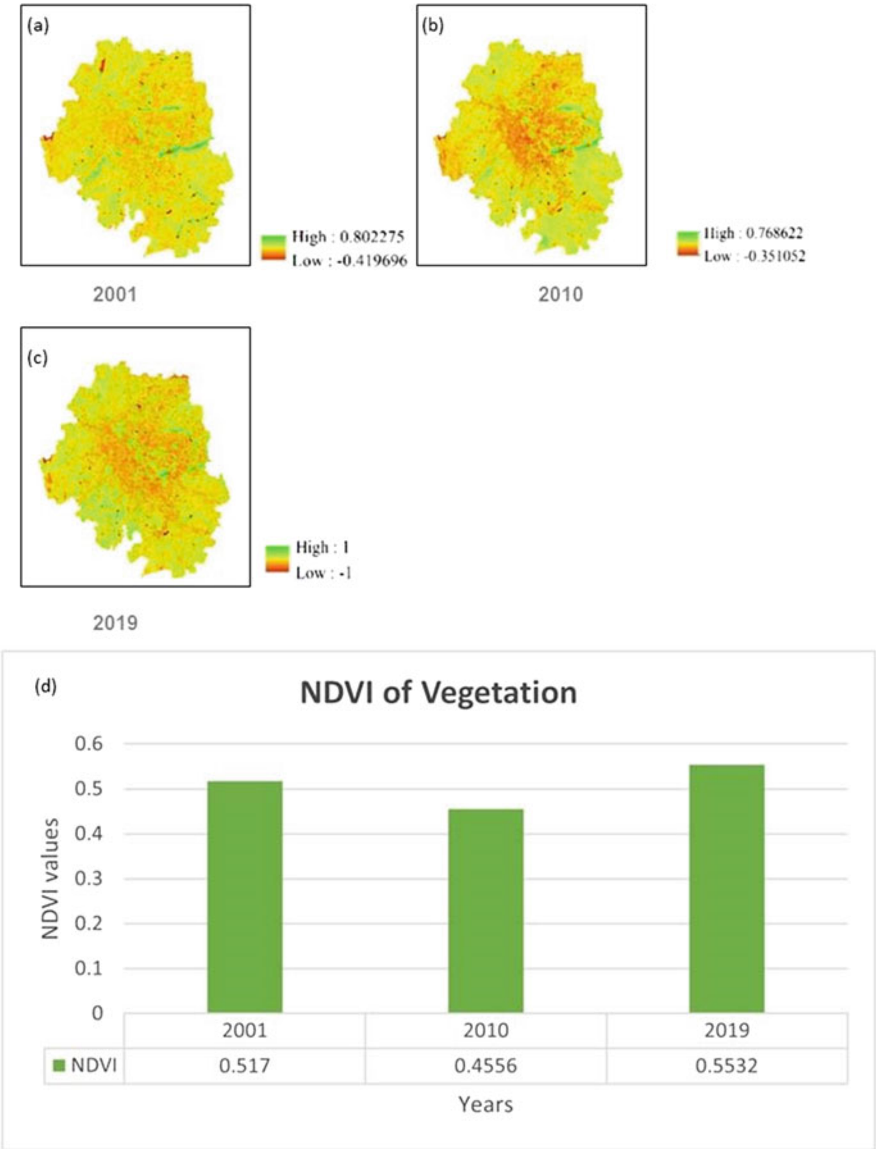


Fig. 8.6 Normalised Difference Vegetation Index (NDVI) changes for vegetation for the years (**a**) 2001, (**b**) 2010, (**c**) 2019 and (**d**) illustrates the graph of NDVI for different parts of Bengaluru city

8.4.3 Urbanisation Expansion Index

The rate of growth of urban area can be quantified using the urban expansion index. To understand this, the urban expansion index for each grid considered is shown in

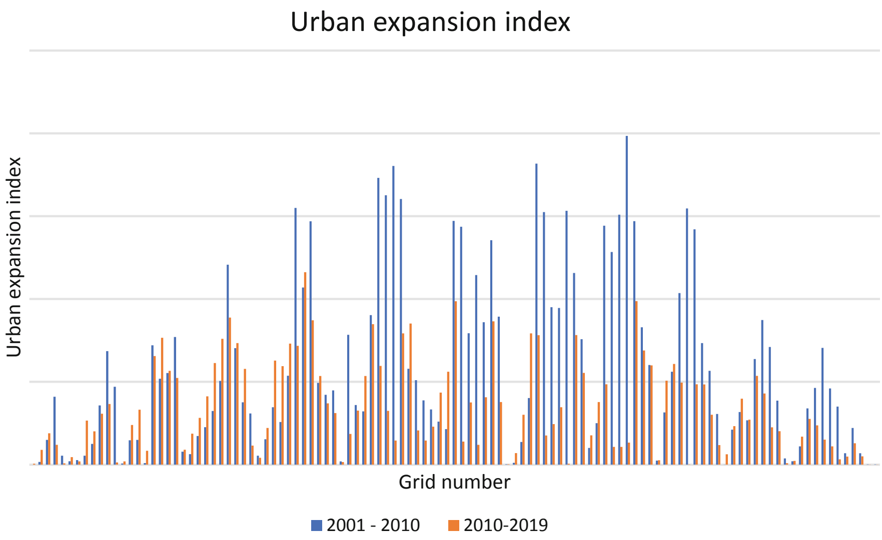


Fig. 8.7 The urban expansion rate for 2001–2010 and 2010–2019

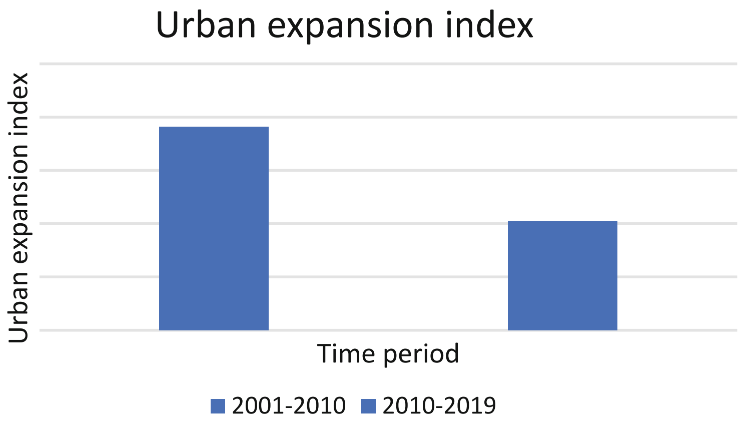


Fig. 8.8 Urban expansion index

Table 8.2 Urban expansion index

Different period	Extension area in km^2	Annual expansion area (km^2/year)	Urbanisation expansion index
2001–2010	334.61	33.461	1.526130904
2010–2019	180.44	18.044	0.822973194

Fig. 8.7. For the same considered grids, the urban expansion index is calculated and plotted as shown in Fig. 8.8. The overall urban expansion index is then calculated as shown in Table 8.2.

The rapid expansion of urban area has taken place from the year 2001 to 2010 as compared to 2010 to 2019. The reason for the sudden development of the city may be due to the development in IT sectors, transportation, job opportunities or resources.

8.4.4 GBR, BBA Ratios and ISA

The blue to built-up area and green-to-blue ratio area are calculated for each grid and then interpolated using IDW technique as shown in Fig. 8.9.

The blue to built-up areas have constantly decreased from 2000 to 2019. The change in pattern of blue to built-up areas shows that the built-up have increased drastically over the period of 2001 to 2019. The green-to-blue ratio areas have decreased a bit from 2001 to 2010 and then had a large increase from 2010 to 2019. This shows that green areas have decreased from 2000 to 2010 and then increased from 2010 to 2019. The LULC and NDVI analyses justify the trend of green-to-blue ratio areas. The impervious surface area and ecological risk index are calculated for each grid, and interpolation is done using IDW. They are shown in Fig. 8.10a. The overlay of blue to built-up area, green-to-blue ratio and impervious surface area on ecological risk index is shown in Fig. 8.10b, c.

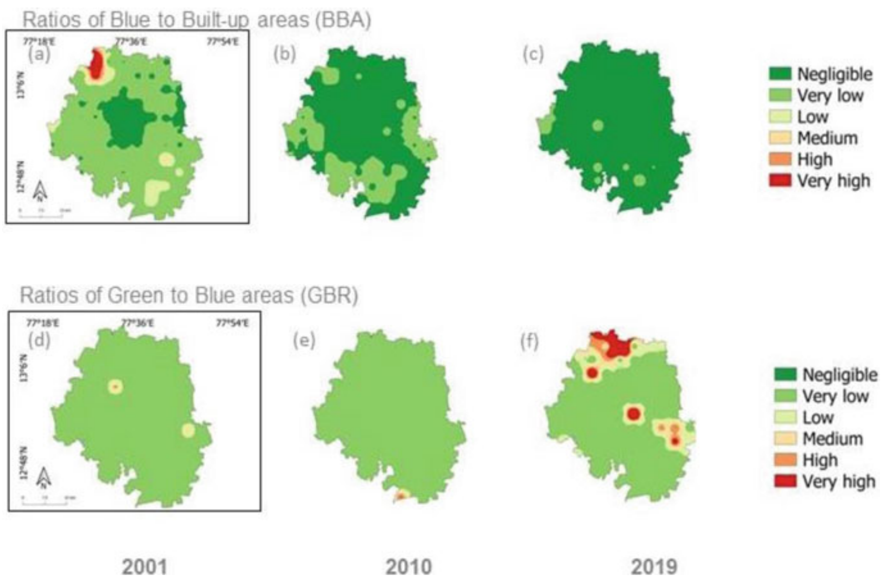


Fig. 8.9 1 Ratios of blue to built-up area (BBA) ratios for the years (**a**) 2001, (**b**) 2010, (**c**) 2019 and, green-to-blue ratio areas (GBR) for Bengaluru during (**d**) 2001, (**e**) 2010 and (**f**) 2019

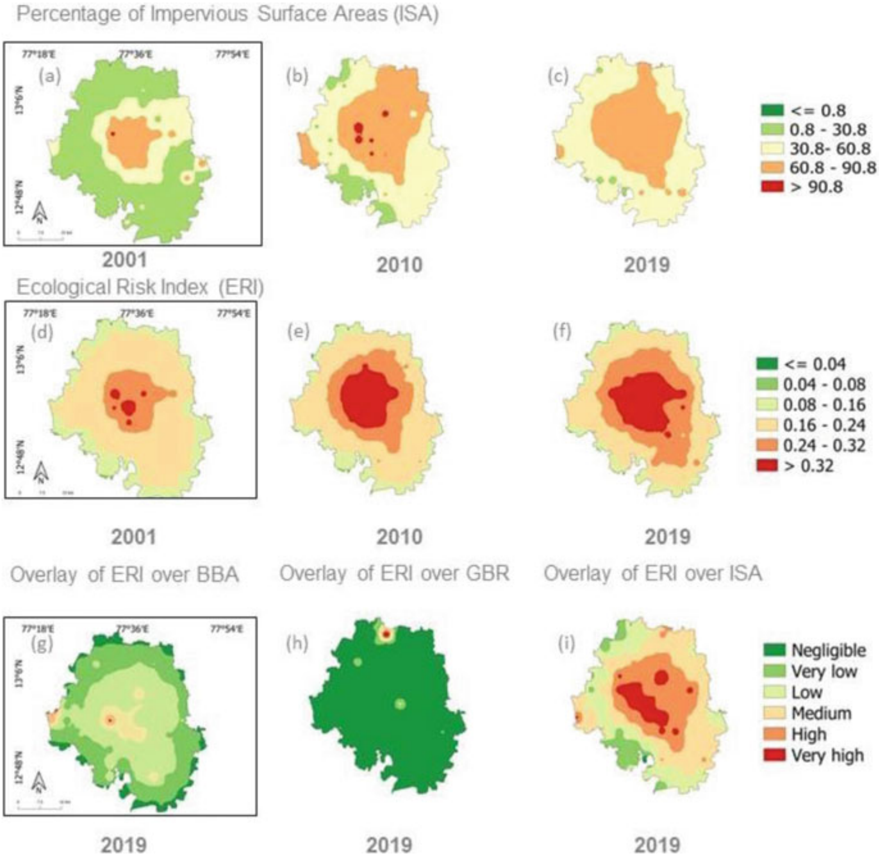


Fig. 8.10 Impervious Surface Areas (ISA) for the years (**a**) 2001, (**b**) 2010, (**c**) 2019 and, Ecological Risk Index (ERI) for Bengaluru during (**d**) 2001, (**e**) 2010 and (**f**) 2019. Overlay analyses are represented as (**g**) ERI over BBA, (**h**) ERI over GBR and (**i**) ERI over ISA

The percentage impervious surface area has increased from the core of the city towards the periphery over the period of 2001 to 2019. The dominating impervious areas represent the urban built-up. The ecological risk index is shown in the part of urban area, and it has increased as the urban area expansion has taken place. The overlay of blue to built-up area on ecological risk index for the year 2019 shows very high and high value in the core representing the built-up area with high ecological risk involved. The overlay of green-to-blue ratio on ecological risk index for the year 2019 shows negligible to very low value. This means that in high ecological risk area, the value of green-to-blue ratio area is less which implies that the green cover is very low in that area. The overlay of impervious surface area on ecological risk index for the year 2019 shows very high to high value in the core. It can be inferred that the core of the city which has high ecological risk index will have high impervious surface area due to built-up.

8.4.5 Air Quality Index and Its Parameters

Highest emission of nitrogen dioxide is observed in and around areas of Peenya and Peenya Industrial Area which are around 28 μg/m^3, while the spread is observed quite lower in ITPL, Silk Board and Domlur regions (Fig. 8.11). Lowest values are observed over central part of Bengaluru region over surroundings of KR Circle, KR Market and Banaswadi areas where values range between 22 and 24 μg/m^3. The concentrations of particulate matter less than 2.5 micrometre ($PM_{2.5}$) show highest concentration in Silk Board region which is more than 38 μg/m^3. Concentration levels are reasonably low compared to concentration levels in Silk Board in area like Peenya, Peenya Industrial area, ITPL and Yeshwanthpur regions. Values are relatively lower in central regions like Khaji Sonnenahalli, KR Circle, KR Market, AMCO Batteries and some parts of Yelahanka with concentration levels around 27 μg/m^3 (Fig. 8.11).

Particulate matter having size less than 10 micrometre and more than 2.5 micrometre (PM_{10}) exhibit indistinguishable spatial patterns as $PM_{2.5}$ except areas like Yelahanka. The overall Air Quality Index (AQI) for Bengaluru urban region shows highest accumulation in areas like White Field, Silk Board, Peenya Industrial Region and Yelahanka. This is largely due to higher level of emission from vehicles as well as emission from industries. The value of AQI ranges from 61 to 92 which is almost near to National Ambient Air Quality Standards (Fig. 8.12).

Overlay analysis of NO_2 and PM_{10} over Air Quality Index exhibits similar pattern showing higher values around Peenya, Peenya Industrial Area, Silk Board and Yelahanka and lower values in central region, while the only difference of $PM_{2.5}$

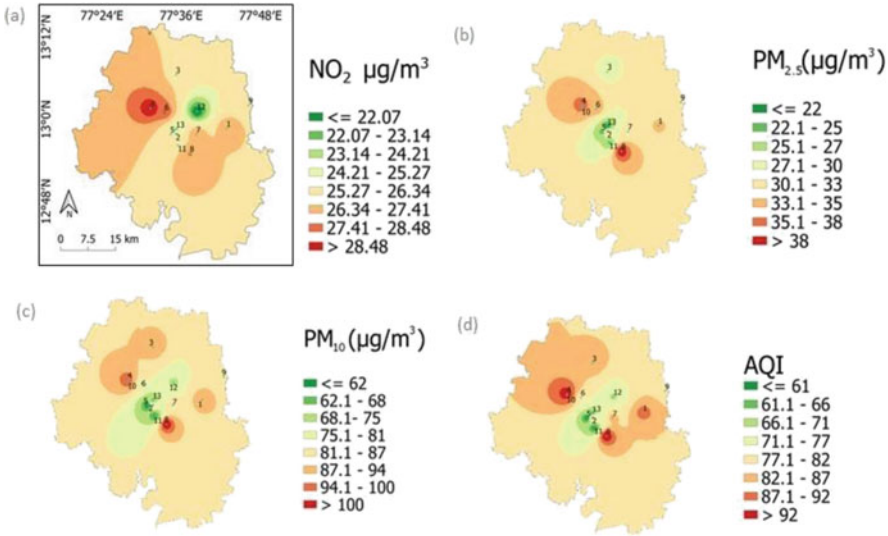


Fig. 8.11 Spatial distribution of air pollutants nitrogen dioxide and particulate matter as well as Air Quality Index (AQI) for Bengaluru city in 2019

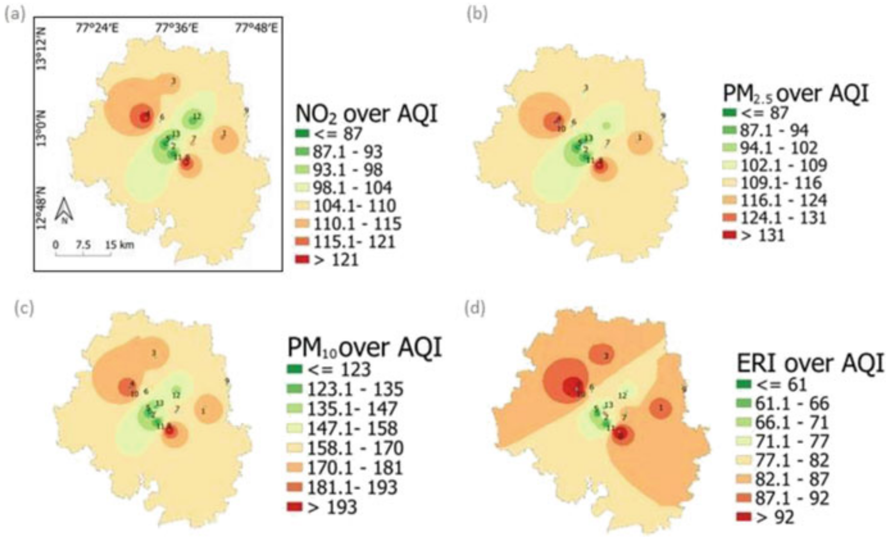


Fig. 8.12 Overlay analyses of air pollutants over Air Quality Index (AQI) to determine their relative contributions to the overall AQI for Bengaluru city, illustrating the overlay of (**a**) NO_2 over AQI, (**b**) $PM_{2.5}$ over AQI, (**c**) PM_{10} over AQI and (**d**) ERI over AQI

over AQI is that the values are lower around Yelahanka. Ecological risk index over AQI shows higher values in north-west and south-east region of Bengaluru, while it shows lower values in central regions of the city.

8.4.6 Derivation of NbS Scenarios Based on the AQI, ERI, BBA, GBR and ISA (Under Preparation)

The results of the NbS analyses are shown in Fig. 8.13. It has emerged from the study that the combination of the indices causing major decrease in score is associated with very low values of GBR and ISA suggesting that the presence of very less impervious surface area influenced the increase in the ERI observed here. Hence, the appropriate NbS options would be the increase in the GBR which corresponds to an increase in the green and blue areas in the respective area corresponding to this scenario (e.g. Dhyani et al. 2021). Further, a combination of high and medium AQI with high ISA caused major increase in score, suggesting that both high AQI and high ISA caused a high ERI. The combined increase in air pollution indicated by high AQI as well as the increase in the impervious surface had increased the ecological risks associated with the combined influences on the environmental quality, possibly due to longer resuspension of the particulate matter in the air in selected regions of the city. The appropriate NbS for dealing with the above scenario should hence be targeted towards both a decrease in the AQI and the ISA. Although the increasing presence of the green areas seem more effective, other NbS measures

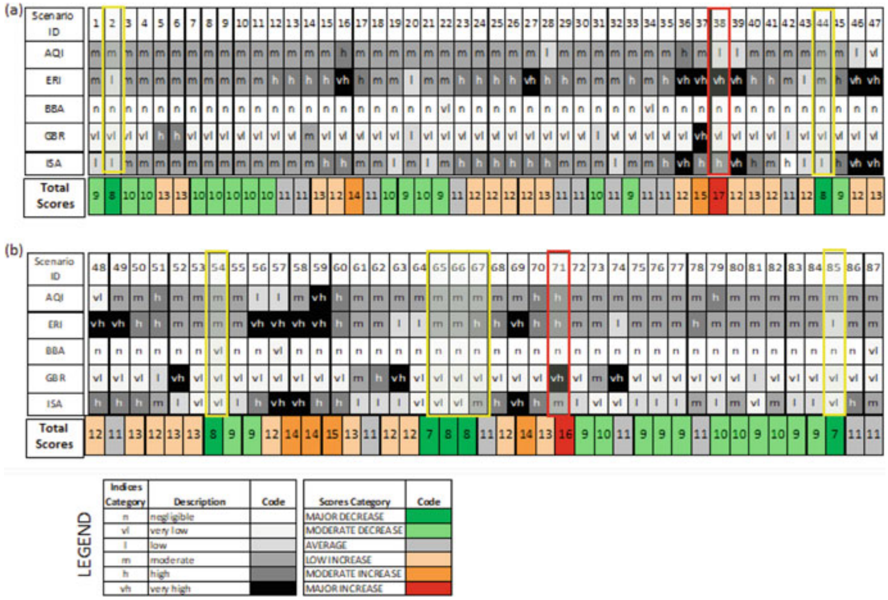


Fig. 8.13 Various NbS scenarios evolved with respect to AQI (Air Quality Index), ERI (ecological risk index), GBR (green-to-blue ratio), BBA (blue built-up ratio) and ISA (percentage impervious surface area) for Bengaluru city with the corresponding legends

such as particulate settlement strategies (considering the local scale meteorology) as well as the prevention of overland flooding by using permeable pavement networks (e.g. Santhanam and Majumdar 2020) seem effective. Designing planting configuration in urban areas can be more practical than selection of tree species (following air pollution tolerance index or APTI) for attenuation of the ambient PM concentrations (Chen et al. 2016). Hence it is observed that two different scenarios of NbS have emerged from the present investigation, which requires the mainstreaming of unique NbS strategies. It is interesting to note that major decrease and increase of ERI scores were observed only in selected areas of the city where there may be the new construction of built-up area could have overlain the water bodies previously located at the same place as observed using the LULC. It is observed that a moderate decrease in score is mostly related to the low to moderate ISA, while high to very high ISA and moderate to very high AQI caused a moderate increase in the score.

Further activity-based assessments of the existing scenarios revealed interesting results detailed as follows. As evident from the observations detailed above, the combined effects of ISA and AQI are found to be critical in increasing or decreasing the overall scores for Bengaluru city. For example, the NbS scenarios corresponding to numbers 37 and 71 (Fig. 8.13) illustrate a major increase in scores due to the high AQI and high ISA, respectively. Therefore, it can be said that the grids (representing the respective wards) associated with 37 are highly impacted by the increase in the

AQI indicating higher incidence of air pollution. On the other hand, grids corresponding to scenario 71 are associated with few pervious areas and/or disappearance of water bodies due to the increase in the built-up areas here. Similarly, the present study illustrated major decreases in the overall scores for scenarios 2, 43, 53, 64, 65, 66 and 85 mainly attributed to the presence of very low ISA in the respective grids.

The present analyses also showed that the combination of low ISA (i.e. low built-up area) as well as presence of more blue regions, i.e. water bodies, lakes, etc., can be used as effective land cover planning strategies only in few areas within the Bangalore city due to the limitations in space as well as the absence of conducive geomorphology for creation of moderately sized basins as unique NbS options. It is interesting to note that the scale of the decrease or increase in the overall scores (high to moderate or low) could be an important factor to be considered for the duration of selection of the appropriate NbS strategies for lowering the respective ERI. For example, NbS such as creation of street tree networks can be achieved on short-term planning basis for areas where the overall scores are low to moderate. The areas having less space for plantation of trees in the city should focus on having mandatory installation of more vertical green walls (like flyover and metro pillars), green roofs (offices and industrial setups) and green buildings (well ventilated, with indoor vegetation) to reduce air pollution, heat island effects and less energy-intensive future city plan. Whereas, to reduce the risks associated with flash floods, polluted lakes and wetlands in the city NbS is growing choice for mainstreaming can be bioswales, biopores, constructed wetlands and sponge gardens by involving citizen based efforts and initiatives (For details please refer Chap. 1). NbS implementation framework by Albert et al. (2020) will be relevant to be referred for urban area-specific planning that clearly works on three important criteria that follow six planning steps, viz. co-defining the urban context and settings, understanding the specific local challenges, developing better planning for better future scenarios, evaluating the potential impacts of NbS that are to be implemented, development of NbS strategies and implementation following active monitoring of NbS. However, it is also important to mention here that the strongest barriers are in the form of political, institutional and knowledge-related barriers crucial for NbS mainstreaming hence, urban planners should prioritize NbS for managing their actions (Sarabi et al., 2020). It is pertinent that NbS should not be having isolated discussions within scientific communities and experts; it should be further introduced, and capacity building should happen for urban planners, bureaucrats, politicians, civil engineers and architects. To understand the severity of the urban risks and hazards in the warming world for Bangalore as also comprehensively elaborated in the results of NDVI, concretisation of the city, LULC changes and increasing air pollution especially PM, there is a need for proactive planning to ensure which ward requires specific blue-green infrastructure as an important NbS to address the place-specific context with active community participation (Fig. 8.13).

The costs associated with such NbS is also quite less, requiring low investment and maintenance. Still, there is dearth of sufficient economical support available for the implementation of NbS in urban areas. To provide sufficient funding support to realise implementation of diverse place-specific NbS convergence of policies, public-private partnership mode (PPP) and inner municipal cooperation, creating financial incentives for communities can help achieve the targets for mainstreaming NbS (Droste et al. 2017). However, the long-term effects of such NbS strategy may not be immediately evident. On the other hand, NbS such as creation and/or maintenance of lake-beds or blue spaces may require to be implemented across high to moderate spatio-temporal scales, involve huge investments and sustained community participation as well as stewardship. It is also important to consider and understand that with exponential rise in population and increasing influx to urban areas, every year more cities are expanding and becoming tier II and tier I cities. This is especially true for India where every census in decade adds more small towns graduating to tier III and tier III to tier I cities, while there is less scope for integrating NbS and BGI in fully expanded tier I cities in India because of the over concretisation, infrastructure build-up and shortage of space. Still NbS that cover less space and can give larger benefits should be integrated in urban planning along with proactive restoration of degraded green and blue spaces. The study provides some significant research-based evidence to support efficient NbS planning and implementation in Bangalore. However, there is still a lot of scope for the effective use of NbS in the design of urban infrastructures of small towns, tier II and tier III cities that are expanding where restrictions to control air and water pollution should be applied. Efforts should also undertaken to make them disaster proof, resilient and sustainable by enforcing NbS as a mandatory compliance followed by regulated expansion.

8.5 Conclusions

The present investigation thus provides a suitable quantification of the effects of the LULC, air quality statuses and the prevalence of ecological risks at high spatio-temporal resolutions at a city level, associated with different areas of a city as Bengaluru. The ecological risks can be attributed to the following:

1. The increase in the built-up regions of the different portions of the city causes the high incidence of increase in the ecological risks as indicated by the increase in the values of the indices.
2. The rise in air pollution proves be the co-factor enhancing the ecological risks for the city of Bengaluru.
3. Simulation of various NbS scenarios reflects that the decrease in the built-up to green area, as well as the AQI, corresponding to an increase in the GBR can provide optimal scenarios for reduction of the overall ecological risks across all the wards of Bengaluru city.

The study further provides the scope to select the appropriate NbS options for implementation based on the availability of monetary and labour investments, public participatory approaches as well as planning on varied spatio-temporal scales. The

NbS scenarios associated with major decrease in score can be investigated to derive appropriate city-level plans/framework for effective mainstreaming of NbS and to meet the targets of SDG 11.

Acknowledgement The first (VS) and second (KH) authors acknowledge the use of the open-source geospatial data sources accessed from the Karnataka State Remote Sensing Applications Centre, Bengaluru, from which data was partially used for the present work. The ecological risk analyses and the air quality analyses reported herein had been presented in part in their (VS and KH) respective M.Tech (Geoinformatics) theses on the applications of remote sensing and GIS. VS and KH acknowledge the Project Assistantship and SKK acknowledges the PhD Fellowship provided by the Ministry of Earth Sciences (MoES), Government of India, vide Grant No. MoES/16/15/11-RDEAS (NIAS) awarded to the National Institute of Advanced Studies, Bengaluru, Karnataka. SKK is grateful for the use of geostatistical analyses in QGIS for deriving ward-wise NbS scores. HS acknowledges the use of Turnitin software for plagiarism checking at NIAS Bengaluru.

Conflict of Interest Statement The authors report no conflict of interest for this publication.

References

Ahmed B, Kamruzzaman MD, Zhu X, Rahman M, Choi K (2013) Simulating land cover changes and their impacts on land surface temperature in Dhaka, Bangladesh. Remote Sens 5(11): 5969–5998. https://doi.org/10.3390/rs5115969

Albert C, Brillinger M, Guerrero P, Gottwald S, Henze J, Schmidt S, Ott E, Schröter B (2021) Planning nature-based solutions: principles, steps, and insights. Ambio 50(8):1446–1461

Albert C, Fürst C, Ring I, Sandström C (2020) Research note: spatial planning in Europe and Central Asia–Enhancing the consideration of biodiversity and ecosystem services. Landsc Urban Plan 196:103741

Balica SF, Douben N, Wright NG (2009) Flood vulnerability indices at varying spatial scales. Water Sci Technol 60(10):2571–2580. https://doi.org/10.2166/wst.2009.183

Bush J, Doyon A (2019) Building urban resilience with nature-based solutions: how can urban planning contribute? Cities 95:102483

Chen H, Burnett RT, Copes R, Kwong JC, Villeneuve PJ, Goldberg MS, Brook RD, Van Donkelaar A, Jerrett M, Martin RV, Brook JR (2016) Ambient fine particulate matter and mortality among survivors of myocardial infarction: population-based cohort study. Environ Health Perspect 124 (9):1421–1428

Chinnaswamy AK, Galvez MCD, Balisane H, Nguyen QT, Naguib RN, Trodd N, Marshall IM, Yaacob N, Santos GNC, Vallar EA, Shaker M (2016) Air pollution in Bangalore, India: an eight-year trend analysis. Int J Environ Technol Manag 19(3–4):177–197. https://doi.org/10.1504/IJETM.2016.10003102

Cohen-Shacham E, Andrade A, Dalton J, Dudley N, Jones M, Kumar C, Maginnis S, Maynard S, Nelson CR, Renaud FG, Welling R (2019) Core principles for successfully implementing and upscaling nature-based solutions. Environ Sci Pol 98:20–29

Corburn J (2004) Confronting the challenges in reconnecting urban planning and public health. Am J Public Health 94(4):541–546. https://doi.org/10.2105/ajph.94.4.541

Croeser T, Garrard GE, Thomas FM, Tran TD, Mell I, Clement S, Sánchez R, Bekessy S (2021) Diagnosing delivery capabilities on a large international nature-based solutions project. Urban Sustainability 1(1):1–9

De US, Singh GP, Rase DM (2013) Urban flooding in recent decades in four mega cities of India. J Indian Geophys Union 17(2):153–165

Deng F, Yu YJ, Quan ZZ (2011) Research progresses of regional ecological risk assessment. Environ Sci Technol 34(6G):141–147

Dhyani S, Karki M, Gupta AK (2020) Opportunities and advances to mainstream nature-based solutions in disaster risk management and climate strategy. In: Nature-based solutions for resilient ecosystems and societies. Springer, Singapore, pp 1–26

Dhyani S, Lahoti S, Khare S, Pujari P, Verma P (2018) Ecosystem based Disaster Risk Reduction approaches (EbDRR) as a prerequisite for inclusive urban transformation of Nagpur City, India. International journal of disaster risk reduction 32:95–105

Dhyani S, Maikhuri RK, Dhyani D (2019) Impact of anthropogenic interferences on species composition, regeneration and stand quality in moist temperate forests of Central Himalaya. Trop Ecol 60(4):539–551

Dhyani S, Majumdar R, Santhanam H (2021) Scaling-up nature-based solutions for mainstreaming resilience in Indian cities. In: Mukherjee M, Shaw R (eds) Ecosystem-based disaster and climate resilience, Disaster and risk research: GADRI book series. Springer, Singapore. https://doi.org/10.1007/978-981-16-4815-1_12

Droste N, Schröter-Schlaack C, Hansjürgens B, Zimmermann H (2017) Implementing nature-based solutions in urban areas: financing and governance aspects. In nature-based solutions to climate change adaptation in urban areas. Springer, Cham, pp 307–321

Frantzeskaki N (2019) Seven lessons for planning nature-based solutions in cities. Environ Sci Pol 93:101–111

Ibrahim MA (2020) Risk of spontaneous and anthropogenic fires in waste management chain and hazards of secondary fires. Resour Conserv Recycl 159:104852. https://doi.org/10.1016/j.resconrec.2020.104852

Jax K (2006) Ecological units: definitions and application. Q Rev Biol 81(3):237–258. https://doi.org/10.1086/506237

Jha, A.K., Bloch, R. and Lamond, J., 2012. Cities and flooding: a guide to integrated urban flood risk management for the 21st century. World Bank Publications.

Oral HV, Carvalho P, Gajewska M, Ursino N, Masi F, Hullebusch EDV, Kazak JK, Exposito A, Cipolletta G, Andersen TR, Finger DC (2020) A review of nature-based solutions for urban water management in European circular cities: a critical assessment based on case studies and literature. Blue-Green Systems 2(1):112–136

Patra S, Sahoo S, Mishra P, Mahapatra SC (2018) Impacts of urbanization on land use/cover changes and its probable implications on local climate and groundwater level. J Urban Manag 7(2):70–84. https://doi.org/10.1016/j.jum.2018.04.006

Pickett STA, Kolasa J, Armesto JJ, Collins SL (1989) The ecological concept of disturbance and its expression at various hierarchical levels. Oikos 54:129–136. https://doi.org/10.2307/3565258

Power M, McCarty LS (2002) Trends in the development of ecological risk assessment and management frameworks. Hum Ecol Risk Assess 8(1):7–18. https://doi.org/10.1080/20028091056683

Santhanam H, Majumdar R (2020) Permeable pavements as sustainable nature-based solutions for the management of Urban Lake Ecosystems. In: Dhyani S, Gupta A, Karki M (eds) Nature-based solutions for resilient ecosystems and societies, Disaster Resilience and Green Growth. Springer, Singapore. https://doi.org/10.1007/978-981-15-4712-6_19

Sarabi S, Han Q, Romme AGL, de Vries B, Valkenburg R, den Ouden E (2020) Uptake and implementation of nature-based solutions: an analysis of barriers using interpretive structural modeling. J Environ Manag 270:110749

Seddon N, Smith A, Smith P, Key I, Chausson A, Girardin C, House J, Srivastava S, Turner B (2021) Getting the message right on nature-based solutions to climate change. Glob Chang Biol 27(8):1518–1546

Swartjes FA, Breure AM, Beaulieu M (2011) Introduction to ecological risk assessment. In dealing with contaminated sites. Springer, Dordrecht, pp 573–624

Tang L, Wang L, Li Q, Zhao J (2018) A framework designation for the assessment of urban ecological risks. Int J Sustain Dev World Ecol 25(5):387–395. https://doi.org/10.1080/13504509.2018.1434570

The Times of India Report (2020, January 30) Bengaluru has world's worst traffic congestion, Mumbai at number 4. https://timesofindia.indiatimes.com/india/bengaluru-has-worlds-worst-traffic-congestion-mumbai-at-number-4/articleshow/73747725.cms

Verma S, Chatterjee A, Mandal NR (2017) Analysing urban sprawl and shifting of urban growth Centre of Bengaluru City, India using Shannon's entropy method. J Settlements Spatial Planning 8(2):89–98. https://doi.org/10.24193/JSSP.2017.2.02

Villa M, Ceballos RF (2021) Analysis and forecasting of fire incidence in Davao City. Recoletos Multidiscip Res J 8(2):35–50. https://arxiv.org/ftp/arxiv/papers/2101/2101.00356.pdf

Wu XQ, Hong SQ, Wu XC, Cai SQ (2004) The principle, way and technique of environmental policy risk assessment-also discussing the policy environment risk assessment. Safe Environ Eng 11(3):34–36

Zhao J, Xiao H, Wu G (2000) Comparison analysis on physical and value assessment methods for ecosystems services. J Appl Ecol 11(2):290–292. PMID: 11767617

Zhou D, Shi P, Wu X, Ma J, Yu J (2014) Effects of urbanization expansion on landscape pattern and region ecological risk in Chinese coastal city: a case study of Yantai city. Sci World J:821781. https://doi.org/10.1155/2014/821781

S. Varshini is a Project Assistant at the National Institute of Advanced Studies (NIAS), Bengaluru, India.

Kiran Hungund is a Project Assistant working with the National Institute of Advanced Studies (NIAS), Bengaluru, India.

Sudip Kumar Kundu is a doctoral student with the National Institute of Advanced Studies (NIAS), Bengaluru, India.

Harini Santhanam is an environmental scientist working as an Assistant Professor with the School of Natural Sciences and Engineering at the National Institute of Advanced Studies (NIAS), Bengaluru, India.

Shalini Dhyani is a Senior Scientist at Critical Zone Group (CZO) of Water Technology and Management Division (WT&MD), CSIR-National Environmental Engineering Research Institute (CSIR-NEERI), Nagpur, India.

9 Do People Appreciate Economic Value of Water in Baku City of Azerbaijan?

Pasquale Lucio Scandizzo and Rovshan Abbasov

Abstract

The increase in demand in potable water, in response to the growing population, assumes great significance in the context of Azerbaijan due to its implications for economic growth, productivity, and poverty reduction. Efficient and equitable management of water, wastewater, and stormwater for the big cities is becoming an increasingly complex task. Increasing shortages of water and pollution issues in and around urban centers are superimposed on issues such as continuing urbanization, inadequate management capacities, poor governance, and inadequate legal and regulatory regimes, posing a daunting task for the future.

This study aimed to develop the quantitative basis for a comprehensive analysis and evaluation of water use and non-use values in the Great Baku Area of Azerbaijan, with a vision of integrated water management, including potable water and wastewater treatment. Water distribution system, with its leakages, patches, and breaks, gradually worsens the quality of the water causing it to fall well below the standards. Low service quality and reliability have also driven consumers to resort to various coping strategies such as use of overhead storage tanks, household filters, pumps, boiling of water, and consumption of bottled water, at considerable financial cost.

The Contingent Valuation (CV) methodology is used to estimate willingness to pay (WTP) of Baku residents for improved water services in the context of integrated demand. Results suggest that Baku residents behave as rational

P. L. Scandizzo
Center for Economic and International Studies, Tor Vergata University of Rome, Rome, Italy

R. Abbasov (✉)
Department of Geography and Environment, Khazar University, Baku, Azerbaijan
e-mail: rabbasov@khazar.org

S. Dhyani et al. (eds.), *Blue-Green Infrastructure Across Asian Countries*,
https://doi.org/10.1007/978-981-16-7128-9_9

consumers in evaluating water opportunity costs and are ready to pay for better water services.

Keywords

Willingness to pay · Water services · Water shortages · Water values · Bidding game · Drinking water

9.1 Introduction

The challenge of ensuring efficient and proper water, wastewater, and stormwater management in large cities is becoming increasingly difficult. Water scarcity and pollution problems are becoming more prevalent in and around urban areas, compounded by issues such as continued urbanization, insufficient management capacities, weak governance, and ineffective legal and regulatory frameworks, posing a daunting challenge for the future (Phu Le 2004).

The increase in demand for drinking water is of great importance in the context of population growth, economic growth, and poverty reduction. The country's limited water resources, scarce water resources, weak natural water supply, and uneven distribution across the country require a quicker solution to these problems (Abbasov and Smakhtin 2012). The water resources of Azerbaijan are not abundant, and they are unevenly distributed both seasonally and geographically (Abbasov and Smakhtin 2010).

Located on the Absheron Peninsula and on the shores of the Caspian Sea, Baku is both the capital and the largest city in the country. Most of the country's industry is connected with Baku. For this reason, a significant part of the Azerbaijani population lives in Baku and the nearby city of Sumgait. Together with Sumgait and the other towns of the Absheron Peninsula, Baku is the central city of the main urban area in Azerbaijan, named the Greater Baku Area (GBA).

GBA population at the early 2019 was estimated at over three million and 65,000 people. Following the disintegration of the Soviet Union, the rural areas of Azerbaijan have been suffering from considerably high unemployment rates, and many people have migrated to the Baku and Sumgait areas in search of jobs and opportunities. In 1993 Baku accommodated 153,400 internally displaced persons and 93,400 refugees. Current (unofficial) estimates indicate that the Greater Baku area has more than three million people, or about 30% of all inhabitants of Azerbaijan (Mammadzadeh 2020).

Several estimates agree on a normal water use in GBA of 400 L per capita per day. While the latest surveys show that real consumption was never more than 170 L/day, the apparently high individual water use rate is the result of several influences, mostly related to the bad condition of the water distribution networks, of home water devices, as well as to the absence of metering (Mammadzadeh 2020).

Despite the high rates of consumption, in most parts of GBA, water supply is not available for 24 h 7 days a week (Fig. 9.1). In most cases, duration of water services

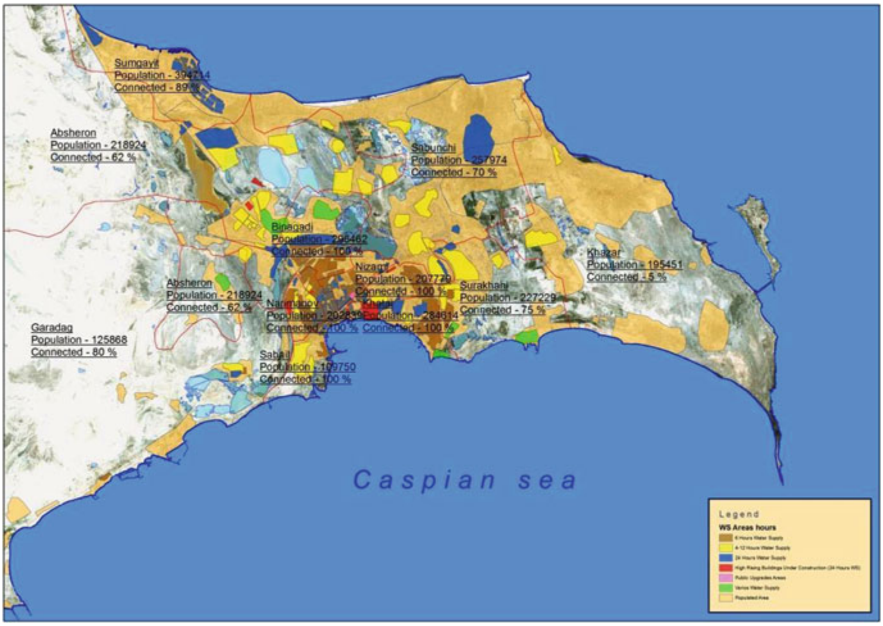


Fig. 9.1 Length of the water services in Greater Baku Area (2017)

has been less than 4 h a day, with most households suffering from low-quality, unreliable water services.

Lacking reliability and safety of water services in GBA are the main causes of the still not satisfactory quality of the water. The old water distribution system, with its leakages, patches, and breaks, gradually worsens the quality of the water causing it to fall well below standards. Reliability is affected by service interruptions and low pressure. The low level of the water quality is also associated to bad color, taste, odor, and chemical/bacteriological contamination.

An additional problem of water supply is the considerable urbanization of the Absheron Peninsula. The problem is not only the rise in number of the Baku population but also the constant inflow of population from the villages and the refugee migration to the GBA area. Various types of small and big houses built by refugees and other migrating population have turned the Baku suburban area into a huge illegal region of shanty towns. None of these shanty towns has been equipped with planning water supply networks, but only after construction, in order to meet daily needs, illegal pipe networks have been laid out and connected to the main pipelines. These illegal pipes are usually shared by three or four and sometimes five or more neighboring houses, which are typically made from low-quality materials and may be easily broken or damaged. These circumstances cause huge amounts of water losses during service hours. In these illegal residential areas, city water is supplied for only few hours each day on a rotating schedule that is incompatible with sanitary requirements. Crossing lines of wastewater and water supply networks make the situation especially risky for public health. Serious health concerns have been raised by the increasing stress on the water supply and the growing pollution problems.

Uneven distribution of the network has been an additional problem of the water supply. Most of the highly urbanized areas are relatively better supplied by the distribution network, while some of the agricultural sub-regions and remote towns are not connected to the network and are supplied only by local groundwater resources.

The other most important problem of the water management in the region relates to the urban wastewater management and the degradation of ground and surface water quality from illegal urbanization, chemicals associated with the oil industry, and fertilizers and pesticides from agriculture. Oil and gas production has polluted large areas of the Absheron Peninsula, including the heavily populated sub-regions. Leaking sewage pipelines have further degraded the water quality in the superficial aquifer, while agricultural production has contributed to nitrate and pesticide pollution. Water supply contamination is aggravated by spills from chemical plants and aerial deposition of pollutants from the highly industrialized areas of Baku and Sumgait as in the rather common cases were oil fragrant water comes directly to households. As a consequence of all these factors, evidence of water contamination is frequently observed throughout the water distribution network, and most of the population is supplied with drinking water that does not meet generally accepted standards.

In GBA, the wastewater network serves roughly 80% of the total households, but only about half of the wastewater is cleaned. The state of wastewater treatment plants is generally deplorable. The key causes are a lack of maintenance for more than a decade, excessive flows due to leaks and infiltration, and a poor quality of construction and materials. Discharges of inadequately treated polluted industrial wastewater into municipal drain systems weaken the effectiveness of the wastewater treatment plants. In some places, the wastewater systems have been constructed by residents but are not adequate to standards and are sources of permanent leakages. These leakages in most cases occur in places, where the water distribution network is located. These circumstances cause mixing of potable waters with sewage waters.

These issues are tackled by the Integrated Urban Water Management (IUWM) strategy, which views water supply as a portion of a larger and more comprehensive problem of strategic urban planning, in which the city serves as a catchment area for water from a variety of sources and uses, including drinking, washing, wastewater disposal, recreational uses of water sources and waterways, recycling, and a variety of other activities (Green and Srinivasan 1978; Srinivasan 1988; Ehrlich and Becker 1972).

Low service quality and reliability have driven consumers to resort to various coping strategies such as use of overhead storage tanks, household filters, pumps, boiling of water, and consumption of bottled water, at considerable financial cost. Inadequate demand side management of available water supply remains an issue in most urban areas.

This research aims to provide a quantitative foundation for a systematic overview of water usage and non-use values in the GBA, with the goal of achieving sustainable water management at the basin level, which includes potable water, wastewater storage, and stormwater.

The study also aims to the more ambitious goal of taking into account that rational choices from water users are performed in the context of dynamic uncertainty, thereby using option values as one the main frameworks of formulation and interpretation of the questions asked. In accordance with the bulk of the literature, the option value is interpreted as something akin to a risk premium arising from a combination of the individual's uncertainty about his future demand for a natural resource or its services and uncertainty about their future availability (Carson and Mitchell 1993). This kind of uncertainty concerns the potential future value of the quantity and quality of the water if it were preserved in the present form or were improved through various means and policies. More generally, it is suggested that option value is the hypothetical risk premium arising from the difference between the expected value of water at a future date and its certainty equivalent, i.e., the object of the usual WTP elicitation at the time of estimation (Trigeorgis 1996; Wilson et al. 2020; Otsetsewe 2001). This suggests that, by asking the respondents to elaborate on their preferences under uncertainty, the survey may be able to obtain a richer set of estimates, where controls for consistency will be more demanding and, if successful, more convincing (Wang et al. 2010; Pearce 1993; Mark 2000).

9.2 Materials and Methods

In order to address these issues within an appropriate economic framework, an approach to water evaluation has been developed that comprises of three complementary methodologies: cost avoidance measurements, hedonic analysis, and contingent evaluation. These three techniques are utilized to measure both use and non-use values (Hausman et al. 1993; Sen 1984; Bueno et al. 2016) from the stakeholders' point of view.

The study is based on a field survey with the main purpose to investigate the most important aspects of water consumption, perception of water quality, health and hygiene, productivity, and value. The survey itself was conducted by asking a sample of GBA residents a series of questions built on the hypothesis that water consumption in its various forms is the consequence of a rational choice (Shaikh et al. 2007). In this sense, the objectives of the survey were as follows:

- To reveal how citizens of GBA cope with the issue of insufficient water supply by implementing a number of strategies to improve the quantity and efficiency of water consumed, from direct purchase and storage of water to various strategies for improving its quality, such as boiling, filtering, purifying it, etc.
- To investigate the importance of water availability, wastewater treatment, and quality of services in determining decisions for choosing one's residence and, as a consequence, as determinants of housing values.

The target groups of the study were the GBA population, and for this purpose the GBA population was divided into several categories, according to the rights and interests held by each group:

1. People who live or work in the Baku city: given the geographic location of the city and its relation with the other areas of GBA, any change affecting water services, or the waterfront, could impact the everyday life of these users.
2. Other GBA citizens: they are the holders of significant interests linked mostly with the public good function of water and water services, and they may be more likely to face a change in their everyday life as a consequence of major improvements in water supply.
3. Visitors/tourists: they represent potential users of both water services and the waterfront.

The questionnaire was composed of closed questions, in order to facilitate the task of the interviewers and because of time constraints. Closed questions tend, in fact, to be quicker to administer and easier to analyze, even though they tend to have also drawbacks (McFadden 1978; Freeman 1979; McFadden 1999; Train and McFadden 1978). The most important drawback is that the respondents cannot raise new issues during the interview, so that relevant and interesting information could be lost (Train 1986, 1998, 2001). To avoid this risk, a question on whether the respondent wanted to add something was included at the end of each questionnaire.

The bulk of the interviews were concentrated on the households connected to the water network, which, according to the official records, comprise 90% of the total population. These households can be classified into four categories, according to the length to the service: 18–24 h, 12–18 h, 4–12 h, and up to 4 h. The last two categories represent the greatest majority of the respondents. The sixth group, represented by the households not still connected to the water network, appears to be a very small proportion of the total. They are mostly dependent either on the provision of a public hydrant or a private tube well. While the average willingness to pay varies somewhat across the different groups, these variations turned out to be not statistically significant.

The following sections were included in the questionnaire:

Socioeconomic data: The sections concerning personal data, education, and income were aimed at framing the answers that the respondent would give in all the other sections of the questionnaire (socioeconomic data are demonstrated to be important drivers of individual preferences and decisions about the consumption and use of public goods). These sections enclose questions concerning age, gender, household status, education level and domain, job, and earnings.

Hedonic prices: This section concerned the location and the quality of the dwelling of the respondent and had the objective to identify characteristics for the hedonic analysis, which may give also the possibility of estimating hedonic prices for water services (Train 1986).

Feelings and knowledge: This section had a special importance for GBA citizens, given their condition of distress and discontent regarding water services. Outlining and understanding the feelings of local community members with respect to the quantity and the quality of water services delivered were also central for framing more specific questions in other sections of the questionnaire and to obtain insights on the value of water from the point of view of the individuals and the community. Answers to the questions of this section can also be used to analyze to what extent and in what forms a communication program would be needed to appropriately implement any rehabilitation plan (Wang et al. 2010).

Possible uses: this section explored the preferences of the respondents with respect to alternative uses of water as a public good (e.g., potable water, irrigation, energy, etc.). A list of facilities and services was presented to the respondent, and she/he was asked to declare whether or not she/he would like to see each of them realized. The objective of these questions was to give the respondents the possibility to combine the uses and services proposed in a way that they would consider suitable for water resources.

WTP: In this section a set of alternatives of quantity/quality of water supply are presented to the respondent, who is asked both to order them on the basis of her preferences and to declare how much she would be willing to pay to see each of them realized, according with a bidding game that progresses gradually across alternative monetary ranges (McFadden 1999). The alternatives represent possible combinations of activities and services that could be implemented inside the area and were chosen to represent different approaches to the rehabilitation of water supply in GBA. In building up the themes, we also chose to stress the social and economic functions of water under the different approaches. Therefore each theme represents a different way to provide and use water. The choices offered to the respondents range from a traditional water supply network to a multifunctional model (water management and waterfront use) fully integrated in the everyday life of GBA citizens. The questions in this segment, when paired with the questions in the previous parts, were designed to see how respondents shape their perceptions about water usage and whether these expectations meet general economic rationality hypotheses (coordination between ends and means, continuity, promotion of individual and communal gains, knowledge of alternative alternatives, sea level rise, etc.).

Feelings and knowledge on climate change: This section had the objective to investigate the level of awareness and the impact of climate changes attitudes on water demand, willingness to pay, and possible changes of behavior of GBA citizens.

9.3 Results and Discussion

9.3.1 Survey Results

The survey lasted approximately 6 weeks. A total of 24 enumerators and 3 tabulators were involved in the process with average number of 90 questionnaires filled by each enumerator. The questionnaires completed were 2155.

Table 9.1 presents some general results of the survey of willingness to pay (WTP) for potable water service. Average WTP (additional to the tariff already paid) for the full service is about 15 AZN. A comparison of survey results with official government data reveals many differences. Official data were provided by the State Statistics Committee.

Respondents showed a high interest in better services, including wastewater, and most of them (70–80%) exhibited enthusiasm and cooperation in participating to the survey process. Women tended to participate more actively than men and more often asked enumerators about the purpose of the survey. Respondents also posed a variety of questions on social problems and future plans of the government. In several cases, nevertheless, for various reasons, respondents declined to be interviewed, because they were either tired or busy.

The duration of the interview was one of the main challenges for enumerators. According to them, the interest on the questions of the respondents tended to wane after the first 30–40 min, with cases when respondents interrupted the interview, because they were "tired." After the pretest of the questionnaire, short breaks

Table 9.1 Comparison of the survey results with official data of government of Azerbaijan

Monthly expenses on (AZN)	Survey averages	Survey modes	Official data
Food	237.6	200	390.656
Clothing	67.4	50	57.988
Housing (rent, repair etc.)	42.7	10	
Transport	112.9	50	68.016
Utilities	54.1	50	61.912
Education	161.2	100	20.928
Health	42.5	20	32.264
Other	129	100	
Number of persons that contribute to household income	1.736419	2	
Yearly savings if any	1299.4	0	1891
Total household income per month	857.77	1000	833
Number of persons living in the household	2.96	4	4.36
No. of adults (>16 years)	2.92	2	2.08
No. of minors (<16 years)	1.43	2	2.38
Education (years)			>12
Value of the house, for 1 sq.m; AZN	1650.4		1350

Table 9.2 Water service characteristics

Water availability	Maximum	Minimum	Average	Variance	Mode	S.D.
Length of the daily water services in hours	24	2	9.2744	47.55	6	6.9
Number of days per week with water service	7	2	6.77	0.52	7	0.72
Number of days with water service during July–September	90	0	85.1845	66.42863	90	8.15
Number of days with water service during December–March	93	0	85.4129	59.72332	90	7.73
Number of days in a year with no water service	250	0	14.2097	702.8351	1	26.51

(5–10 min) were used to keep respondents' interest high. During these breaks, respondents asked additional questions regarding the goals of the survey, and some of them expressed opinions on the social policy of the government.

The responders, who contained water users, were asked if they would agree to a rise in their monthly water bill to help another investment project outcome such as improving water provision, sewage treatment, and the protection of the environment. These projects included investment to secure immediately and with certainty (i) uninterrupted water supply to the users, and/or (ii) full wastewater treatment, and longer term investment with the same aims but on a longer time horizon and with some uncertainty.

Table 9.1 shows a comparison between the survey results and the official statistics, which points to very similar mean values for almost all variables, including the most difficult to measure such as income and savings. However, major discrepancies appear in the statistics on transport and education, where the sample means are much larger than those reported in the government statistics. Table 9.1 shows descriptive statistics for the sample data.

According to the interviews (Table 9.2), water interruption happens in the summer for 512 of the households connected, for 243 households in the winter, and for 1042 households "all the time." The irregularities in water provision, however, appear, paradoxically, very regular, as Table 9.1 shows very little variation (relatively low variances) of all answers to the questions inquiring on the number of days of water service, water availability during the different seasons, and complete lack of service. While most of the households declared that the water service was available seven times a week, however, the average length of water service per day was 9.2 h and the mode only of 6 h. The number of days without any service during the year, on the other hand, was said on average to be 14 days but with a standard deviation of about 27 and a mode of only 1 day. Thus, the picture of potable water service emerging from the survey is not a dismal one, and most households do

Table 9.3 For households with primary source from a public street hydrant

Water availability from public water hydrants	Maximum	Minimum	Average	Variance	Mode	S.D.
Distance from the public street hydrant, m	150	3	21.7742	1076.637	6	32.80
Consumption (L/day)	400	5	116.947	11220.39	100	105.92
Collecting time (min/day)	120	1	35.7059	1533.564	10	39.15
Monthly charges, if any	50	2	14.3636	168.4545	15	12.96
How many hours per day do you receive water from the public street hydrant?	24	1	10.3333	46.47179	7	6.78
How many days per week do you receive water from the public street hydrant?	7	1	6.72308	0.703365	7	0.84
In summer/dry season, how many days per week do you receive water from the public street hydrant?	7	3	6.46	0.824898	7	0.91
In winter/rainy season, how many days per week do you receive water from the public street hydrant?	7	5	6.02273	0.67389	6	0.82

appear to have access to fresh water throughout the year, even though the reliability of such an access is low and appears to be rather variable across the population.

The households using water from a street hydrant (Table 9.3), on their part, with much lower water consumption than the average (116 vs. 400 L per day), show a somewhat less variable picture of availability and continuity of supply, with the same average provision of water in number of days (6.72) of the households connected, but with more continuous service throughout the year. The households receiving water from other sources, such as street vendors and bottled water, manage an average level of consumption near 200 L per day, with similar regularity

Table 9.4 Water quality and waterborne diseases

			1	2	3
Water quality	Taste	1. Good 2. Average 3. Bad	109	1524	347
	Smell	1. Good 2. Average 3. Bad	121	1628	225
	Color	1. Good 2. Average 3. Bad	54	1377	543
Information of responders about the quality of consumed water		1. Yes 2. No	392	1551	
Waterborne diseases occurred in the household during the last year		1. Cholera 2. Typhoid 3. Malaria	4	3	16

Table 9.5 Characteristics of waterborne diseases

Characteristics	Maximum	Minimum	Average	Variance	Mode
Number of persons that were ill in one household due to the consumption of unsafe water	10	1	1.57143	2.920635	1
Duration of sickness, days	90	1	20.3103	591.7217	30
Medical costs (Manat)	1200	2	211.759	61675.98	250

parameters to the public hydrant sources, with a majority stating that the present arrangement is satisfactory.

Tables 9.4 and 9.5 offer a picture of the perception of the quality of the water and its effects. While most respondents consider the quality "average" and the great majority professes of not being informed, a considerable number of not identified illnesses are attributed to the bad quality of the water. Finally, Tables 9.6 and 9.7 show some statistics on water use that reveal a consistent picture of low pressure, poor availability, and widespread practices both to purify the water, mostly through boiling and filtering, and to use privately installed storage capacity to secure more continuous water supply. This last practice, in particular, appears to be costly, both for capital costs (about300 AZN on average) and for maintenance (about 50 AZN per year).

Table 9.8 presents some general results of the survey of WTP for potable water service. Average WTP (additional to the tariff already paid) for the full service is about 15 AZN (Manat), with a standard deviation (S.D.) of about 7 and a mode of only 10 AZN. For a long-term investment with the same results, but only in 10 years' time and with a 20% probability of failure, average WTP is about 9 AZN per month, with a mode of 8 AZN and S.D. of 2.8. This WTP can be interpreted as an option value, i.e., as a risk premium that users would be willing to pay to avoid further

Table 9.6 Characteristics of household water use

		1	2	3	4	5	6
Water pressure	1. Strong 2. Generally strong 3. Weak 4. Sometimes weak 5. Very weak 6. I use own pumping engine to create pressure	631	274	338	204	205	211
House water treatment	1. Boil 2. Filter 3. Precipitate 4. Others	1343	339	106	16		
Type of water collector	1. Overhead tank 2. Underground tank 3. Drum 4. Bucket/vessel	1107	70	213	82		
Preferred payment	1. Fixed charge 2. Metered bill	198	1692				
Water from secondary source, if any	1. Neighbor 2. Public street hydrant	11	331	0	0		

Table 9.7 Characteristics of overhead tank use

	Maximum	Minimum	Average	Variance	Mode	S.D.
Total volume of a water tank	6000	50	1004.48	458.313	500	676.99
Installation cost (Manat)	1200	0	124.543	18136.8	50	134.67
Capital costs (initial purchase costs in AZN)	1380	0	241.281	54409.93	150	233.26
Purchase cost of pump (AZN)	500	0	64.5545	10146.52	20	100.73
Cost of other materials (AZN)	100	5	26.5385	530.9201	5	27.04
Annual maintenance cost (cleanup, energy, etc.)	50	0	23.7895	306.731	10	17.51
How many additional hours per day of water supply will be required to meet all your needs?	24	0	6.54054	13.65525	5	3.70

deterioration of the service. As shown in Table 9.9, the willingness to pay for service improvement extends to wastewater disposal, both in the scenario of immediate action and in the option like scenario of uncertain, time delayed action. WTP for

Table 9.8 Willingness to pay: potable water

Willingness to pay characteristics	1	2	3	4	Maximum	Average	Variance	Mode	S. D.
WTP for 24/7 quantity of water with adequate pressure and high quality (AZN)					60	15.1	52.8	10	7.26
Agreement for general tax increase for 24/7 quantity of water with adequate pressure and high quality instead of paying for bill 1. Yes 2. No	938	1031							
Percentage increases in income taxes instead of paying for bill 1. 5% 2. 10% 3. 20% 4. 40%	703	145	42	20					
WTP for 24/7 quantity of water with adequate pressure and high quality, but only after 10 years with 50% of success and 50% failure (AZN)					16	10			
Agreement for general tax increase for 24/7 quantity of water with adequate pressure and high quality instead of paying for bill but only after 10 years with 50% of success and 50% failure 1. Yes 2. No	428	1359							
Percentage increases in income taxes instead of paying for bill 1. 5% 2. 10% 3. 20% 4. 40%	294	78	17	12					
WTP for 24/7 quantity of water with adequate pressure and high quality, but only after 10 years with 80% of success and 20% failure (AZN)					20	9.12	7.84	8	2.79

(continued)

Table 9.8 (continued)

Willingness to pay characteristics	1	2	3	4	Maximum	Average	Variance	Mode	S. D.
Agreement for general tax increase for 24/7 quantity of water with adequate pressure and high quality instead of paying for bill but only after 10 years with 80% of success and 20% failure 1. Yes 2. No		431	1443						
Percentage increases in income taxes instead of paying for bill 1. 5% 2. 10% 3. 20% 4. 40%	219	64	52	11					

Table 9.9 Willingness to pay for better wastewater services and recreational water use

	1	2	3	4	Maximum	Average	Variance	Mode	S.D.
Disposal of wastewater 1. Sewerage system 2. Septic tank 3. Open drainage canals 4. Into the street/road	1891	42	29	2					
Satisfaction with the current disposal of your wastewater 1. Satisfied 2. Partially satisfied 3. Not satisfied	884	685	427						
Preference to have an improved wastewater system 1. Yes 2. No	494	318							
Type of the desired wastewater disposal system 1. Septic tank 2. Open drains 3. Improved sewage	6	11	1740						
WTP for better wastewater disposal services (AZN)					45	6.39	27.7	0	5.26
Willingness to pay for better wastewater disposal services, but only after 10 years with 50% of success and 50% failure (AZN)					45	3.78	28.5	0	5.34
Willingness to pay for better wastewater disposal services, but only after 10 years with 80% of success and 20% failure (AZN)					150	5.20	166.4	0	12.90
Willingness to pay via credit scheme monthly (AZN)					3	1.63	0.23	2	1.28
Willingness to pay for recreational water use (boating, swimming, surfing, fishing, etc.) through general tax increasing 1. Yes 2. No	631	1088							

(continued)

Table 9.9 (continued)

	1	2	3	4	Maximum	Average	Variance	Mode	S.D.
Percentage increases in income taxes for recreational water use 1. 5% 2. 10% 3. 20% 4. 40%	514	45	33	34					
Willingness to pay for better wastewater disposal to protect valuable fish in the Caspian Sea 1. Yes 2. No	1053	755							
Willingness to pay to protect Caspian Sea fish species through general tax increases; percentage increases in income taxes 1. 5% 2. 10% 3. 20% 4. 40%	528	289	75	40					

waste disposal is roughly one third or less of WTP for potable water and tends to decline sharply with uncertainty and time delayed investment.

9.4 Econometric Analysis: A Structural Model of Demand for Integrated Water Services

9.4.1 Random Utility Model

WTP can be rigorously defined in the indirect utility framework as follows (Train 1986; McFadden 2001): for a fixed level of public good provision, a respondent's WTP is defined as the dollar amount Y, which equalizes two indirect utilities:

$$V_1(I - Y|Z, \varepsilon) = V_0(I|Z, \varepsilon) \tag{9.1}$$

In Eq. (9.1), I is disposable income, Z is a vector of observed social demographic characteristics, ε is a scalar variable representing unobserved personal characteristics, and V_1 and V_0 are, respectively, the respondents indirect utility with and without the provision of the public good. When two levels of the public good provision are compared, V_1 and V_2 may have the same functional form but include the level as an independent function argument. Assume that for any fixed (Z, ε), V_1 ($u|Z$, ε) is monotonically increasing in u. Then there exists an inverse function U (v: Z, ε) such that $U(V_1(u|Z, \varepsilon) : Z, \sum) = u$ for all $u \geq 0$. Therefore, WTP can be expressed as

$$Y = I - U(V_0(I|Z, \varepsilon) : Z, \varepsilon) \equiv \Phi * (X, \varepsilon), \text{where } X = (I, Z) \tag{9.2}$$

Marschak (1960) developed the random utility model in Eq. (9.1), which has since been researched, modified, and applied by a number of scholars, including McFadden (1978, 1999, 2001), Train (1998, 2001), Train and McFadden (1978), and Hausman et al. (1993). The model assumes that economic agents' decisions are heterogeneous due to two factors: a systematic component based on the agent's measurable socioeconomic characteristics (e.g., sex, age, wages, family size, etc.) and an unobservable random component. Using this hypothesis, we can thus investigate the preferences of a sample of agents by using a survey designed on the assumption that the WTP of each given agent could be considered as a latent process explained by a number of socioeconomic and behavioral variables and by a random shock.

Each interviewee was asked a question on her WTP for a particular investment outcome, using the so called "bidding game" procedure (Nam and Son 2004). According to whether the interviewee responded "yes" or "no" to the question, the interviewer asked the same question for the next highest price or the next lowest price. As a consequence, for each series of questions, the WTP of the ith interviewed lies in an interval whose lower bound, $WTLP_i$, is given by the highest value to which the respondent answered "yes" and the upper bound, $WTHP_i$, by the lowest value to which he answered “no.” Because the intervals were designed to be rather small, in our survey, upper and lower bounds for each interval are sufficiently close that the last “yes” answer can be considered to approximate reasonably well the maximum willingness to pay of the respondent.

In the literature on willingness to pay for water services, WTP is generally interpreted as a “demand price,” i.e., as the maximum amount of money that the respondent is willing to pay for one or more specific features of the water service (e.g., 24 h continuous availability of potable water). Problems of separability arise, however, for several reasons. First, water services are likely to be interdependent both in demand and in supply, and respondents may be presumed to perceive this interdependence in their own responses. Second, because service improvements are proposed as outcomes of a specific investment program, respondents are likely to consider their delivery to be jointly conditional to the program’s success. Third, the hypothetical nature of the improvements and the fact that they are contingent on projects yet to be decided upon and depending on a host of external factors (politics, financing, etc.) cast a common shadow of uncertainty on all elicited WTPs, creating one more sources of interdependence.

Because of these reasons, the WTPs elicited with the survey can be considered altogether indexes of integrated water demand. Even though their analysis cannot be simplified by strong separability assumptions, it can provide important information on the extent to which consumers’ utility is affected by joint performance of key water services.

Even though it has been criticized because its results may be affected by the initial value provided to the interviewees, the bidding game has the advantage to yield a direct measure of the maximum willingness to pay, comprising the whole consumer’s surplus of the respondent. In our survey, in particular, any possible initial value bias is partly neutralized by the fact that we explicitly anchor our questions to the last monthly bill paid by the respondent. The effect of this variable can thus be explicitly factored out and taken into account in the statistical analysis. That said, the WTP can be either retrieved from the ordered choice questions or, more directly, from a regression of the maximum WTP bid on a series of explanatory variables collected by the survey. These variables include income, a few measures of wealth, various types of consumption, several socioeconomic characteristics of the household, and a number of features related to the quantity and the quality of the water provided today. As the results of some studies (e.g., Otsetsewe 2001) suggest, these variables are likely to be the main determinants of households’ WTPs. However, several critiques have been made to CV studies and their conclusions. These critiques range from responses to please the interviewer to the lack of a real budget constraint and from various responses to starting point biases (Mitchel and Richard 1989). Because cross-sectional CV studies have often shown low R-squared, several studies (e.g., Carson and Mitchell 1993) have indicated that a minimum level of fitness to the data (such as an R2 of at least 15%) is necessary to reject the hypothesis that the CV results are just the effect of random responses on the part of the interviewees.

In our study, we follow the stochastic utility model in assuming that the expected WTP is linearly dependent on a vector of social and economic characteristics X_i and on a stochastic term with zero mean:

$$\mathrm{WTP}_{ij} = E\left(\mathrm{WTP}_{ij}/X\right) + \varepsilon_{ij} = \alpha_j + \beta_j X_{li} + \beta_{2j} X_{2i} + \ldots + \beta_{nj} X_{ni} + \varepsilon_{ij}, i = 1, 2 \ldots N \tag{9.3}$$

where WTP_{ij} is the ith stakeholder's willingness to pay for the j-th investment, given by the highest bid he has accepted, X_k $k = 1,2,\ldots n$ a set of conditioning variables, and ε_{ij} a random disturbance. We confine our estimates to households connected to the water pipe (98% of the population), and, because of the interdependencies across the range of water services and the consequent problems of identification, we specify and estimate the following structural demand model for integrated water services:

$$C_i = a_c + b_c S_i\_c_c M_i + \beta_{1c} X_{1c} + \beta_{2c} X_{2i} + \ldots + \beta_{2c} X_{ni} + \varepsilon_{ic} \tag{9.4}$$

$$S_i = a_s + b_s C_i + c_s M_i + \beta_{2s} X_{2i} + \ldots + \beta_{ns} X_{ni} + \varepsilon_{is} \tag{9.5}$$

$$M_i = a_m + b_m C_i + c_m S_i + \beta_{2m} X_{2i} + \ldots + \beta_{nm} X_{ni} + \varepsilon_{im} \tag{9.6}$$

$$WTP_i = a_w + b_w C_i + \gamma_w S_i + \lambda_w M_i + \mu_w WWTP_i + \beta_{1w} X_{li} + \beta_{2w} X_{2i} + \ldots + \beta_{nw} X_{ni} + \varepsilon_{iw} \tag{9.7}$$

$$WTPU_i = a_u + b_u C_i + \gamma_u S_i + \lambda_u M_i + \beta_{1w} X_{li} + \beta_{2w} X_{2i} + \ldots + \beta_{nw} X_{ni} + \varepsilon_{iw} \tag{9.8}$$

In Eqs. (9.4), (9.5), (9.6), and (9.7), the X_{ji} are the exogenous variables, while the endogenous variables are specified as follows[1]:

C_i = water consumption of the ith household; S_i = storage volume installed of the ith household; M_i = market value of the dwelling of the ith household; WTP_i = willingness to pay for an investment aimed at improving water supply and/or wastewater treatment; WWTP_i = willingness to pay for an investment aimed at improving water supply and/or wastewater treatment different from the above; and WTPU_i = willingness to pay to reduce uncertainty (option price—willingness to pay either in water supply or in water supply and wastewater treatment).

The model in Eqs. (9.4), (9.5), (9.6), (9.7), and (9.8) is based on the hypothesis that demand levels for water, storage, and housing are simultaneously determined, while, at the same time, willingness to pay measures are interdependent with water demand and are themselves simultaneously determined. Equation (9.7), in particular, hypothesizes that WTP to contribute to a project to improve water

[1]Because of the literature suggestion that WTP and the perceived quality of water may be simultaneously determined (e.g., Whittington 2003), we tested and rejected the hypothesis of endogeneity of water quality in our sample.

supply depends on the present level of water consumption, the demand for storage, the value of the dwelling, and, possibly, on WTP measures for other improvements. Equation (9.8), on the other hand, shows a similar hypothesis for the WTP to reduce uncertainty, obtained by subtracting from the WTP for improvement the WTP stated under uncertainty, which in the question asked was quantified as a 50% probability in 10 years for the improvement to be delivered.

9.4.2 The Econometric Estimates

The model in Eqs. (9.1), (9.2), (9.3), (9.4), (9.5), (9.6), (9.7), and (9.8) has been estimated with two stage least squares and white heteroskedasticity consistent covariance. Tables 9.10, 9.11, 9.12, 9.13, 9.14, and 9.15 present the estimation results and show that the following hypotheses cannot be rejected at a high level of statistical confidence:

1. WTP depends on present conditions of water supply, the current level of consumption, available storage, and how users perceive the quality of the existing water.
2. Women are more active in the survey and interested in paying more for better water and sanitation services.
3. Income and wealth of a household positively affect the WTP for improved water service.
4. Educational level of the respondent positively affects WTP.
5. Households would be willing to pay for their water use at the rate equivalent to the average incremental cost of provision better water service.
6. WTPs and demand for different water services are interdependent and depend positively on incomes, current water prices paid, and per capita water consumption.

While these are general conclusions, the equations estimated present also several interesting features.

First, R-squared are generally well over the threshold of 0.15 indicated by Mitchel and Richard (1989), but they increase considerably when zero (possibly protest) responses are singled out as fixed effect variables. This can be seen in the equation estimated by using the first principal component of all WTP measures and by a set of parallel results shown in the appendix. The latter can also be considered a robustness test of the main results presented in the text.

Second, for per capita consumption of water, in spite of some elements of rationing in water supply and the flat rate component dominating the water bill, the equation estimated displays the typical features of market demand, with positive income and negative price elasticities of the same orders of magnitude of most studies reported in the literature. For example, our estimated price elasticity is around −0.65 which is just at the top of the range of −0.3 to −0.6 reported by

Table 9.10 Estimates of the integrated water service demand model

	P.c. water consumption (log)		Storage volume installed (log)		Market value of the dwelling (log)		WTP for water delivery improvement (log)	
Method	TSLS		TSLS		TSLS		TSLS	
Variable	Coefficient	*p*-value	Coefficient	*p*-value	Coefficient	*p*-value	Coefficient	*p*-value
Constant	0.28	0.179	2.04	0.402	10.51**	0.000	−0.60	0.46
Log (income)	0.16***	0.000			0.15**	0.001	0.044	0.11
Log (bill/cons)	−0.65***	0.000						
Log (bill)			0.43**	0.006			0.498***	0.000
Log (p.c. water cons.)							−0.004***	0.026
Log (volume storage)	0.02***	0.000			−0.026**	0.002	−0.009***	0.0027
Log (tot persons in household)	−0.81***	0.000	−0.01*	0.046				
Education (years)	0.05**	0.009	0.04**	0.001				
Log (education)					0.019***	0.0038		
Log (water bad quality rating)	0.21**	0.004	1.30**	0.0061				
Log (house market value)			−0.44**	0.00324			0.063*	0.0003
Hours per day of service	0.01***	0.000	0.00	0.112			0.184*	0.0382
No delivery during dry season			−0.19*	0.057				
Lack of water pressure			0.29**	0.0000	−0.022*	0.0747		
Index of water shortage (lack of availability)					−0.040*	0.0654		
Log (distance from subway)					−0.042**	0.0033		
R2	0.34		0.06		0.237		0.464	
Observations	1444		904		375		1562	

Note: 1. Stars stand for degrees of significance: *** = 0.001 or better, ** = 0.01 or better, * = 0.05 or better; 2. Dummy variables are defined as being equal to 1 when the response to the corresponding variable is non-zero and zero otherwise

Table 9.11 Estimates of the integrated water service demand model

	Log total WTP (water and waste treatment)		All WTPs' first principal component	
Method	TSLS		TSLS	
Variable	Coefficient	*p*-value	Coefficient	*p*-value
Constant	0.617*	0.056	−4.969***	0.0003
Log (income)	0.105***	0.000	0.048***	0.0000
Log (water cons.)	−0.051**	0.0066	−0.020	0.323
Log (bill)	0.440***	0.000	0.121***	0.0000
Log (vol. storage)	−0.0075*	0.0302	−0.058*	0.0299
Gender (1 = female, 0 = male)	0.067***	0.0002	0.043*	0.0612
Lack of water pressure	0.026***	0.0004		
No delivery season	0.036***	0.0003		
Education (years)	0.082***	0.0000	0.024*	0.0293
Log (water bad quality rating)			−0.048	0.223
Log (house market value)	0.065**	0.0023	0.051**	0.0026
Dummy WTP			1.958***	0.000
Dummy WTP waste			1.744***	0.000
Dummy WTP waste 50			1.393***	0.000
R2	0.337		0.943	
Observations	1575		1620	

Note: 1. Stars stand for degrees of significance: *** = 0.001 or better, ** = 0.01 or better, * = 0.05 or better; 2. All dummy variables are defined as being equal to 1 when the response to the corresponding variable is non-zero and zero otherwise

Nauges and Whittington (2010) for LDCs and is not significantly different from the average price elasticity (−0.51) reported by Espey et al. (1997) for industrialized countries. Similarly, our estimate of income elasticity equals 0.159, well within the typically estimated range (0.1–0.4) reported in the study of Arbués-Gracia et al. (2003). The effect of household size is found to be significant, implying a reduction of per capita consumption of about 87% when the number of permanent residents doubles, a result larger, but of comparable magnitude of the effect (50%) estimated by Cheesman et al. (2008) for Vietnam. Also similarly to results reported in the literature, an extra hour of piped water availability would increase per capita consumption of households of 2.2%. Nauges and Van Den Berg (2009) estimate for Sri Lanka an average effect of by 2%.

Third, estimates of demand for storage volume and the value of the dwelling are based on a smaller number of useful responses and, even though plausible enough in the coefficient estimates, exhibit much lower fits. Demand for storage appears to be not significantly affected by p.c. income but positively related to the size of the bill, education, the index of bad quality rating for water, the lack of water pressure, and the reliability of water delivery. The value of the dwelling, as shown in several classical studies (e.g., Freeman 1979), turns out to be significantly related to income (the income elasticity is approximately the same as for water consumption) and

Table 9.12 Estimates of the integrated water service demand model

	Log risk premium = WTP to reduce uncertainty in the improvement of water supply		Log risk premium = WTP to reduce uncertainty in the improvement of water supply and wastewater treatment		Log WTP Waste treatment (recreational use of water)		WTP credit for sanitation (log)	
Method	TSLS		TSLS		Probit		TSLS	
Variable	Coefficient	*p*-value	Coefficient	*p*-value	Coefficient	*p*-value	Coefficient	*p*-value
Constant	0.909	0.0088	1.053	0.000	−1.95	0.037	−4.442	0.000
Log (income)	0.113	0.0129	0.120	0.0005	0.048	0.477	0.000	0.926
Log (p.c. water cons.)	0.815	0.000	0.711	0.000	−0.380	0.0008	0.143	0.0013
Log(bill)					0.456	0.0003	0.161	0.000
Log (bill/water cons.)	0.995	0.000	0.791	0.000	−0.408	0.0133		
Log (vol. storage)					0.045	0.0005		
Log (water bad quality rating)					−0.888	0.000		
Waterfront					0.586	0.000		
Log (house market value)					0.183	0.0253		
Dummy WTP waste treatment							−0.512	0.0042
Dummy credit							170.577	0.000
R2	0.323		0.313		0.10			0.968
Observations	319		353		1327			1344

education of the head of the household and negatively related to the volume of storage installed, unreliable water supply, and distance from the subway.

9.5 Conclusions

This paper has presented the results of a study on water services and WTP in the GBA, in the context of integrated demand. The main results confirm the integrated nature of water services and suggest the following conclusions:

1. Water consumption preferences are exercised in the context of constrained choices and depend on the present conditions of water supply, as well as on past investment in housing and water storage.
2. As a consequence, water consumption, available storage, housing values, and WTPs for water supply improvements are all interdependent.
3. Water demand, storage, housing values, and WTPs are all significantly dependent, but inelastic, on per capita incomes.
4. While water demand is negatively related (in an inelastic way) to water price, WTPs appear to be positively related (though still inelastic) to it.
5. The introduction of uncertainty tends to reduce WTPs of an amount that is itself a function of the present conditions of water supply, incomes, and water prices.
6. Gender significantly affects willingness to pay for improved water services (women are willing to pay more, especially for sanitation).
7. The educational level of the respondent positively affects WTP.
8. Households would be willing to pay for their water consumption at the rate equal to the average incremental cost of supplying improved water service.

From a theoretical point of view, the results obtained provide support to the hypothesis that demand for water services is consistent with the economic paradigm of rational choice. From the policy perspective, this implies that WTP for existing and expanded water services is sizable and appears to justify further investment in increasing integrated water supply services, in terms of size, reliability, and quality of the water for all its uses, including drinking, sanitation, and recreation.

Conflict of Interest Statement The authors report no conflict of interest for this publication.

Appendix

Estimates with dummy variables for zero (protest) responses (Tables 9.13, 9.14, and 9.15)

Table 9.13 Estimates of the integrated water service demand model

	P.c. water consumption (log)		Storage volume installed (log)		WTP for water delivery improvement (log)		Long-term WTP under uncertainty (log)	
Method	TSLS		OLS		TSLS		TSLS	
Variable	Coefficient	*p*-value	Coefficient	*p*-value	Coefficient	*p*-value	Coefficient	*p*-value
Constant	−5.036***	0.000	−5.21***	0.000	−6.83***	0.000	−4.40***	0.000
Log (income)	0.161***	0.000	0.049**	0.0004	0.076***	0.000	0.069***	0.0011
Log (bill/cons)	−0.567***	0.000						
Log (bill)					0.501***	0.000		
Log (p.c. water cons.)					−0.003**	0.033	0.009	0.675
Log (volume storage)	0.022***	0.000			−0.009***	0.0006	−0.0096*	0.0218
Log (tot persons in household)	−0.869***	0.000	−0.0044*	0.0458				
Number adults	0.037*	0.0224						
Education (years)	0.051**	0.0112	0.041***	0.0002			0.061***	0.0004
Log (water bad quality rating)	0.225**	0.0016	−0.127**	0.0074				
Log (house market value)	0.136*	0.0152	0.044**	0.0093	0.063*	0.0003		
Hours per day of service	0.013***	0.000	0.002	0.112				
No delivery during dry season			−0.062***	0.000				
Lack of water pressure			0.010*	0.0842				
Log (WTP)							0.140**	0.0085
Dummy water cons.	5.459***	0.000						
Dummy storage			6.805***	0.000				
Dummy WTP					7.429***	0.000	−1.061**	0.0161
Dummy long WTP							6.967***	0.000
R2	0.443		0.988		0.847		0.942	
Observations	1517		1774		1671		1646	

Note: 1. Stars stand for degrees of significance: *** = 0.001 or better, ** = 0.01 or better, *= 0.05 or better; 2. All dummy variables are defined as being equal to 1 when the response to the corresponding variable is non-zero and zero otherwise

Table 9.14 Estimates of the integrated water service demand model

	WTP waste		WTP waste 50		All WTPs' first principal component	
Method	TSLS		TSLS		TSLS	
Variable	Coefficient	*p*-value	Coefficient	*p*-value	Coefficient	*p*-value
Constant	−6.474***	0.000	−4.969***	0.000	−4.969***	0.0003
Log (income)	0.087***	0.000	0.051***	0.000	0.048***	0.0000
Log (water cons.)	−0.111***	0.0004	−0.021**	0.0014	−0.020	0.323
Log (bill)	0.116***	0.0012	0.117***	0.0007	0.121***	0.0000
Log (vol. storage)					−0.058*	0.0299
Gender (1 = female, 0 = male)	0.131***	0.0002	0.043*	0.0493	0.043*	0.0612
Education (years)	0.082***	0.0000	0.025*	0.031	0.024*	0.0293
Log (water bad quality rating)	−0.147**	0.0180	−0.071**	0.0014	−0.048	0.223
Log (house market value)	0.115***	0.0000	0.053***		0.051**	0.0026
Log (WTP water)	0.051**	0.0034	1.958*	0.0872		
Log (WTP waste)			1.744*	0.0856		
Dummy WTP	1.399***	0.000			1.958***	0.000
Dummy WTP waste	6.574***	0.000	0.938***	0.000	1.744***	0.000
Dummy WTP waste50			6.607***	0.000	1.393***	0.000
R2	0.971		0.989		0.943	
Observations	1517		1774		1620	

Note: 1. Stars stand for degrees of significance: *** = 0.001 or better, ** = 0.01 or better, * = 0.05 or better; 2. All dummy variables are defined as being equal to 1 when the response to the corresponding variable is non-zero and zero otherwise

Table 9.15 Estimates of the integrated water service demand model

	Log WTP waste treatment (recreational use of water)		WTP credit for sanitation (log)	
Method	Probit		TSLS	
Variable	Coefficient	*p*-value	Coefficient	*p*-value
Constant	−1.95	0.037	−4.442	0.000
Log (income)	0.048	0.477	−0.000	0.926
Log (p.c. water cons.)	−0.380	0.0008	0.143	0.0013
Log (bill)	0.456	0.0003	0.161	0.000
Log (bill/water cons.)	−0.408	0.0133		
Log (vol. storage)	0.045	0.0005		
Log (water bad quality rating)	−0.888	0.000		
Waterfront	0.586	0.000		
Log (house market value)	0.183	0.0253		
Dummy WTP waste treatment			−0.512	0.0042
Dummy credit			170.577	0.000
R2	0.10			0.968
Observations	1327			1344

References

Abbasov RK, Smakhtin VU (2010) Introducing environmental thresholds into water withdrawal management of mountain streams in the Kura River basin, Azerbaijan. Hydrol Sci J 54(6): 1068–1078

Abbasov RK, Smakhtin VU (2012) Indexing the environmental vulnerability of mountain streams in Azerbaijan. Mt Res Dev 32(1):73–82. https://doi.org/10.1659/MRD-JOURNAL-D-11-00012.1

Arbués-Gracia F, García-Valiñas MA, Martínez-Espiñeira R (2003) Estimation of residential water demand: a state of the art review. J Socio-Econ 32(1):81–102

Bueno EA, Ancog R, Obalan E et al (2016) Measuring households' willingness to pay for water quality restoration of a Natural Urban Lake in the Philippines. Environ Process 3:875–894. https://doi.org/10.1007/s40710-016-0169-8

Carson TR, Mitchell RC (1993) The value of clean water: the public's willingness to pay for Boatable, fishable, and swimmable quality water. Water Resour Res 29(7):2445–2454

Cheesman J, Bennett J, Son T (2008) Estimating household water demand using revealed and contingent behaviors: evidence from Viet Nam. Water Resour Res 44:W11428. https://doi.org/10.1029/2007WR006265

Ehrlich I, Becker GS (1972) Market insurance, self-insurance, and self-protection. J Polit Econ 80(4):623–648

Espey M, Espey J, Shaw WD (1997) Price elasticity of residential demand for water: a meta-analysis. Water Resour Res 33(6):1369–1374

Freeman MA (1979) Hedonic prices, property values and measuring environmental benefits: a survey of the issues. Scand J Econ 81(2):154–173

Green P, Srinivasan V (1978) Conjoint analysis in consumer research: issues and outlook. J Consum Res 5:103–123

Hausman JA, Leonard GK, McFadden D (1993) Assessing use value losses caused by natural resource injury. Elsevier Science Publishers BV, pp 341–363

Mammadzadeh I (2020) Water resources Management in the Republic of Azerbaijan: overview and outlook. Baku, 32–39

Mark YA (2000) A semiparametric distribution for willingness to pay and statistical inference with dichotomous choice contingent valuation data. Am J Agric Econ Agric Appl Econ Assoc 82(3): 487–500

Marschak J (1960) Binary choice constraints on random utility indicators. In: Arrow K (ed) Mathematical methods in the social sciences, 1959. Stanford University Press, Stanford, CA, pp 312–329

McFadden D (1978) Modeling the choice of residential location. In: Karlqvist A, Lundqvist L, Snickars F, Weibull J (eds) Spatial interaction theory and planning models. North-Holland, Amsterdam, pp 75–96

McFadden D (1999) Computing willingness-to-pay in random utility models. In: Moore J, Riezman R (eds) Trade, theory and econometrics: essays in honour of John S. Chipman London. Routledge, New York, pp 253–274

McFadden D (2001) Economic choices. Am Econ Rev 91:351–378

Mitchel RC, Richard CT (1989) Using surveys to value public goods: the contingent valuation method. Resources for the Future, Washington, DC

Nam PK, Son TVH (2004) Recreational value of the coral surrounding the Hon Mun Islands in Vietnam: a travel cost and contingent valuation study1. In: Economic valuation and policy priorities for sustainable management of coral reefs, p 84

Nauges C, Van Den Berg C (2009) Perception of health risk and averting behavior: an analysis of household water consumption in Southwest Sri Lanka. TSE working papers 09–139, Toulouse School of Economics (TSE)

Nauges C, Whittington D (2010) Estimation of water demand in developing countries - an overview. World Bank Res Obs 25(2):263–294

Otsetsewe M (2001) Willingness to pay for private water connection in Kanye: a contingent valuation approach. Unpublished BA Project, Department of Economics, University of Botswana
Pearce D (1993) Economic values and the natural world. Earthscan Publications Ltd, London
Phu Le V (2004) Urbanization and water Management in ho chi Minh City Vietnam – issues, challenges perspective. Geo J 70(1):75–89
Sen AK (1984) Resources, values and development. Basil Blackwell, Oxford
Shaikh SL, Sun L, Kooten CG (2007) Treating respondent uncertainty in contingent valuation: a comparison of empirical treatments. Ecol Econ 62(1):115–125
Srinivasan V (1988) A conjunctive-compensatory approach to the self-explication of multi attributed preferences. Decis Sci 19:295–305
Train K (1986) Qualitative choice analysis. MIT Press, Cambridge
Train K (1998) Recreation demand models with taste variation. Land Econ 74(2):230–239
Train K (2001) Discrete choice methods with simulation. Cambridge University Press, Cambridge
Train K, McFadden D (1978) The goods-leisure tradeoff and disaggregate work trip mode choice models. Transp Res 12(5):349–353
Trigeorgis L (1996) Real options: managerial flexibility and strategy in resource allocation. MIT Press, Cambridge/London, pp 13–427
Wang H, Xie J, Li H (2010) Water pricing with household surveys: a study of acceptability and willingness to pay in Chongqing, China. China Econ Rev 21:136–149
Wilson C, Athukorala W, Torgler B et al (2020) Willingness to pay to ensure a continuous water supply with minimum restrictions. Empir Econ. https://doi.org/10.1007/s00181-020-01955-8

Pasquale Lucio Scandizzo is a distinguished Environmental Economist and Professor of Economic Policy, University of Rome "Tor Vergata" Rome, Italy.

Rovshan Abbasov is the Head of the Geography and Environment Department at the Department of Geography and Environment, Khazar University, Baku, Azerbaijan.

Part III

Multiscale Environmental Design for BGI

10 Homegardens as Sustainable Urban Agroforestry Systems to Promote Household Well-Being in Kandy, Sri Lanka

Sachini Kavinda Jayakody and Mrittika Basu

Abstract

Accessibility to green space is vital for physical and mental well-being and homegardens in urban areas present space to connect with nature and derive benefits. Homegardens, whether small scale or large scale, represent sustainable agroforestry systems as spaces for physical exercise and mental health and also are a repository of a wide range of biological diversity that provides multiple benefits including provisioning, regulatory and supporting services. With increasing urbanization, urban hinterlands and rural areas are often encroached, threatening the ecosystem sustainability. Homegardens in Sri Lanka boast of age-old traditional knowledge and hold distinctive and multifunctional characteristics. They have been an integral part of Sri Lankan culture and a source of household food security. Though no immediate dangers to the homegardens in Sri Lanka are witnessed, the urbanization impacts are becoming evident and the future sustainability of homegardens is questionable. This chapter attempts to summarize the existing literature on homegardens in Sri Lanka, especially Kandyan homegardens, their characteristics, significance and threats. Due to the distinctive features of Kandyan homegardens and their benefits to the local community, they are an ideal example of agroforestry systems and provide instances that can be downscaled or upscaled for effective implementation in other parts of the world. This chapter explains the threats to homegardens and urban green policies/ programmes in Sri Lanka as an opportunity to identify the challenges faced in mainstreaming policies and/or programmes on homegardens. This chapter

S. K. Jayakody · M. Basu (✉)
Laboratory of Sustainable Rural Development, Graduate School of Global Environmental Studies, Kyoto University, Kyoto, Japan
e-mail: basu.mrittika.4r@kyoto-u.ac.jp

S. Dhyani et al. (eds.), *Blue-Green Infrastructure Across Asian Countries*,
https://doi.org/10.1007/978-981-16-7128-9_10

discusses future urban planning strategies for inclusion of homegardens in rural as well as urban areas of Sri Lanka.

Keywords

Homegardens · Urban green spaces · Agroforestry systems · Kandy · Sri Lanka

10.1 Introduction

Urbanization results in physical and socioeconomic changes including changes in land use as well as lifestyle of people (Madsen et al. 2010). Urban green spaces (UGS) present important solutions to these impacts that arise from the unsustainable activities that include not only environmental impacts but also social and economic impacts (Rostami et al. 2015). UGS are natural or man-made vegetated areas that are private or open to and accessible by the public in urban areas, allowing urban dwellers to be close to nature and for biodiversity within the urban area to be conserved. They have the ability to enhance air and water quality, reduce noise pollution, provide a barrier for extreme events, as well as provide health benefits for people, such as improving social interactions and reducing stress (Rostami et al. 2015; World Health Organization 2017). A study by Dobbs et al. (2017) studied 100 cities from 6 continents to evaluate the principal factors behind the global patterns of the landscape structure of urban vegetation. They determined that the main factors driving these global urban vegetation patterns were population and Gini index (a measure of income inequality within societies). Consequently, as population increased, green cover was observed to decrease and vegetation fragmentation to increase (Dobbs et al. 2017; Basu et al. 2020). Furthermore, cities with a higher level of income inequality were observed to have more fragmented vegetation (Dobbs et al. 2017). There is also some differences in participation between lower income households and higher income households of urban areas as those with lower income may not have a property with an area to grow food (Ranasinghe and Hemakumara 2018; Jayasinghe et al. 2021). They determined these findings to be supported by several other studies that have been conducted at the local and regional scale. When developing UGS, it is important to ensure that the different spaces, such as parks and forests, are interconnected using links, such as green corridors, to enable the flow of ecosystems (Benedict and McMahon 2002; Lafortezza et al. 2013; Semeraro et al. 2021). The percentage of urban area that has been allocated for green spaces from the total extent of the urban area can be used to assess the environmental sustainability of a city (Chiesura 2004). Various organizations suggested different standards with the aim of assessing the ecological sustainability of cities. One such method is determining the per capita green space extent of a city (Laghai and Bahmanpour 2012). This value represents the extent of green space in square meters (m^2) per individual. UN has expressed that the per capita green space should be more than 30 m^2 and such cities are named as sustainable cities, while the European Union (EU) stated the minimum value as 26 m^2 (Khalil 2014). The World

Health Organization (WHO) has defined that an area of 9 m^2 of green space should be maintained for each person in an urban area to provide a better quality life (Khalil 2014). Sometimes, developed countries have their own per capita green space values, for example, 50 m^2 in the USA, 30–60 m^2 in Germany and 50–60 m^2 in Switzerland (Hosseini et al. 2015). Major cities, too, in developed countries have defined individual values, for example, 154 m^2 by Los Angeles and 47 m^2 by New York (Hosseini et al. 2015).

As the urban green spaces are under immense pressure from urbanization and are rapidly vanishing, and access to green spaces at a distance becomes troublesome, homegardens and/or community gardens are considered as potential UGS that help to reconnect people to nature in an urban space (Teuber et al. 2019). This connection contributes to the resilience in cities, as it fosters ecosystem services on local to regional scales (Ernstson et al. 2010). Especially, the direct human-environment interaction of gardening might increase the resilience of the urban social-ecological system, as gardens provide ecosystem services like food and habitat provision or local climate regulation (Cabral et al. 2017; Speak et al. 2015). The provision of food by homegardens can also play a vital role in alleviating food insecurity. Food insecurity is already a major problem faced by many parts of the world, and with the increment of the world's population and rapid urbanization, this may become a crisis for both developed and developing countries, more so for developing countries (Lal 2020). It was recently intensified by the COVID-19 pandemic from interferences to food supply chains (Lal 2020; Sofo and Sofo 2020). People resorted to growing food at home for various reasons such as to avoid going outside to crowded places, a solution to food shortages and increase in food prices, as well as to fill the day with outside activity during lockdown (Chenarides et al. 2021). Apart from food security during the pandemic, homegardens are reported to significantly contribute to physical and mental well-being by helping them to connect to nature as well as providing them a space for physical exercise (Corley et al. 2021). Despite all the importance and services provided by homegardens, they are not extensively studied in a comprehensive manner and often ignored as potential urban green spaces (Calvet-Mir et al. 2012; Mohri et al. 2013).

Sri Lanka has a population of 21 million people, with approximately 18% residing in urban areas, of these about 15% of urban dwellers live in Colombo (Li 2017). The land use land cover map of Sri Lanka (Fig. 10.1) provides some insight into the vegetated and built-up areas in Sri Lanka. As clearly illustrated, the highest built-up area is in Colombo which is situated on the western coast of Sri Lanka. When analysing urbanization and UGS in Sri Lanka, the city of Colombo is the most studied area being the commercial capital that has observed a rapidly increasing migration from other parts of Sri Lanka. Maintaining or increasing green spaces in urban areas proves to be difficult due to more space being required to accommodate the growing population as well as increased urbanization. The study by Li (2017) on Colombo meeting UGS standards showed that the 83.1% of green space in Colombo in 1980 dropped to 13.5% by 2015, with a 20.7% increment in population by 2015 compared to 1980. It can also be observed that Sri Lanka consists of significant areas of homesteads/homegardens which was determined by

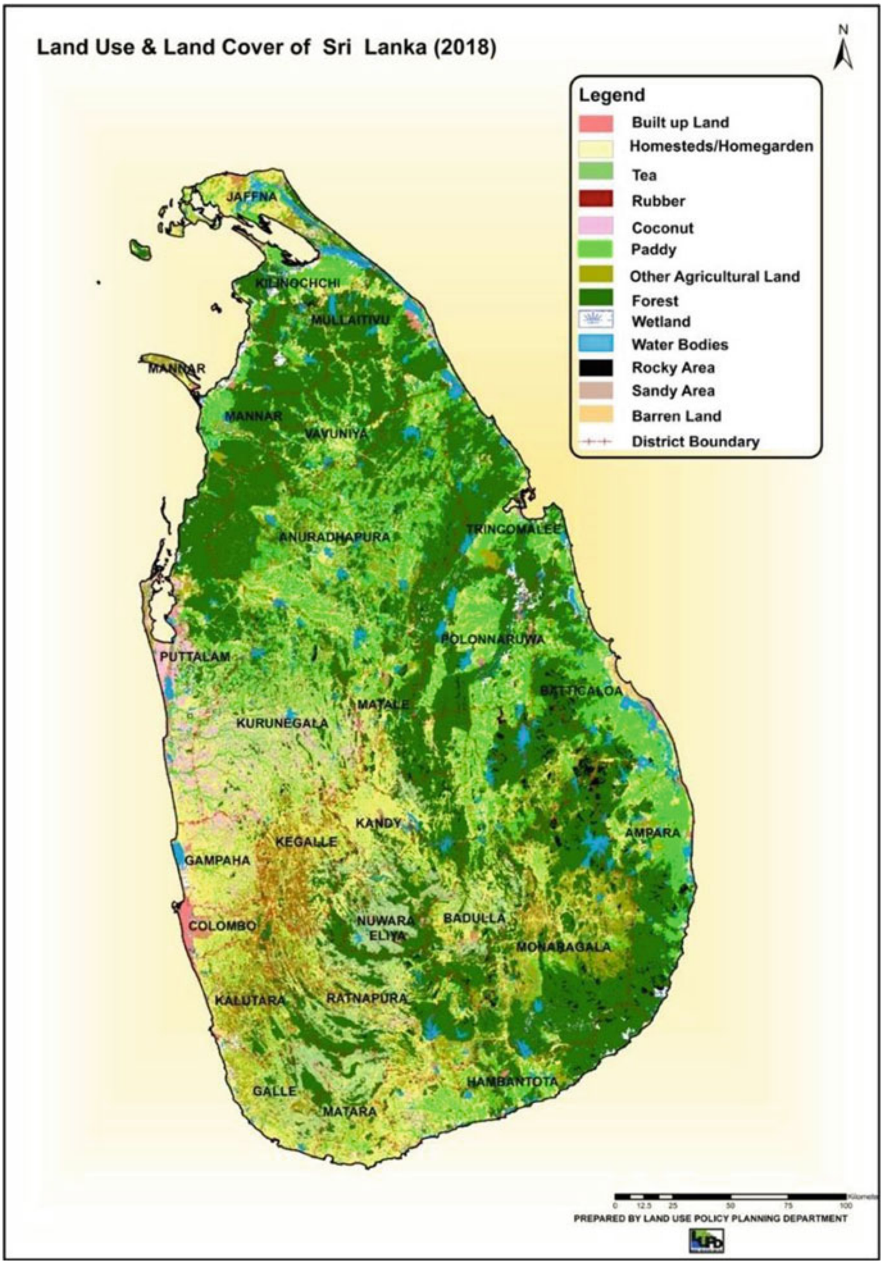


Fig. 10.1 Land use and land cover of Sri Lanka. (Source: Land Use Policy and Planning Department 2021)

the Land Use and Policy Planning Department to be 18.18% of all land in 2018. In Sri Lanka, the Kandyan area, which is in the mid-country region, is renowned for homegardens. They come from ancient and traditional ways of sustainable production that comprises of a wide variety of plant species with multiple uses and sometimes include livestock (Pushpakumara et al. 2010; Mohri et al. 2013). Their importance come from their ability to act similar to natural forests and provide food, an income and an aesthetically pleasing environment for home owners (Pushpakumara et al. 2010). It should be noted that the availability of UGS in Sri Lanka depends on whether settlements are planned and unplanned (Senanayake et al. 2013) and on the perception of the residents (Ranasinghe and Hemakumara 2018; Jayasinghe et al. 2021). With the pressures experienced by public UGS in Sri Lanka, gardens that are privately maintained may provide a solution to fulfilling the UGS requirement.

The homegardens of Sri Lanka are well known for their expanse and varied composition and multiple ecosystem services. However, with increasing threats from urbanization and other anthropogenic factors, homegardens in Sri Lanka have also become vulnerable. With the understanding of the importance of UGS and the threats they face, this chapter aims to explore the homegardens in Sri Lanka, especially Kandy, and to identify its role as important small-scale green spaces in Sri Lanka that can support urban sustainability. The findings will provide an understanding about the characteristics of homegardens and their role in improving urban socio-ecological resilience.

10.2 Literature Review

10.2.1 Urban Green Space Policy in Sri Lanka: Initiatives and Strategies

As previously explained, most literature on UGS in Sri Lanka focusses on Colombo. Colombo has seen a 83.8% drop in green space between 1980 and 2015 (Li 2017). The availability of UGS in Colombo may depend on planned and unplanned settlements such as the differences in UGS observed in the Southern Colombo Municipal Council (CMC) area (planned) and north-central CMC area (unplanned), where planned settlements had more access to UGS (Senanayake et al. 2013). As per two studies conducted in the city of Galle and a town in Matara in Sri Lanka, availability of residential gardens can depend on various factors such as land area, land ownership, residents' orientation towards nature, time availability to maintain a residential garden and perception of advantages and disadvantages of having a residential garden (Ranasinghe and Hemakumara 2018; Jayasinghe et al. 2021). Because there are a variety of factors that affect the presence of green spaces, it is important that proper policies and strategies are in place to ensure that current UGS are protected and sustainably utilized.

There are several policies/initiatives/plans/strategies in Sri Lanka that involve sustainable development, environmental management and land management with regard to urban development as per the information given in Table 10.1. The documents show that governing bodies have identified the importance of maintaining and improving UGS, with many of these documents placing emphasis on protecting and increasing urban green cover. However, there is no clear directive on accomplishing this, as was also determined in the study by Asmone et al. (2016). For example, the Annual Performance Report & Accounts in 2015 by the Ministry of Mahaweli Development and Environment states that, with regard to Mission 8 of the *Haritha Lanka* Programme of 2009 (Table 10.1), “a policy has to be developed to enhance and manage urban green cover” and that it will be considered in Megapolis Planning. While the Megapolis—Western Region Master Plan of 2016 refers to certain actions that can and should be undertaken, no policy on urban green cover has been developed so far in Sri Lanka. However, a lot of focus has been given for the enhancement of homegardens through programmes such as *Haritha Lanka*, *Api Wawamu Rata Nagamu* (let us grow and uplift the nation) and *Divi Neguma* (livelihood development) (Pushpakumara et al. 2012), mainly at the rural level. Irrespective of urban and rural areas, considering the important role of homegardens in food security, people are encouraged to cultivate vegetables and multipurpose tree species (food and fruits) in their own backyards for their daily consumption under the current Food Production National Programme aimed at eliminating poverty and making the country self-sufficient in food. Homegardens are also indirectly referred in Sri Lanka’s Intended Nationally Determined Contributions (INDCs) to the United Nations Framework Convention on Climate Change (UNFCCC 2016) and are identified to have a prominent role in meeting climate mitigation goals under Sri Lanka’s UN REDD+ Programme to sequester carbon (UN-REDD 2015). Homegardens are also recognized as a good practice to promote traditional methods of biodiversity conservation for increased crop resilience in Sri Lanka’s National Adaptation Plan for Climate Change (NAP) for 2016–2025 (Ministry of Mahaweli Development and Environment 2015).

10.2.2 Homegardens in Sri Lanka

Agroecosystems provide bunch of social benefits that usually transcend from their provisioning services. Apart from food, fuel and fibre, some agroecosystems provide important regulatory, supporting and cultural services which in turn depend on the intensity of use and diversity of the ecosystems. Despite the recognition of ecosystem services provided by agroecosystems, ecosystem services and benefits provided by homegardens or homestead lands remain somewhat unexplored. Studies are available from Global North where homegardens have been identified as potential agroecosystems that significantly contribute to quality of life. However, existing knowledge on homegardens from Global South is still at an infant stage even though homegardens are common throughout the tropics and often referred to as household or homestead farms, multi-strata tree gardens, analogue forests, compound farms, backyard gardens, village forest gardens, dooryard gardens and house gardens. This demonstrates lack of knowledge about the services provided by homegardens among

Table 10.1 Policies, initiatives and strategies in Sri Lanka on UGS

Policies/initiatives/ strategies	Year	Potentially applicable principles/statements from the document	Reference to UGS
The National Environmental Policy	2003	– Traditional knowledge and practices will be respected in the development of environmental management systems – Sri Lanka's attractive landscapes—rural and urban, coastal and inland—as well as sites of archaeological, cultural and religious interest are protected – Sri Lanka's traditional knowledge on biodiversity is protected – Adopt strict planning of urban centres, allowing for the expected growth of the urban population and paying special attention to maintaining a healthy environment	No reference
National Action Plan for *Haritha Lanka* Programme	2009	Mission 8: Green cities for health and prosperity – Keep adequate lands for conservation needs in urban areas – Encourage urban biodiversity parks as part of the public outdoor recreation space network in each urban area – Declaration of wetlands and establishing city-based monitoring systems for declared wetlands – Establish landscape units and design the city incorporating greening aspects, design management and implementation, in all local authorities – Transform urban cities into green urban cities extending the green cover at all appropriate places	Some reference to ensuring urban environmental sustainability and increasing urban green cover

(continued)

Table 10.1 (continued)

Policies/initiatives/ strategies	Year	Potentially applicable principles/statements from the document	Reference to UGS
National Land Use Policy	2009	Conversion of good agricultural lands for non-agricultural uses in urban fringe areas will be discouraged	No reference
Mahinda Chinthana—Vision for the Future—Manifest regarded as a national policy	2010	Beautiful cities—"Green villages" to be launched under *Gama Neguma* Programme	No reference nor any specific actions listed for green villages
The Megapolis—Western Region Master Plan 2030	2016	– Ensure that wetland in Western region is conserved and are well integrated as public spaces in urban areas – Campuses to be designed with green buildings and open spaces – Basic recreational facilities to include public spaces and parks – Conserve the natural capital of the Western region by demarcation and protection of the environmental sensitive and ecologically important hotspots, by declaring three types of eco zones that include forests, wetlands, urban parks, green belts, buffer zones, paddy fields, etc.	Reference to public open spaces and urban parks in the Western region
National Physical Planning Policy & The Plan 2050	2019	5.2 The Urban Development Strategy: – Selection of the most appropriate lands as part of assuring environmentally sustainable and "green" developments – Minimum un-built open area requirement and space for green cover strictly regulated and maintained within urban areas as specified in respective urban development plans – An island-wide programme to shade main streets and major public	Specific reference to urban green cover and proposes preserving of 60% of agricultural lands and plantations within development corridors

(continued)

Table 10.1 (continued)

Policies/initiatives/ strategies	Year	Potentially applicable principles/statements from the document	Reference to UGS
		spaces of all urban areas with trees of endemic species, implemented by the Urban Development Authority 5.7 Agriculture and Plantations – Respective urban development plans shall evaluate the non-market-based benefits of urban agricultural land such as open public spaces – The agricultural lands and the rubber plantations within the proposed development corridors to be thoroughly evaluated for their alternative uses such as carbon sequestration if demanded for alternative developments. In general, at least 60% of these lands in urban environments are proposed to be preserved to meet the national forestry improvement targets as set by the UN REDD Programme (2016)	
Sri Lanka 2030 Vision and Strategic Path	2019	Open spaces—Present urban development schemes don't meet the general requirement of 1 ha per 1000 people – Enforcing the National Physical Planning Policy	Reference to open spaces
Draft National Policy and Strategy on Sustainable Development	2020	Policy goal 11: Cities and human settlements are made inclusive, safe, resilient and sustainable – By 2030, provide universal access to open and green public spaces, develop standards/design guidelines and introduce regulatory provisions to mandate incorporation of sufficient green and public	Specific reference to urban green spaces and increasing urban green cover

(continued)

Table 10.1 (continued)

Policies/initiatives/ strategies	Year	Potentially applicable principles/statements from the document	Reference to UGS
		spaces in city planning Policy goal 15: Sustainable use and conservation of terrestrial ecosystems are ensured – By 2022, promote the implementation of sustainable management of all types of forests, halt deforestation, restore degraded forests and substantially increase afforestation and reforestation—increase the tree cover wherever appropriate covering both urban and rural areas	
National Agriculture Policy	2021	Policy statement 1: Improve production and productivity of food and feed crops through a well-organized agricultural production system while harnessing the agroecological potential and strengthening the food system – Promote and support systematic home gardening – Promote different production technologies (e.g., vertical farming, family farming, rooftop gardening, community gardens), especially focussing on urban and peri-urban food systems and metro agriculture	References to homegardens and farming/gardening in urban and peri-urban areas

Global South population which is also leading to the degradation of these agroecosystems along with other factors like increasing population, urbanization, climate change, etc.

Though there is no established definition of homegardens yet, a homegarden can be generally defined as "a farming system that combines physical, social and economic functions on the area of land around the family home" (Landon-Lane 2004). Homegardens are an agroforestry system that can be found in both rural and urban areas, providing food, herbs and medicine, and sometimes livestock, for home

Table 10.2 Common traits of homegardens

Trait	Description
Species density	High
Species type	Stable, vegetable, fruit (cultural)
Main production objective	Home consumption
Labour source	Family (female, elderly, children)
Labour requirements	Part time
Water requirements type	High irrigation
Harvest frequency	Daily, seasonal
Size of unit	Small (relative)
Space utilization	Horizontal, vertical
Fencing	Frequent
Location	Close to dwelling
Cropping patterns	Irregular, row
Economic role	Supplementary
Technology	Simple hand tool
Inputs—cost	Low
Geographical distribution	Rural and urban
Skills	Gardening—Horticulture
Government assistance	None or minor

Source: Niñez (1984)

use, but it can also be an additional source of income if extra food is produced (Galhena et al. 2013). The study by Calvet-Mir et al. (2012) in Spain identified that while the most important and obvious service provided by homegardens is quality food for consumption, there are many other less recognized services that are highly valuable. These include services such as habitat services (maintenance of landraces) and cultural services (heritage value, enjoyment of homegardens, etc.). Mazumdar and Mazumdar (2012), in their study on homegardens in the houses of immigrants from different countries, reported that homegardens represent a space for religious, cultural and ecological socialization, and it helps them to continue their identity. Since homegardens can vary based on cultural, ecological and socioeconomic factors, Niñez (1984) determined common traits to help identify homegardens as mentioned in Table 10.2.

Homegardens in Sri Lanka have been studied for a long time (Perera and Rajapakse 1991; Weerahewa et al. 2012; Galhena et al. 2013; De Zoysa and Inoue 2014; Mattsson et al. 2013, 2018; Marambe et al. 2018; deHaan et al. 2020; Herath et al. 2021; Jayasinghe et al. 2021; Melvani et al. 2020; Mohri et al. 2013, 2018; Pushpakumara et al. 2010, 2012, 2016). Homegardens, often a traditional life supporting system, cover a significant land area (18.18%) of the country and was estimated to increase at an extent of 1% per year until 2020 (FAO 2009). Homegardens in Sri Lanka are often characterized as a piece of land, which has a dwelling house and some form of cultivation on a total area of between 0.05 and 2.5 ha (mean 0.4 ha) (Pushpakumara et al. 2010). These gardens are mostly privately owned and are managed through family labour using indigenous technologies that rely on rich local knowledge systems (Pushpakumara et al. 2010, 2012). In Sri Lanka, homegardens represent complex sustainable land use system that combines multiple farming components, such as annual and perennial crops, livestock and occasionally fish, which provides environmental services, resources for household needs as well as employment and income generation opportunities (Weerahewa et al. 2012; deHaan et al. 2020; Jayasinghe et al. 2021). Apart from the provisioning services like supply of food, the role of Sri Lankan homegardens in providing regulating and supporting ecosystem services like maintaining carbon stock, pollination, water retention, soil retention, etc. is well evident. Apart from this, cultural services like aesthetic and ornamental preferences and social relations through homegarden product sharing are found to be quite prominent (Saito et al. 2013).

The composition of Sri Lankan homegardens is reported to be different based on the different climatic zones of the country (Mattsson et al. 2013). Dry zone (with annual rainfall $\leq$1750 mm) homegardens have lower tree density when compared to wet zone (with annual rainfall $\geq$2500 mm) homegardens and are often larger in size. The biomass production in dry zone homegardens is often limited by moisture, leading to a weaker capacity to replenish soil fertility by organic matter inputs than wet zone homegardens (Sangakkara and Frossard 2014). Wet zone homegardens are characterized by higher level of plant diversity and a denser canopy structure than dry zone homegardens due to climatic conditions favourable for high growth (FAO 2009; Pushpakumara et al. 2010; Ali and Mattsson 2016). Wet zone of the country also records a high population density, higher urbanization, low land availability, a developed infrastructure and high opportunity for off-farm jobs. An estimation reported more than 400 different woody species in Sri Lankan homegardens (Ariyadasa 2002) with a total of 153,493 million trees across 20 districts. The average density of trees in homegardens of Sri Lanka is varying from 20 to 475 trees per hectare.

10.3 Homegardens in Kandy

10.3.1 Kandy District: A Glimpse

The district of Kandy, with an area of 1940 km^2 of which land and an internal reservoir take up 98.04% and 1.96%, respectively (DCS 2020a), is located in the Central Province of Sri Lanka, as shown in Fig. 10.2. Its administrative capital is Kandy city which was named by UNESCO as a World Heritage Site, and it is well known as the last kingdom of medieval Sri Lanka (Priyantha and Harankahawa 2018) where the last monarch was betrayed by his own ministers to the British.

Located in the transition between wet and intermediate zone, Kandy district is mountainous and boasts much greenery. In 2019, forests and homegardens contributed to 33.03% and 35.03% of Kandy, respectively, and the built-up area covered only 1.53% of the district's land area (DCS 2020a). With an annual rainfall of about 1840 mm (Statistics Division Kandy 2020), the highest rainfall in 2019 was

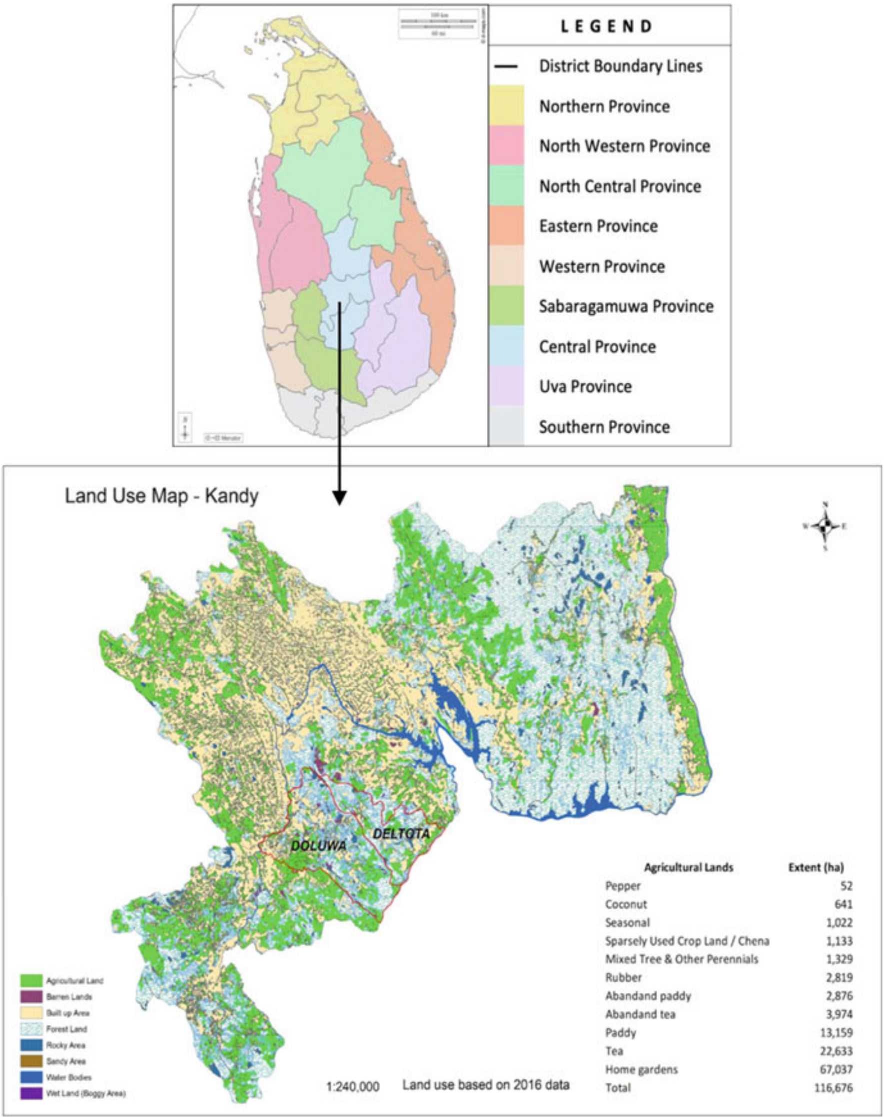


Fig. 10.2 Land use map of Kandy district based on data from 2016. (*Source*: SriCAT 2019)

in October while the lowest was recorded in January, and the observed temperature varied between 18.5 °C and 33.2 °C (DCS 2020a). The socio-demographic characteristics of Kandy district are given in Table 10.3. Kandy is sustained by the Mahaweli River, the longest river in Sri Lanka, which flows around Kandy city keeping it hydrated and luscious (UDA 2019). The river is fed by many streams, some of which are nourished by Udawatta and Wakarewatta forests that surround

Table 10.3 Socio-demographic characteristics of Kandy district of 2019

Indicator		Value
Area (in km^2)		1940.0
Population		1,475,627
Population density (per sq. km)		761
Urban population		182,974
Rural population		1,200,796
Gender	Male	703,588
	Female	772,039
Employment	Total	513,443
	Male	334,311
	Female	179,132
Literacy rate *(for the year 2012, in %)*		95.4

Source: DCS (2020a, b)

Kandy city (UDA 2019), but the water for the river is mainly obtained from the summits of the Knuckles mountain range (Statistics Division Kandy 2020).

10.3.2 Kandyan Homegardens and Their Characteristics

Homegardens in Kandy district are often called as Kandyan Homegardens (KHGs) or Kandyan forest gardens. While primarily found in Kandy district, KHGs can also be found in the other mid-country areas of Kegalle, Rathnapura, Matale and Kurunegala districts (Pushpakumara et al. 2010). Land use changes, in the form of deforestation for coffee and tea plantations, occurred under the British rule. The indigenous people had to adapt to losing forest resources; thus homegardens became even more important, especially in terms of conserving a wide variety of species (Wickramasinghe 1995). Kandy district was reported to have nearly 82,563 homegardens that covered about 32 per cent of its land area and are attached to about 70 per cent of households (FAO 2009; Mohri et al. 2013). Only the urban households were reported to either have no homegardens or they share homegardens with relatives in neighbouring households (Landreth and Saito 2014).

The composition of homegardens can differ from home to home in addition to the differences observed across regions and agroecological zones in Sri Lanka (Wickramasinghe 1995), depending on the physical characteristics of the area, the expected outputs as well as how much time the homeowners spend to tend to the plants. For example, if the homeowner has more time to spend in the garden, then plants that need more tending to may be available in the homegarden. Consequently, KHGs are uniquely diverse within the district and can consist of both agri-silvicultural systems and agro-silvopastoral systems (Wickramasinghe 1995; Pushpakumara et al. 2010).

The characteristics of KHGs, as reported by Pushpakumara et al. (2010), are given in Table 10.4. A study by Perera and Rajapakse (1991) determined that there were four distinct vertical canopy strata in the Kandy area, and the study by

Table 10.4 Characteristics of KHGs (Pushpakumara et al. 2010)

Characteristics	Value
Size of HG (ha)	0.05–2.5 (mean = 0.4)
Family size (numbers)	2–9
Number of vertical canopy strata	3–5
Canopy coverage (%)	45–98
Ground coverage (%)	50–90
Dominant soil type	Reddish brown latosolic to immature brown loam
Slope of land (%)	10–40
Number of species per KHG	37–143
Number of woody taxa per KHG	11–39
Tree species density per ha (over 5 cm DBH)	92–3736
Plant species density per ha (including annuals)	654–5663
Dominant natural vegetation of the area	Tropical wet evergreen forests
Land tenure	Mainly privately owned

Wickramasinghe (1995) determined that two neighbouring villages consisted of five layers, both of which are within the range stated in Table 10.4**.** In general, the most distinctive physical features of Kandyan homegardens are multi-storeyed canopy cover, high natural and cultivated species diversity and steep hillside gradients. The topmost layer of tree canopy includes valuable, mature timber species, such as sandalwood, teak, mahogany, jackfruit and coconut trees. The second layer below includes smaller fruit, ornamental, medicinal and spice trees, such as nutmeg and clove. The lowest layer consists of wild ground cover and cleared patches for cultivating annuals and vegetables. No specific arrangement is considered while planting, but there is significant correlation between crop and tree species, such as introduced *Gliricidia* trees cultivated to support pepper vines and provide high nutrient compost. In addition, as reported by Pushpakumara et al. (2010), about 15% of KHGs include livestock, principally cattle and poultry. Homegardens from the suburbs of Kandy city centre, Mapanawathura, Anniewatta and Dodamwala, as shown in Figs. 10.3, 10.4, 10.5, and 10.6 clearly demonstrate the different multi-storied layers and diversity of homegardens in Kandy. For example, the homegarden from Anniewatta (Fig. 10.4) is spread across an area of 0.18 ha and consists of a wide variety of plants and trees such as pomegranate, guava, star fruit, soursop, passion fruit vine, coconut, banana, papaya, bird chilli, governor plum, cardamom, rambutan and breadfruit as well as flowers. There is also a small apiary for beekeeping and a well which is used to water the plants using an electric motor. Similarly, a homegarden from Dodamwala (Fig. 10.6), located around 5 km from Kandy city centre, is mainly maintained as an ornamental garden with a small pond and includes various fruit-bearing and other trees like durian, wood apple, mango, red palm, mangosteen, king coconut, coconut, cashew, jackfruit, lemon, lime, curry tree, hummingbird tree, snow pea vines, neem, arecanut, guava, papaya, bird chilli,

Fig. 10.3 KHG with trees and a scattered plantation of cassava in the middle and a small stream

Fig. 10.4 KHG with diverse plants, trees and apiary in Anniewatta, Kandy

sweet orange, canereed, ivy gourd and nutmeg. The two homegardens from Mapanawathura (Figs. 10.3 and 10.5) clearly demonstrate the plant succession and tree canopy structure, one of the most distinctive characteristics of KHGs.

The different resource requirements of the different species mean that the plants can flourish in the varying KHG configurations and develop into self-sustaining systems (Wickramasinghe 1995; Pushpakumara et al. 2010). The most common

Fig. 10.5 KHG consisting of a variety of trees and plants including coconut, king coconut, fishtail palm and banana, next to an abandoned paddy field, which consists of a scattered planting of elephant ears

Fig. 10.6 KHG surrounding a house in Dodamwala, Kandy

floral species found in KHGs are stated in Table 10.5 from the study by Perera and Rajapakse (1991) which include the frequency of their occurrence as well as the uses of each species. Their results were obtained from analysing 50 randomly selected households in five sub-administrative divisions from Kandy district.

Table 10.5 Common floral species found in KHGs

Frequency of occurrence	Species	Life form	Uses	Canopy layer height (m)
90% (very common)	Jackfruit	Tree	Multipurpose	>10
	Coconut	Tree	Multipurpose	>10
	Cloves	Tree	Cash	2.5–10
	Avocado	Tree	Fruit	2.5–10
	Mango	Tree	Fruit	2.5–10
70–90% (common)	Coffee	Shrub	Cash	1–2.5
	Pepper	Climber	Cash	–
	Arecanut	Tree	Cash	2.5–10
	Gliricidia	Tree	Multipurpose	2.5–10
	Fishtail palm	Tree	Multipurpose	2.5–10
	Papaya	Tree	Fruit	1–2.5
	Alstonia	Tree	Timber	>10

Source: Perera and Rajapakse (1991)

As demonstrated in Table 10.5, the most common life forms in KHGs are tree species. While the produce from trees in KHGs are generally used for home consumption and/or sometimes sold, there may also be some sharing of extra food with neighbouring houses, relatives and friends, especially if that household with the homegarden does not require the additional income from selling the extra produce. This helps maintain social relations within communities.

It has been reported that the KHGs conserve about 50% of fruit crop species diversity in Sri Lanka (Pushpakumara et al. 2016). The diverse floral species found in KHGs also provide suitable habitats for a range of fauna to nest and feed. Pushpakumara et al. (2010) stated that the wide variety of fruit trees and low disturbance are among few reasons for the high faunal diversity observed in KHGs.

10.3.3 Importance of KHGs in Sustainability and Resilience Building

Climate change and its impacts are widely accepted around the world. As a developing country, Sri Lanka is especially vulnerable since Sri Lanka's GDP is highly dependent on the agriculture sector, which is sensitive to changes in the climate (Mendelsohn 2008). In fact, changes in rainfall patterns are already prevalent in Sri Lanka, and it has forced farmers to adapt in several ways to protect their livelihood like changing cropping patterns and adjusting sowing date (Marambe et al. 2018). The farmer is a key player in the adaptation of agroecosystems, and in developing countries, this means the farmer has to rely on his instincts and own innovation rather than new expensive technologies (Verchot et al. 2007).

Verchot et al. (2007) suggested that an agroecosystem, such as a homegarden, that is well adapted and houses high diversity is less sensitive to changes in climate and also enables the farmer (or homeowner) to quickly adapt to any changes.

Accordingly, agroforestry systems such as KHGs are sustainable systems due to the many benefits they provide. These include high biodiversity and conservation of endemic species, acting as carbon sinks, hindering soil erosion and nutrient leaching, enabling nitrogen fixing, controlling pests and diseases and connecting canopy patches (De Zoysa and Inoue 2014; Marambe et al. 2018).

Furthermore, the presence of a high density of trees in homegardens may provide much needed resilience to climatic changes (De Zoysa and Inoue 2014). For example, the inclusion of a large number of trees provides many advantages over changing rainfall patterns; these include longer roots that are able to reach deeper into the soil for water and nutrients, higher water infiltration due to the more porous soils that also have a better cover from the canopy helping to reduce run-off and erosion, better soil aeration due to the higher evapotranspiration of trees and having trees that yield better value produce than row crops (Verchot et al. 2007; De Zoysa and Inoue 2014). While more research into the resilience that can be provided by these systems is required, it has been reported that homegardens that are diverse and dense, and also include livestock, are able to endure climatic changes (Verchot et al. 2007). This means that even with the impacts of climate change, homes with agroforestry systems such as KHGs will be able to sustain the lives of those who rely on them.

10.3.4 Threats to Homegardens

Pushpakumara et al. (2012), based on reports over the 20-year period before his 2012 study, stated that homegardens in the wet zone experienced fragmentation and urbanization, causing degradation to homegardens. This refers to the fact that the quality of ecosystem services that KHGs were once able to provide had deteriorated. In addition, farmers are increasingly choosing to replace traditional homegarden tree species with high yielding cash crops by clearing a part of their homegarden area to sustain their needs, thus converting the highly diverse homegardens into lands with mono crops and reduced vertical layers, which may lead to a loss in canopy cover, carbon stocks and genetic material (Pushpakumara et al. 2012, 2016). Despite this, the study by Herath et al. (2021) shows that the overall extent of homegardens in the Mahaweli Upper Catchment area, which includes Kandy district, have increased by 60% (approximately 32,000 ha) between 1992 and 2017 through the conversion of agricultural lands (excluding paddy) and some tea land. At the same time, the study reports that 1000 ha of homegardens were lost due to urbanization. As it was highlighted, it is extremely important to ensure and retain high biodiversity in these newly converted homegardens so that the ecosystem services provided are of high quality.

Households with homegardens often perceive the disservices from wild animals, insects and other pests, and this threatens the high biodiversity of homegardens (Mohri et al. 2018; deHaan et al. 2020). In the study by Mohri et al. (2018), macaques, boars and porcupines were observed to be the primary culprit, and the households stated that these incidents have only grown over the years. This is also

Fig. 10.7 Bitter gourd (**a**) and guava (**b**) covered with plastic bags and bottle containing methyl eugenol on namnam (*Cynometra cauliflora*) (**c**), to protect the fruits from pests and insects

confirmed by deHaan et al. (2020), who also adds rats, mice and squirrels to the list, and by Melvani et al. (2020), who further added giant squirrels, grey langurs, elephants and peacocks. Consequently, some owners abandon homegardens while others change various aspects to discourage/stop the wild animals from venturing in to cause damage. An example of this is clearing surrounding canopy so that macaques do not have a direct path to reach the homegarden (Mohri et al. 2018). People also resort to shooting at the macaques and other pests such as giant squirrels (sometimes with rubber bullets) to scare them away; however, this is a very temporary solution. In addition, when food is primarily used for domestic consumption, they are less inclined to use pesticides on the produce; thus, they will find other methods to protect their produce. Examples of this are provided in Fig. 10.7. If such methods do not work, they are likely to eliminate the species of flora that attracts the pest (Melvani et al. 2020). For example, banana plants were infested with snails at a homegarden, and the snails eventually moved to attacking the other plants in the garden; thus, the only solution for the homegarden owner was to eliminate the banana plants completely.

Wild animal incursions and attacks from insects and pests mean that households may be unable to sustain their needs and thus depend on outside markets and that households are not able to replace damaged crops with new plants as the wild animals will destroy the new plants as well (Mohri et al. 2018). Changing of the homegarden structure or composition (such as from food crops to only spices or eliminating certain species) leads to loss in biodiversity, while abandonment will lead to the formation of secondary forests that are ideal ecosystems for these very same wild animals to thrive, creating a feedback loop that is likely not beneficial for the household or the community (Mohri et al. 2018; deHaan et al. 2020). It is therefore important to conserve remnant forest patches surrounding these areas to ensure wild animals do not feel the need to venture into homegardens (Melvani et al. 2020).

Another threat to KHGs is the succession by secondary forest which leads to the loss of agricultural diversity—without active human management, endemic plants covering the ground are often out-competed by dominant secondary forest species, including invasive coffee, or lack of sunlight in the ground because of unpruned tree canopies. KHGs provide almost a quarter of household staples, and abandonment increases vulnerability to market price fluctuations, especially expensive vegetables. Other threats include climatic changes causing unpredictable rainfall which forces homegarden owners to seek alternative income sources (Mohri et al. 2013), unavailability of labour to harvest produce from homegardens, lack of interest in younger generations to continue the gardening practises and reduction of available land to expand homegardens due to high population density and urbanization (deHaan et al. 2020). Finally, another important threat identified is the loss of the traditional and cultural knowledge that has been passed down for generations due to the structural changes being made to homegardens as well as younger generations not taking part in homegarden activities (deHaan et al. 2020).

10.3.5 How Can Homegardens Be Incorporated in Urban Planning Strategies in Kandy

Kandy city of the Kandy Municipal Council (KMC), being the second largest city in Sri Lanka, experiences major congestion and threats to the cultural heritage and environmentally sensitive sites (UDA 2019). To alleviate these issues, fostering developmental corridors between special-inclined suburban centres was proposed in the Kandy Town Development Plan from 2019 to 2030 by the UDA (2019) as illustrated in Fig. 10.8. This means that certain activities from the central business district (CBD) of Kandy will be pushed towards the surrounding towns of Katugastota, Kundasale-Digana and Peradeniya, and these will be developed further to accommodate the needs of the growing population of Kandy city. It is expected that focussing development on these areas will control/halt the unplanned development occurring in environmentally sensitive areas and landslide-prone areas. In this plan, it is also proposed that the Udawatta and Wakarewatta forest reserves are protected due their importance in terms of environmental services and scenic beauty. Furthermore, environmental sensitive zones are to be declared, and open spaces in the form of parks are to be established.

With the planned expansion into neighbouring towns, it is important to ensure that the greenery and climate that Kandy is known for are protected. The benefits provided by homegardens will greatly compliment this and, in addition, provide areas of high carbon stock compared to other open spaces. Open spaces such as parks and golf courses are seen by urban planners to be more in line with the image of urban areas (Drescher et al. 2006).

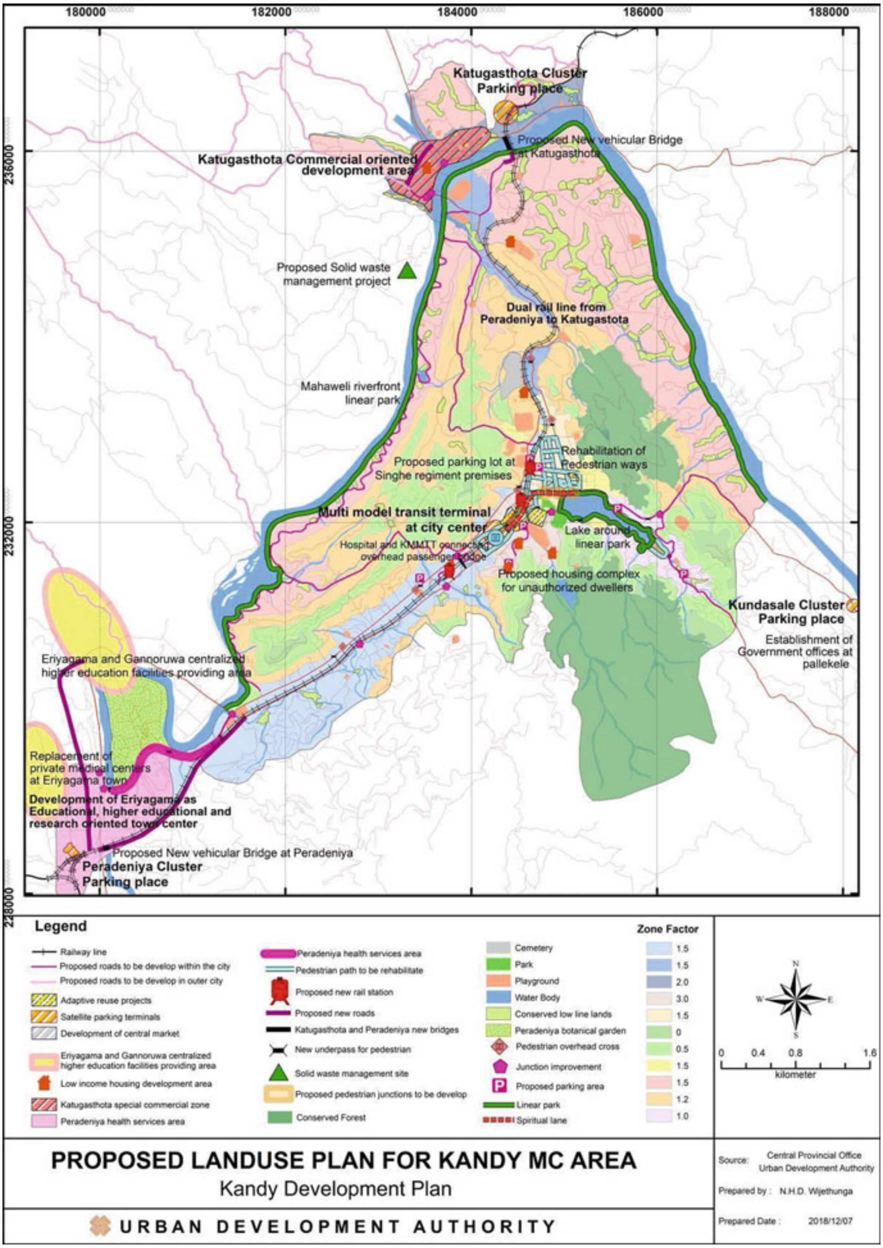


Fig. 10.8 Proposed land use plan in the Kandy Town Development Plan 2019–2030 by the UDA (2019)

Mattsson et al. (2013) proposed expanding homegardens into abandoned and degraded lands, and this can be incorporated into the planned development and expansion of Kandy city. Therefore, it is first necessary to identify any abandoned or degraded lands along these developmental corridors and in cluster towns that have the potential to be converted into homegardens. Then, owners of the lands can be incentivized to convert the lands into homegardens instead of selling the land for construction. Incentives can include, among others, promoting homegardens and highlighting their importance and benefits and providing seeds or seedlings of crops free of charge or at a low cost. However, it is also necessary to determine the cause of abandonment and propose solid strategies and provide access to new technologies to alleviate the issues faced by the homegarden owners.

It is also imperative to ensure that proper land zoning is implemented to protect surrounding forest patches from clearing for construction or other purposes so that wild animals and other pests do not need to venture into homegardens in urban areas in search of food. The establishment of these urban homegardens will also conserve the biodiversity, provide food security and improve the hydrology of the developing urban areas (Mattsson et al. 2018). Land zoning can also be used to specify the certain land areas of the planned development that can only be used to establish homegardens.

10.4 Conclusion

Demographic changes and globalization pressurize the existing traditional agroforestry systems like homegardens, with visible changes in urban areas. Commercialization is leading to oversimplification of homegardens. This leads to disappearance of homegardens and the traditional knowledge associated with it and subsequent loss of species richness, the genetic diversity it contains and the ecosystem services. The high structural and floristic diversity of Sri Lankan homegardens reflects the unique biophysical environment and sociocultural factors under which they exist. Vast and diverse number of plants around the home and in direct and constant interaction with its owners fulfils specific economic, social and cultural needs of the garden owners as well as provides biological conservation, carbon sequestration and such other intangible yet valuable benefits to the society. Kandyan homegardens present distinctive biophysical characteristics that make them multifunctional and sustainable. Irrespective of the demographic pressures and expansion of urban areas, Kandy district has still been able to maintain the homegardens as they can be considered as ecological assets of Kandy that helped to socially connect its inhabitants and sustain the community for the last 2000 years. However, the multiple existing threats like urbanization, commercialization, wildlife threats, economic changes, climatic variations, etc. endanger the existence and sustenance of Kandyan homegardens in future. In addition to the different programmes and strategies adopted by both the national and regional government, it is required to create awareness among the local people, especially the younger generation about the values of homegardens and also involve them in conservation and maintenance so that they develop a sense of ownership towards these gardens and maintain them in future. Kandyan homegardens demonstrate ideal examples of microscale agroforestry systems that can be practiced and implemented. Hence, reinforcing and augmenting the Kandyan homegarden systems so that they continue to provide sustainable ecological habitats and other social and economic functions, and connect wild and other cultivated habitats, are important for the future adaptation of this globally important landscape.

Conflict of Interest Statement The authors report no conflict of interest for this publication.

References

Ali A, Mattsson E (2016) Individual tree size inequality enhances aboveground biomass in homegarden agroforestry systems in the dry zone of Sri Lanka. Sci Total Environ 575:6–11

Ariyadasa KP (2002) Assessment of tree resources in the homegardens of Sri Lanka. Bangkok, ECFAO Partnership Programme on Information and Analysis for Sustainable Forest management (FAO 2005)

Asmone AS, Conejos S, Chew MYL et al (2016) Urban Green Cover Protocol to Reduce Urban heat Island in Sri Lanka. Paper presented at the 4th International Conference on Countermeasures to Urban Heat Island, National University of Singapore, Singapore, 30–31 May and 1 June 2016

Basu M, Saito O, Hashimoto S, Dasgupta R (2020) Sharing place: a case study on the loss of Peri-urban landscape to urbanization in India. In: Sharing ecosystem services. Springer, Singapore, pp 197–213

Benedict MA, McMahon ET (2002) Green infrastructure: smart conservation for the 21st century. Renew Resour J 20(3):12–17

Cabral I, Keim J, Engelmann R, Kraemer R, Siebert J, Bonn A (2017) Ecosystem services of allotment and community gardens: a Leipzig, Germany case study. Urban For Urban Green 23:44–53

Calvet-Mir L, Gómez-Baggethun E, Reyes-García V (2012) Beyond food production: ecosystem services provided by homegardens. 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

Chenarides L, Grebitus C, Lusk JL et al (2021) Who practices urban agriculture? An empirical analysis of participation before and during the COVID-19 pandemic. Agribusiness 37(1): 142–159. https://doi.org/10.1002/agr.21675

Chiesura A (2004) The role of urban parks for the sustainable city. Landsc Urban Plan 68(1): 129–138

Corley J, Okely JA, Taylor AM et al (2021) Home garden use during COVID-19: associations with physical and mental wellbeing in older adults. J Environ Psychol 73:101545

DCS (2020a) District statistical handbook. Department of Census and Statistics. http://www.statistics.gov.lk/ref/HandbookDictionary. Accessed: 16 Jul 2021

DCS (2020b) Statistical abstract 2020: chapter XIV - education. Department of Census and Statistics. http://www.statistics.gov.lk/abstract2020/CHAP14. Accessed 16 Jul 2021

De Zoysa M, Inoue M (2014) Climate change impacts, agroforestry adaptation and policy environment in Sri Lanka. Open J For 04(05):439–456. https://doi.org/10.4236/ojf.2014.45049

deHaan R, Odame H, Thevathasan N et al (2020) Local knowledge and perspectives of change in Homegardens: a photovoice study in Kandy District, Sri Lanka. Sustainability 12(17):6866. https://doi.org/10.3390/su12176866

Dobbs C, Nitschke C, Kendal D (2017) Assessing the drivers shaping global patterns of urban vegetation landscape structure. Sci Total Environ 592:171–177. https://doi.org/10.1016/j.scitotenv.2017.03.058

Drescher AW, Holmer RJ, Iaquinta DL (2006) Urban homegardens and allotment gardens for sustainable livelihoods: management strategies and institutional environments. In: Kumar BM, Nair PKR (eds) Tropical homegardens. Springer Netherlands, Dordrecht, pp 317–338. https://doi.org/10.1007/978-1-4020-4948-4_18
Ernstson H, Van der Leeuw SE, Redman CL et al (2010) Urban transitions: on urban resilience and human-dominated ecosystems. Ambio 39(8):531–545
FAO (2009) Sri Lanka Forestry Outlook Study. Asia Pacific Forestry Outlook Sector Outlook Study II, Working Paper No. APFSOS II/WP/2009/29, Bangkok, FAO Regional Office for Asia and the Pacific
Galhena DH, Freed R, Maredia KM (2013) Homegardens: a promising approach to enhance household food security and wellbeing. Agric Food Secur 2(1):8. https://doi.org/10.1186/2048-7010-2-8
Herath HMBS, Pushpakumara DKNG, Hewson M et al (2021) Spatial and temporal changes of Homegarden land use as a tree resource outside forests in upper Mahaweli catchment of Sri Lanka: biophysical and socioeconomic determinants of major changes. Trop Agric Res 32(2): 229. https://doi.org/10.4038/tar.v32i2.8470
Hosseini MI, Anjomshoa E, Abdollahi AA (2015) Standardizing green space capitation of Kerman City, emphasizing on the environment and sustainable development. Mediterr J Soc Sci 6(5): 654–654
Jayasinghe BC, Hemakumara GPTS, Hewage P (2021) Socio-demographic factors influencing the extent of residential green spaces in Galle City, Sri Lanka. Int J E-Plan Res 10(1):58–83. https://doi.org/10.4018/IJEPR.2021010104
Khalil (2014) Quantitative evaluation of distribution and accessibility of urban green spaces (case study: City of Jeddah). Int J Geomat Geosci 4(3):526–535
Lafortezza R, Davies C, Sanesi G et al (2013) Green infrastructure as a tool to support spatial planning in European urban regions. iForest 6(3):102–108. https://doi.org/10.3832/ifor0723-006
Laghai HA, Bahmanpour H (2012) GIS application in urban green space per capita evaluation:(case study: City of Tehran). Ann Biol Res 3(5):2439–2446
Lal R (2020) Home gardening and urban agriculture for advancing food and nutritional security in response to the COVID-19 pandemic. Food Secur 12(4):871–876. https://doi.org/10.1007/s12571-020-01058-3
Land Use Policy Planning Department (2021) Land Use and Land Cover of Sri Lanka In: Sri Lanka Land Use Map - 2018 https://luppd.gov.lk/images/land_use_map/srilanka_land_use_map_2018.zip. Accessed 8 July 2021
Landon-Lane C (2004) Livelihoods grow in gardens: diversifying rural incomes through homegardens. Food and Agriculture Organization of the United Nations, Rome. http://www.fao.org/3/y5112e/y5112e00.htm#Contents. Accessed 14 July 2021
Landreth N, Saito O (2014) An ecosystem services approach to sustainable livelihoods in the homegardens of Kandy, Sri Lanka. Aust Geogr 45(3):355–373
Li L (2017) Is Colombo city, Sri Lanka secured for urban green space standards? Appl Ecol environ res 15(3):1789–1799. Doi: https://doi.org/10.15666/aeer/1503_17891799
Madsen MF, Kristensen SBP, Fertner C et al (2010) Urbanisation of rural areas: a case study from Jutland, Denmark. Geogr Tidsskr 110(1):47–63. https://doi.org/10.1080/00167223.2010.10669496
Marambe B, Weerahewa J, Pushpakumara G et al (2018) Climate variability and adaptation of Homegardens in South Asia: case studies from Sri Lanka, Bangladesh and India. Sri Lanka J Food Agric 4(2):7. https://doi.org/10.4038/sljfa.v4i2.61
Mattsson E, Ostwald M, Nissanka SP et al (2013) Homegardens as a multi-functional land-use strategy in Sri Lanka with focus on carbon sequestration. Ambio 42(7):892–902. https://doi.org/10.1007/s13280-013-0390-x

Mattsson E, Ostwald M, Nissanka SP (2018) What is good about Sri Lankan homegardens with regards to food security? A synthesis of the current scientific knowledge of a multifunctional land-use system. Agrofor Syst 92(6):1469–1484. https://doi.org/10.1007/s10457-017-0093-6
Mazumdar S, Mazumdar S (2012) Immigrant homegardens: places of religion, culture, ecology, and family. Landsc Urban Plan 105(3):258–265
Melvani K, Myers B, Palaniandavan N et al (2020) Forest gardens increase the financial viability of farming enterprises in Sri Lanka. Agrofor Syst. https://doi.org/10.1007/s10457-020-00564-9
Mendelsohn R (2008) The impact of climate change on agriculture in developing countries. J Nat Resour Policy Res 1(1):5–19. https://doi.org/10.1080/19390450802495882
Ministry of Mahaweli Development and Environment (2015) National adaptation plan for climate change impacts in Sri Lanka 2016–2025. http://www.climatechange.lk/NAP/NationalAdaptationPlan_RevisedFinal.26.10.2015.pdf
Mohri H, Lahoti S, Saito O et al (2013) Assessment of ecosystem services in homegarden systems in Indonesia, Sri Lanka, and Vietnam. Ecosyst Serv 5:124–136. https://doi.org/10.1016/j.ecoser.2013.07.006
Mohri H, Landreth N, Lahoti S et al (2018) Ecosystem services of traditional homegardens in South and Southeast Asia. In: Takeuchi K, Saito O, Matsuda H et al (eds) Resilient Asia. Science for Sustainable Societies. Springer, Tokyo, pp 95–121. https://doi.org/10.1007/978-4-431-56597-0_6
Niñez VK (1984) Household gardens: theoretical considerations on an old survival strategy. Potatoes in food systems report 1. International Potato Center, Lima, p 39
Perera AH, Rajapakse RMN (1991) A baseline study of Kandyan Forest gardens of Sri Lanka: structure, composition and utilization. For Ecol Manag 45(1–4):269–280. https://doi.org/10.1016/0378-1127(91)90222-H
Priyantha AAC, Harankahawa SB (2018) Island-wide construction raw material survey report on Kandy District. In: MR/CRM/17/2018. Geological Survey and Mines Bureau, Pitakotte, p 35. http://www.gsmb.gov.lk/web/images/pdf/Kandy/kandy-report.pdf
Pushpakumara DKNG, Wijesekara A, Hunter DG (2010) Kandyan homegardens: A promising land management system in Sri Lanka. In: Sustainable use of biological diversity in socio-ecological production landscapes: Background to the 'Satoyama initiative for the benefit of biodiversity and human well-being.' Technical Series no. 52. Secretariat of the Convention on Biological Diversity, Montreal, p 103–115
Pushpakumara DKNG, Marambe B, Silva GLLP et al (2012) A review research on homegardens in Sri Lanka: the status, importance and future perspective. Trop Agric 160:55–125
Pushpakumara DKNG, Heenkenda HMS, Marambe B et al (2016) Kandyan homegardens: a time-tested good practice from Sri Lanka for conserving tropical fruit tree diversity. In: Tropical fruit tree diversity: good practices for in situ and on-farm conservation, 1st edn. Earthscan from Routledge, Taylor & Francis Group, pp 127–146
Ranasinghe WC, Hemakumara GPTS (2018) Spatial modelling of the householders' perception and assess the potentiality to improve the urban green coverage in the residential areas: a case study from Issadeen town Matara, Sri Lanka. Ruhuna J Sci 9(1):44. https://doi.org/10.4038/rjs.v9i1.32
Rostami R, Lamit H, Khoshnava SM et al (2015) Sustainable cities and the contribution of historical urban green spaces: a case study of historical Persian gardens. Sustainability 7(10):13290–13316. https://doi.org/10.3390/su71013290
Saito O, Landreth N, Kawasaki J et al (2013) Ecosystem services of Kandyan Homegarden systems and Rural Livelihood under climate and ecosystem changes in Sri Lanka. 環境システム研究論文発表会講演集 41:357–364
Sangakkara UR, Frossard E (2014) Homegardens and Dioscorea species - a case study from the climatic zones of Sri Lanka. J Agric Rural Dev Trop 115:55–65
Semeraro T, Scarano A, Buccolieri R et al (2021) Planning of urban green spaces: an ecological perspective on human benefits. Land 10(2):105. https://doi.org/10.3390/land10020105

Senanayake IP, Welivitiya DDP, Nadeeka PM (2013) Urban green spaces analysis for development planning in Colombo, Sri Lanka, utilizing THEOS satellite imagery – a remote sensing and GIS approach. Urban For Urban Green 12(3):307–314. https://doi.org/10.1016/j.ufug.2013.03.011
Sofo A, Sofo A (2020) Converting home spaces into food gardens at the time of Covid-19 quarantine: all the benefits of plants in this difficult and unprecedented period. Hum Eco 48(2):131–139
Speak AF, Mizgajski A, Borysiak J (2015) Allotment gardens and parks: provision of ecosystem services with an emphasis on biodiversity. Urban For Urban Green 14(4):772–781
SriCAT (2019) Sustainable Land Management in Sri Lanka - LU-Map Kandy district. https://sricat.net/index.php/en/media-gallery/maps/176-lu-map-kandy-district. Accessed 15 July 2021
Statistics Division Kandy (2020) Statistical hand book 2020 - Kandy District. Department of Census and Statistics, Sri Lanka
Teuber S, Schmidt K, Kühn P et al (2019) Engaging with urban green spaces - a comparison of urban and rural allotment gardens in southwestern Germany. Urban For Urban Green 43:126381
UDA (2019) Kandy town development plan 2019–2030. Urban Development Authority. https://www.uda.gov.lk/attachments/devplan_detailed/Development%20Plans%202019-2030/Kandy/English.pdf. Accessed 16 July 2021
UNFCCC (2016) Intended nationally determined contributions. Ministry of Mahaweli development and environment, Sri Lanka (date of submission 2016-04-25). http://www.4unfccc.int/submissions/INDC/Submission%20Pages/submissions.aspx. Accessed 1 June 2016
UN-REDD (2015) Community based REDD+ (CBR+) country plan for Sri Lanka. http://www.redd.lk/web/images/contents/documentcentre/Community-Based-REDDSummary.pdf
Verchot LV, Van Noordwijk M, Kandji S et al (2007) Climate change: linking adaptation and mitigation through agroforestry. Mitig Adapt Strateg Glob Chang 12(5):901–918. https://doi.org/10.1007/s11027-007-9105-6
Weerahewa J, Pushpakumara G, Silva P et al (2012) Are homegarden ecosystems resilient to climate change? An analysis of the adaptation strategies of homegardeners in Sri Lanka. APN Sci Bull 2:22–27
Wickramasinghe A (1995) The evolution of Kandyan home-gardens. In: Halladay P et al (eds) Conserving biodiversity outside protected areas: the role of traditional agro-ecosystems. IUCN--the World Conservation Union; AMA-Andalucía; Centro de Investigación F. González-Bernáldez, Gland, Switzerland: [Andalusia, Spain], Madrid, pp 164–182
World Health Organisation (2017) Urban green spaces: a brief for action. World Health Organisation. https://www.euro.who.int/__data/assets/pdf_file/0010/342289/Urban-Green-Spaces_EN_WHO_web3.pdf. Accessed 5 July 2021

Sachini K. Jayakody is enrolled for Masters in Environmental Management at Kyoto University, Japan.

Mrittika Basu is an Assistant Professor in the Laboratory of Sustainable Rural Development, Graduate School of Global Environmental Studies, Kyoto University, Japan.

Opportunities for Improving Urban Tree Cover: A Case Study in Kochi

11

Kanchana Balasubramanian, Sidhtharthan Segarin, Priya Narayanan, and Pulakesh Das

Abstract

The unprecedented nature of human action has a direct relation to increasing heat, and unlike many other natural disasters, heat risk can be mitigated. Our engagement in Kochi helped prioritize urban heat as a risk, enable identification of potential areas for improving urban tree cover, and facilitate and establish a community-based strategy for continued efforts under the Cities4Forests initiative. Sentinel-2 satellite data was employed to generate the land use land cover (LULC) map, while Land Surface Temperature (LST) map was prepared using Landsat data. Two participatory mapathons were conducted with the local residents and city councillors of Kochi to assess spatial baseline of trees, potential areas for improving tree cover and restoration interventions using Open Foris Collect Earth tool. Focussed analysis was carried out in two wards of Vaduthala, Kochi. The LULC class-wise maximum potential estimates shows higher potential to improve tree cover in the built-up area (49.59%), followed by vacant land (34.77%) in Kochi city. Similarly, Vaduthala region shows maximum potential for vacant land (42.31%) and built-up area (40.38% area), wherein home garden (42.32%), plantation in the entire plot (28.84%) and boundary plantation (23.08%) are recommended as the most suitable interventions. The spatial analysis in Vaduthala indicated the potential for home garden in 96.11 ha (94.75%), avenue/linear plantation in 2.97 ha (2.93%) and mangrove in 1.65 ha (1.63%). Areas of existing tree cover and mangrove (31 ha) in Vaduthala are identified for

K. Balasubramanian (✉)
World Resources Institute India, New Delhi, India

University of Georgia, Athens, GA, USA

S. Segarin · P. Narayanan · P. Das
World Resources Institute India, New Delhi, India
e-mail: Sidhtharthan.Segarin@wri.org; Priya.Narayanan@wri.org; pulakesh.das@wri.org

S. Dhyani et al. (eds.), *Blue-Green Infrastructure Across Asian Countries*,
https://doi.org/10.1007/978-981-16-7128-9_11

protection. The generated data suggests the potential for tree-based interventions, which can improve urban liveability and provide long-term heat resilience in Kochi city.

Keywords

Cities4Forests · Nature-based solutions (NBS) · Heat resilience · Community-based approach · Mapathon · Urban heat island

11.1 Introduction

Extreme heat events are increasing across the globe, and cities are the epicentres of this invisible climate risk. Urban environments are becoming increasingly dense with ever more demand for space for development. Most of our cities are hot, dry, polluted and impermeable (Enzi et al. 2017). Over the past two decades, extreme temperature events have increased in frequency and severity around the world. A study states that trees in urban cities benefit 68.3 million people across 245 cities through reduction in summer maximum air temperatures by approximately 0.5 °C–2.0 °C (0.9 °F–3.6 °F) (McDonald et al. 2016). It has been well established that increasing tree cover and green spaces help combat urban heat island effects, increase urban biodiversity and have positive effects on health and well-being of people. Recent research shows that extreme heatwaves have increased the mortality of urban residents more than rural residents, over the last decade. Studies show that urban heat islands may result in a projected 8 °C increase in temperature in cities by the end of the century (Zhao et al. 2021). Heat islands are common in urban areas, resulting in higher daytime temperatures, reduced night-time cooling and higher air pollution levels. The higher variation in temperature results in heat-related deaths and illnesses amongst the vulnerable groups. It is projected that investing $100 million annually in tree planting could benefit 77 million people with cooler urban region (McDonald et al. 2016). Built environment in cities can be effectively redesigned and retrofitted to provide safe and liveable spaces using tree-based interventions.

To the best of knowledge, there is no comprehensive typology of tree-based restoration interventions in the literature to cover all types of tree interactions in an urban landscape. Most of the literature describes typology of tree intervention based on the interaction of trees in a city landscape or addressing urban environmental issues. In all these classifications, trees within the boundaries of residential and commercial spaces and trees along canals are missing. Similarly, there is no clear definition of trees in open spaces, either public or privately owned lands. Most classification in the literature is incomplete. Based on the historical evidence, a European study mentions three broad categories of tree-based interaction in the cities, depending on the tree plantation carried out in the European cities (Konijnendijk and Gauthier 2006). It includes urban woodlands, trees in parks and open spaces, and street trees. However, it is unclear if trees in open spaces include private or public spaces. The definitions are also overlapping in some cases. In addition to trees along streets, trees in other urban areas such as public spaces along canals, edges of rivers and avenues also fall under street trees. The Food and Agriculture Organization (FAO) guidelines on urban and peri-urban forestry categorize urban forests into city parks greater than 0.5 ha, pocket parks and gardens with trees less than 0.5 ha, trees on streets and other green spaces (Salbitano et al. 2016; FAO 2020). The FAO classification scheme does not encompass trees within residential and commercial complexes, trees in open spaces and those along canals. According to the Urban Greening Guidelines 2014, Government of India, tree interaction in an urban landscape is classified based on the pattern of interaction such as patch, corridor and network structure (Ministry of Urban Development 2014). The patch includes urban domestic gardens, public and private parks and urban forest patches, whereas the corridor consists of roads, avenues, walkways and urban greenways, and the network structure includes a network of patch and corridor patterns. However, using this definition, the categories to classify trees in open spaces and trees along the boundary of buildings is unclear. The lack of an all-encompassing typology of urban tree interventions calls for identifying a comprehensive list of possible restoration interventions for an urban landscape.

Some of the well-recognized restoration interventions are defined based on the literature. These include urban forest parks; gardens; trees along roads, rivers and canals; trees between buildings; trees in open lands; and remnant tree cover patches. It can operate at a scale from a single dispersed tree to a group of trees and patches of forest (FAO 2020). Trees along the roadside, median or pathways are called as linear or avenue plantations (Ministry of Urban Development 2014). It also includes single trees planted for aesthetic appearance along pathways, which is categorized as informal (avenue) plantations. Tree cover in the premises of houses is part of homestead garden or home garden (Niyas et al. 2016). Canal or riverbank plantations include trees along the banks of the canal or river, respectively. Boundary plantations are tree plantations along boundary walls of buildings or boundaries of open spaces (Ministry of Urban Development 2014; Konijnendijk and Gauthier 2006). Parks are public areas developed by the city that include tree cover and various other land covers, which are greater than 0.5 ha in size (Salbitano et al. 2016; FAO 2020). Mangrove plantations are present in backwaters, estuaries, lagoons and creeks (Mohandas et al. 2014; Kerala Forest Research Institute 2009). Urban areas also include patches of green cover that can either be present in private or revenue lands. Some instances define plantations in an open land as a block of trees or block plantation, which are part of social forestry, and plantations in institutions and open space within industrial premises (Gujarat Forest Department 2012; Guidelines for Plantation in the Industrial Parks of Telangana 2015). Since block plantation is a term primarily used in farm forestry, patches of green cover less than 0.5 ha are termed as gardens with trees, including patches of tree cover in private lands and institutional areas. Chaturvedi et al. (2018) developed an atlas for forest cover protection and tree-based restoration interventions at a national scale in India, integrating several thematic layers. However, such initiatives are limited to non-urban areas. This chapter highlights how participatory mapping can help identify potential areas for restoration at a neighbourhood scale and aid in building long-term heat resilience in Kochi city through the Cities4Forests (https://www.wri.org/our-work/project/cities4forests) initiative.

11.1.1 Mapathon: A Methodological Approach

Mapathon is an intensive, multiday event focussed on the collection and interpretation of spatial data. It is a participatory exercise developed based on the tool Collect Earth to systematically assess a landscape (Reytar et al. 2021). Collect Earth is a data collection platform developed by the Open Foris Initiative of the FAO (http://www.openforis.org/tools/collect-earth.html). Collect Earth enables assessing a landscape using very high-resolution satellite images available in Google Earth and Bing maps in conjunction with Google Earth Engine.

11.2 Study Area

Kochi is a coastal city that lies in the district of Ernakulam, located in the state of Kerala, India. Kochi has a complex estuarine system evolved due to the Periyar and Muvattupuzha rivers and many other small canals and backwaters. The Thevara-Perandoor canal is the longest canal of Kochi, running for about 10 km. Kochi Metropolitan Corporation (KMC) is spread over an area of 9,488 ha and has a population of 602,046 (Census 2011). The city is divided into 74 administrative wards. The seacoast is approximately 48 km in length, covering the entire Kochi Taluk in the Ernakulam district with more than 20 km^2 of mangroves forest area. About 80% of the city lies within 5 m of mean sea level, making residents highly vulnerable to sea level rise, coastal inundation and frequent storm surges during the monsoon months.

Nair et al. (2016) study, on run-off change due to urbanization using toposheet and satellite images in Cochin, reported that built-up area increased from 36.51 km^2 in 1968 to 48.07 km^2 in 2010. They observed the majority of the changes are due to the conversion of agricultural land and open spaces into residential, commercial and industrial areas. Urban heat intensity in the city is moderate to high during winter and summer and most intense in “compact mid-rise zones” in the central part of the city, mainly comprising tall buildings (9–24 m) (Thomas et al. 2014). The map below (Fig. 11.1) shows the urbanization context of Kochi city and its greater region, where a significant rise in urbanization is seen after 1990, and most of the new development in the last decade has occurred in the peri-urban region. The rapid peri-urbanization of the Greater Cochin region has increased ecological stress on the region’s rivers, canals and waterbodies and causes waterlogging, flood risk and coastal inundation.

11.3 Materials and Methodology

11.3.1 Data Used

The Sentinel-2 multispectral data was employed for land use land cover (LULC) mapping. The cloud-free Sentinel-2 data for 2019 was accessed from the Copernicus Hub (scihub.copernicus.eu/dhus/#/home). The Landsat satellite data was employed

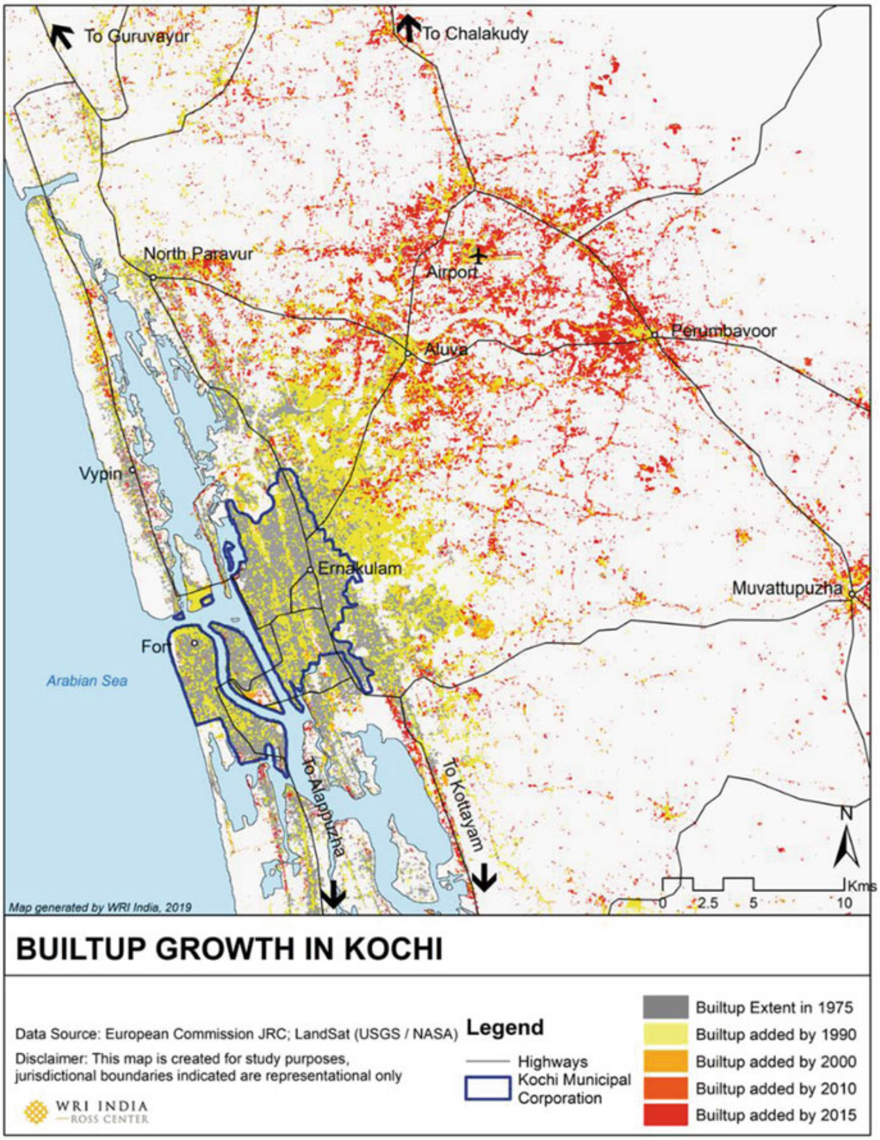


Fig. 11.1 Urbanization trends in Kochi (source: WRI India)

to understand urban heating in Kochi city. The thermal infrared (TIR) band of Landsat data was used to derive the land surface temperature (LST) maps for two time periods (pre-monsoon season of 2015 and 2019).

The first field visit was carried out between 15 and 17 October 2019 in KMC to collect the geolocation of different LULC classes. About 120 ground control data points were collected in the first visit. A second field visit was carried out between

27 February and 1 March 2020 to record and verify the potential areas for restoration as identified in consultation with the local people and government representatives. Additionally, a consultation program was conducted with the local representatives from the selected areas to identify the potential interventions for restoration.

11.3.2 Methodology

An urban heat island is an urban area that indicates a significantly warmer region than its surrounding regions. The land surface temperature (LST) maps were created as a surrogate to urban heat islands using the TIR band of Landsat 8 data. The digital number (DN) value image was converted into the top of the atmosphere spectral radiance band, which was then converted into at sensor temperature, followed by the land surface temperature. Moreover, the ground emissivity factor was applied, which was computed using the normalized difference vegetation index (NDVI) and proportion of vegetation cover (Pv) (Kaplan et al. 2018).

The mapathon event was conducted to collect data on LULC classes, existing tree cover and potential areas for tree-based interventions using citizen science approach. The baseline LULC map was prepared using Sentinel-2 data, where four spectral bands (blue, green, red and NIR) available at 10 m spatial resolution were used. Supervised maximum likelihood classifier (MLC) was applied using Quantum GIS (Q-GIS) software for LULC mapping. The attribute data (existing tree cover, potential area, ownership, etc.) was collected for each land parcel for various LULC categories through the mapathon. The LULC classes, such as highly built-up, major roads and shallow water, which are unsuitable for restoration or tree-based interventions, were excluded. Mapathon data collection was carried out for the remaining classes that includes mixed vegetation, built-up mixed, vacant mixed vegetation and waterbodies. The purpose of including mixed classes is to represent the highly heterogeneous urban landscape as well as considering the resolution of input satellite data. The mixed vegetation class indicates predominant vegetation cover, while the vacant mixed is dominated with vacant land, and the built-up mixed indicates predominant built-up areas. The raster LULC map was converted into polygon vector data, where a random feature collection tool was employed to generate the sampling plots for the mapathon.

Two participatory mapathon events were conducted in Kochi (first Phase: 9–-11 January 2020 at St. Teresa's College, Kochi; second Phase: 25 and 26 February 2020 at Alapatt Heritage, Kochi). These events brought together the participants who were trained in the "Collect Earth" tool with the local participants (local councillors, resident welfare association members and other local experts) from Kochi with intimate knowledge of the landscape.

11.3.3 Mapathon Process

The process of mapathon for Kochi was undertaken in the following steps:

11.3.3.1 Step 1: Planning Phase

WRI India discussed the process and requirements of mapathon with the Centre for Heritage, Environment and Development (C-HED), Kochi, which functions as the research and development wing of KMC. A series of meetings and discussions took place to demonstrate the process of mapathon and emphasize the importance of participation of ward councillors and residents of Kochi. The participants invited for the mapathon include ward councillors, representatives from the ward, members of resident welfare associations, self-help groups and residents of Kochi. The invitations were extended to all 74 wards of KMC to ensure representations from all the wards. The student volunteers from St. Teresa's College, Kerala Agricultural University and School of Architecture, Mookambika Technical Campus, participated in the mapathon event for data analysis and entry.

11.3.3.2 Step 2: Preparatory Phase

1. Identify exclusion area and delineate sampling plots for mapathon
   LULC map enabled identification of exclusion areas and delineating areas for mapathon data collection. About 40% of KMC comes under exclusion areas which include dense built-up and shallow water areas. The inland waterbodies in Kochi include canals, ponds and marshy wetlands, which were not identifiable due to coarse resolution of input data (10 m Sentinel-2). Hence, high-resolution Google Earth (GE) imagery was referred to delineate pond and canal, which are potential for boundary and canal bank plantations. The coastal marshy wetlands were also identified in GE imagery to detect ecologically suitable areas for mangrove plantations. In addition to the sampling plots, the ward councillor or the representatives from the wards also provided information on additional sites potential to improve tree cover. This way, the process ensured extending the intricate local knowledge and capturing potential areas to improve tree cover in KMC.
2. Preparation of the survey form
   Collect Earth survey form was prepared using the Open Foris Collect tool (Fig. 11.2). The following attribute data were collected for each sample plot:
   - Year of available high-resolution GE image.
   - Land use class.
   - Number of existing trees and dominant species.
   - Existing tree-based interventions.
   - Presence of potential to improve tree cover.
   - Land ownership details.
   - Additional comments.

11.3.3.3 Step 3: Mapathon Events

The mapathon events were conducted by pairing trained student volunteers with the local participants (Fig. 11.3). Student volunteers were trained on the Collect Earth tool and provided demonstrations and hands-on training to add information for plots provided by the local participants. Participants in the first mapathon included

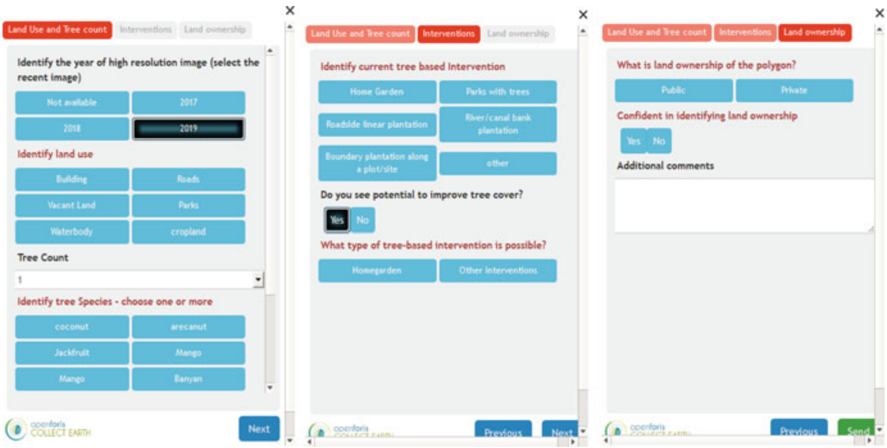


Fig. 11.2 The survey form used in mapathon

30 female student volunteers paired with 60 local people from Kochi, including 34 female and 26 male participants. The local participants included Kochi Mayor, ward councillors, representatives of the ward members and resident welfare association members. Participants in the second phase of the mapathon included one female and six male student volunteers paired with five local people (one female and four male participants) from Kochi resident welfare association members.

11.3.4 Data Curation and Identification of Suitable Wards for Deep Dive Analysis

Data collected in two phases of the mapathon were compiled and cleaned before further analysis. Collect Earth Saiku and Microsoft Excel were used for data cleaning and quantitative analysis. Mapathon data curation included data cleaning and verification of a sample of data on the ground. A deep dive analysis was carried out to develop restoration potential for selected regions. The purpose of selecting regions for the deep dive analysis was (i) total potential area identified for restoration, (ii) heat islands effect and (iii) willingness from the ward councillors and self-help groups. Spatial analysis was carried out to map the existing tree cover area using Google Earth Engine (GEE) employing Sentinel-2 data in the selected regions. The multi-temporal normalized difference vegetation index (NDVI) images were stacked to map the existing tree cover using a threshold-based approach. Composites of Sentinel-2 images from January to March 2019 with cloud cover $<1\%$ were used, where the NDVI threshold value of >0.36 provided the total green cover areas, including tree cover, grassland and scrubs. Further, the NDVI value of the driest period (21 February 2019) was used to remove the grassland and scrubs from the green cover area. The overall classification accuracy in tree cover mapping was estimated as 83%.

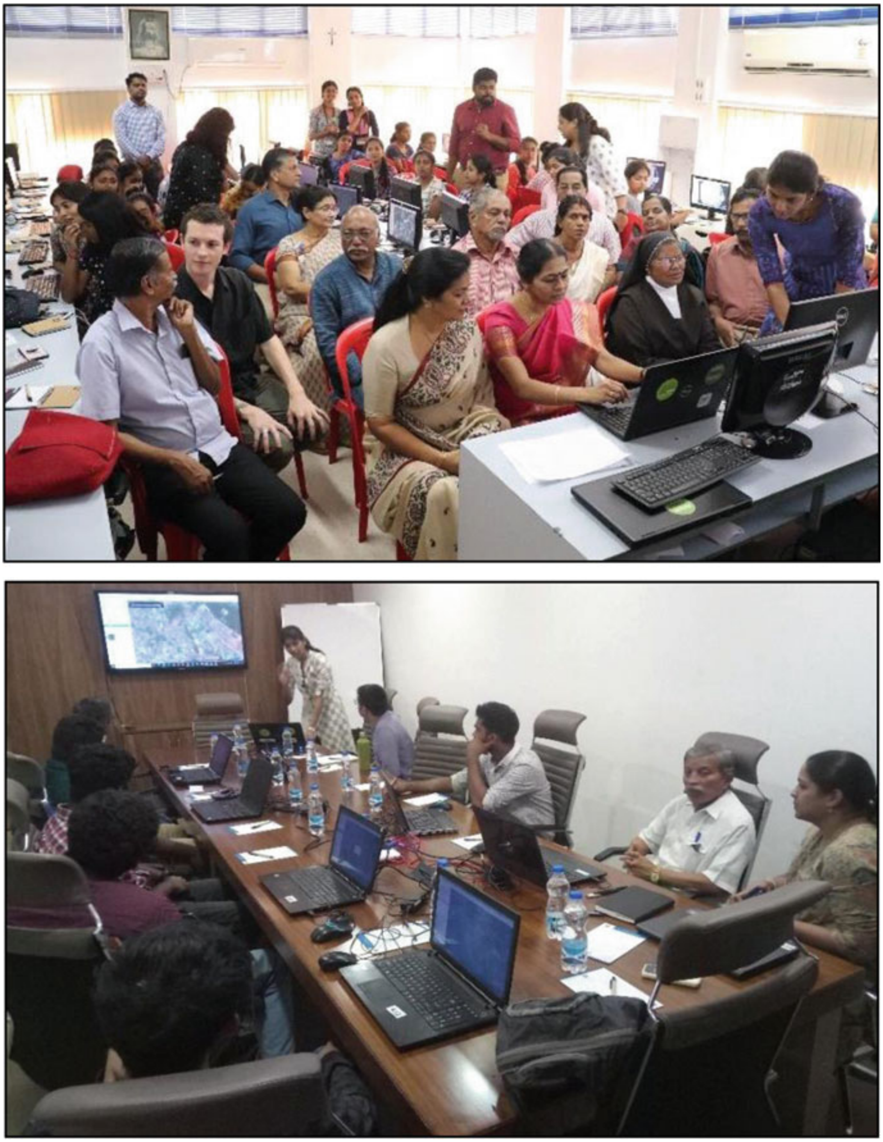


Fig. 11.3 Mapathon exercise in Kochi (photo credit: Nazreen C.J.). Mapathon Phase I (top) and Mapathon Phase II (bottom)

11.3.5 Developing the Restoration Interventions

The tree-based restoration interventions endorsed by the participants are framed and schematically represented in Fig. 11.4. Randomly placed, dispersed trees and

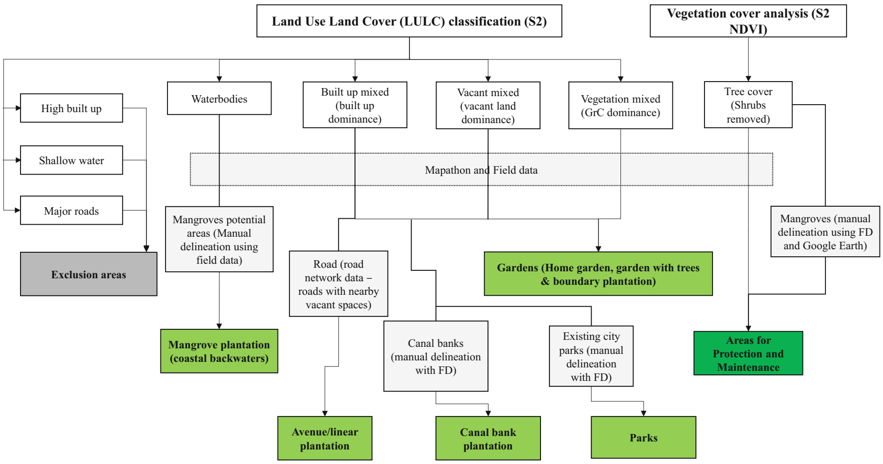


Fig. 11.4 Framework suggested for tree-based intervention in Kochi

boundary plantations are not identified as tree-based intervention, instead considered into other interventions based on the dominant LULC category.

- When the majority of LULC class is built-up:
  - Randomly placed or scattered trees or boundary plantation with built-up area: classified as home garden.
  - Garden or presence of trees: classified as home garden.
  - Roadside linear plantation: classified as avenue/linear plantation.
- When the majority of LULC class is vacant land:
  - Randomly placed trees or vacant land with trees: classified as plantations in a plot/garden with trees.
- When the majority of LULC class is vegetation:
  - Randomly placed trees: classified as gardens with trees.
- When the associated LULC class is canal:
  - Linear plantations along the canal/possibility to plant trees on the riverbank: classified as canal bank plantations.
- Moreover, the suggested potential areas for plantation in marshy land are classified as mangrove plantation.

11.4 Results and Discussion

The classification accuracy of the LULC map was assessed using the field observed data points, which indicated >89%overall accuracy (Fig. 11.5). The raster LULC map was converted into vector polygon data. About 80,000 polygons were generated from the LULC map, wherein 6000 polygons were selected using the stratified random sampling approach. These 6000 polygons cover about 7% of the total area

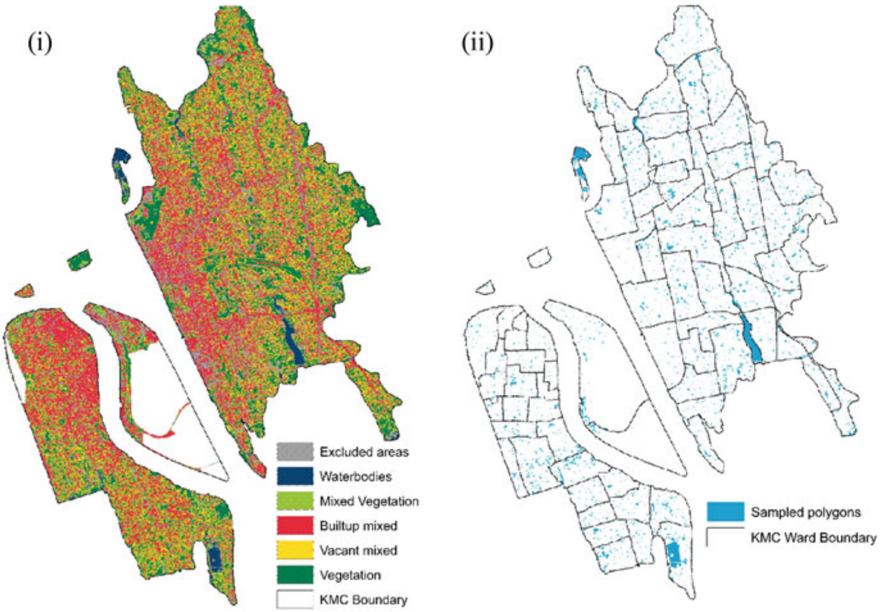


Fig. 11.5 (**a**) LULC map of Kochi Municipality area and (**b**) selected polygons for mapathon

used for mapathon data collection (Fig. 11.4). In the first phase, 2740 sampling plots and 1314 additional plots were assessed across 32 wards in KMC. From the first phase of the mapathon, it was observed that the willingness to participate in the exercise was low. Two major challenges were observed: (i) absence of participants for some wards caused improper representation of existing tree-based intervention of Kochi city, and (ii) under-representation of local participants was observed in some of the wards with larger area and higher sampling plots. Moreover, the average time spent by the local participants was significantly lower (~2–3 h) than the actual requirement. This resulted in incomplete data collection for some wards. Thus, a second mapathon event was conducted, focussing on the Fort Kochi region based on the convergence of other activities of Cities4Forests in Kochi.

11.4.1 Exiting Interventions and Restoration Potential for Kochi Based on Mapathon

The existing interventions, potential areas for restoration and suitable interventions were identified based on the existing LULC distribution, mapathon data and field observations. Restoration potential areas falling within 5 m buffer on either side of the roads is marked for avenue/linear plantation. The restoration potential areas falling along the canal banks are marked as canal bank plantations. The restoration potential for existing parks with less tree cover is classified as parks to improve tree

Table 11.1 Tree-based intervention and interpretation of existing and potential interventions

Tree-based interventions in Kochi	Definition and criteria	Interpretations from mapathon and field visit	
		Existing tree-based interventions	Potential restoration interventions
Avenue/linear plantation	Tree plantation along roads, rail and pathways, including single trees planted along the pathways and squares in public or private lands	Linear plantations along roads from mapathon	Linear plantations along roads from mapathon and field visit
Canal bank plantation	Tree plantation along the bank of the canal in the unpaved surfaces, which are revenue land	Canal bank plantation from mapathon	Canal bank plantation from mapathon and field visit
Mangrove plantation	Mangrove tree species found as coastal vegetation or backwaters or in marshy areas	Mangrove plantation from the field visit	Mangrove plantation from mapathon and field visit
Parks (enrich tree cover)	Public areas developed by the city includes tree cover and a variety of other land covers	Parks identified in the field visit	Parks with potential open spaces to enrich tree cover
Home garden	Tree plantation within the premises of residential buildings, which are private land	Home garden from mapathon	Gardens – Home garden – Boundary plantation – Gardens with trees (trees in a plot/trees in the entire plot/ dispersed or randomly placed trees from mapathon or recreational parks)
Boundary plantation	Trees along the boundary walls of institutional or industrial premises or along the boundary of open vacant land This can be private or revenue lands depending on the premises	Boundary plantation in mapathon and field visit	
Garden with trees	Patches of green cover in open lands, which are private or revenue lands	Trees in a plot/trees in the entire plot/ dispersed or randomly placed trees with existing tree cover	

cover. Other areas as built-up mixed, vacant mixed and vegetation mixed are classified as gardens, where home gardens, gardens with trees in institutional spaces and boundary plantations are possible (Table 11.1). The LULC-wise existing interventions were observed highest for the built-up area (63.53%), followed by vacant land (18.62%), wherein home garden (57.23%) and boundary plantation (25.67%) were dominated (Fig. 11.6a). The potential for tree-based restoration

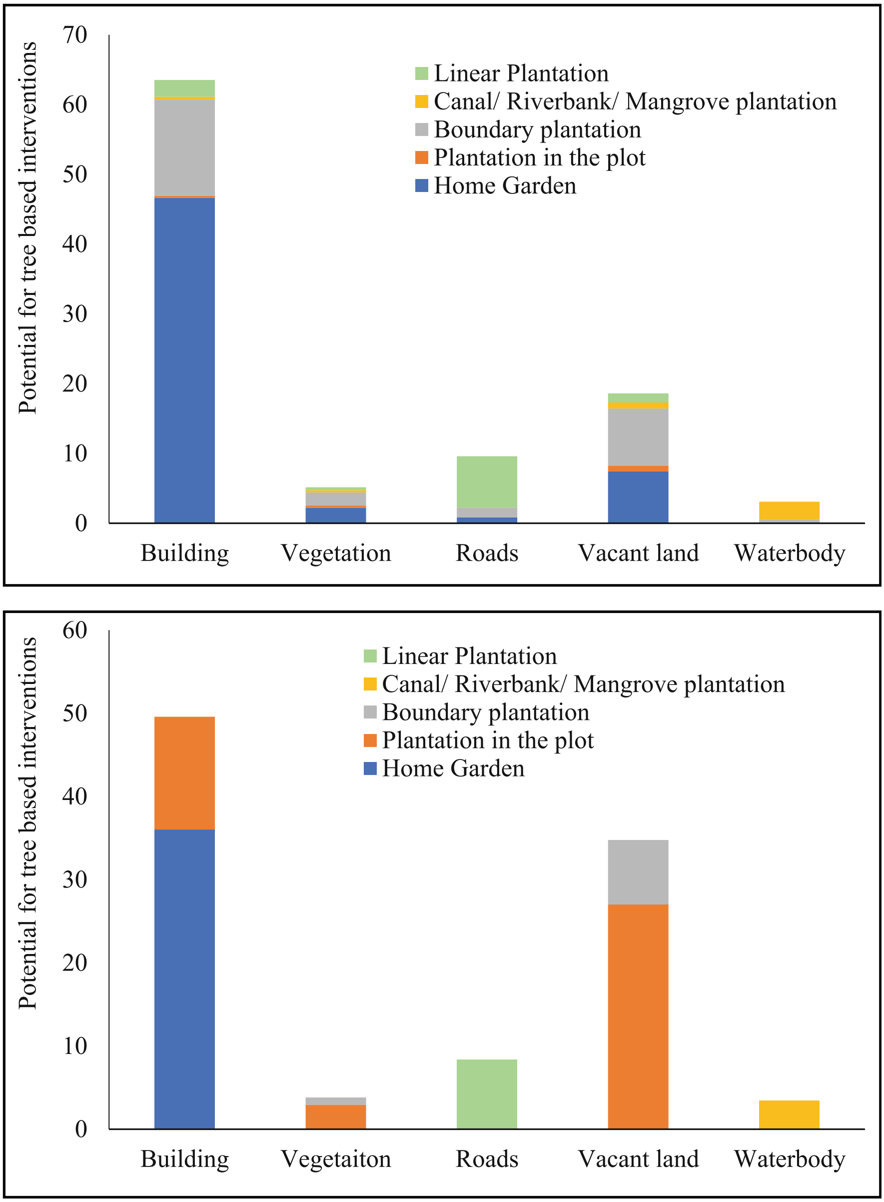


Fig. 11.6 (**a**) Existing and (**b**) potential for tree-based interventions against the existing LULC classes (*the mangrove plantation is merged with canal bank/riverbank plantation)

interventions for various LULC classes in Kochi is shown in Fig. 11.6b. The maximum potential was estimated for the built-up area (49.59%), wherein the dominant contribution is observed for gardens with trees (36.03%). The second highest potential was estimated for the vacant land (34.77%), wherein the plantation in the entire plot (27.01%) has been suggested as the dominant intervention type. Moreover, the existing canal bank/riverbank/mangrove plantation was observed in 4.16% area, while 3.44% area has been recommended under restoration potential. Linear plantation was recommended in 8.37% area of the total plot along the roads. The land ownership details assessed based on 51 plots reveal that more than 90% of the potential areas are private. However, the confidence level in identifying land ownership of public spaces is low. The lower confidence levels and small sample size indicate insufficient data on land ownership, which needs additional consultation with the Kochi Municipal Corporation.

11.4.2 Deep Dive Analysis

The LST change during 2015–2019 indicated an overall increase throughout Kochi, where the maximum increase was observed in the northern part of the Fort Kochi region (Fig. 11.7). It could be attributed to the higher proportion of settlement area compared to green the cover. In comparison, the change in LST was lower in the Willingdon Island and Ernakulam regions. During the field visits, it was observed that most wards in Kochi are densely populated, dominated by the built-up area. Moreover, the willingness to participate and buy-in for restoration was low in several wards. C-HED and a former Mayor also confirmed that the local people would express opposition to improve tree cover in Fort Kochi, given the trade-off with protecting the importance of heritage structures and buildings in the ward. This concern arises as some of the existing tree plantations are damaging the heritage building and threatening the longevity of the structures. Hence, a deep dive analysis was conducted in the Vaduthala region (wards 31 and 32) based on the availability of

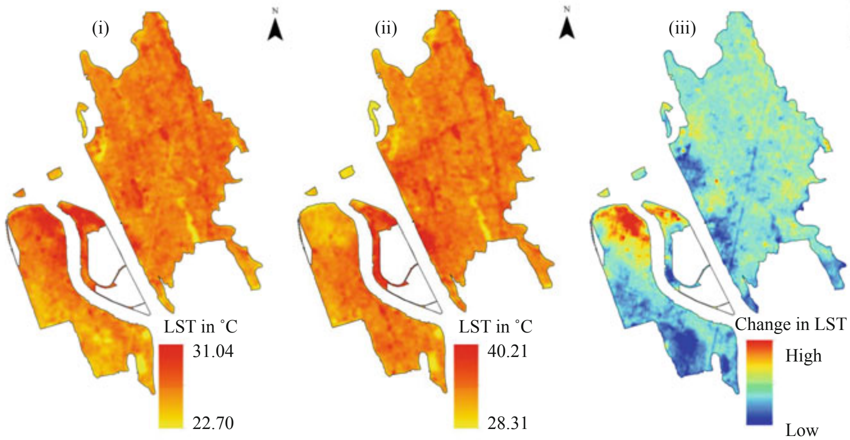


Fig. 11.7 LST change map for the KMC for (i) year 2015 (ii) year 2019 and (iii) change from year 2015 to 2019

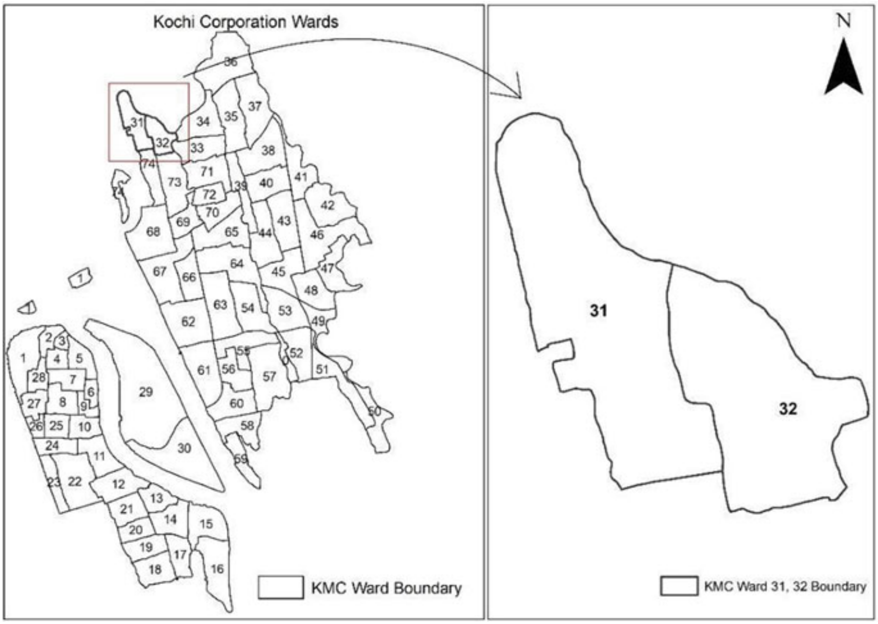


Fig. 11.8 KMC ward map and location of wards 31 and 32 (Vaduthala region)

mapathon data, significant areas for restoration and the interest of the local people (Fig. 11.8).

11.4.3 Existing and Potential for Tree-Based Interventions for Vaduthala Based on Mapathon

Mapathon data was employed to assess existing tree-based interventions using 124 sampling plots with 217 additional plots in the Vaduthala region. Baseline tree estimates for 2019 in the Vaduthala region are 5650 trees with a tree density of 38 trees per ha. It is observed that about 70% of the Vaduthala region has tree cover. The major tree species found in this region include coconut (*C. nucifera*), jackfruit (*A. heterophyllus*) and mango (*M. indica*). Coconut is the most prominent tree species, present in more than 80% of tree-covered areas of the Vaduthala region. Other tree species found are areca nut (*A. catechu*), peepal (*F. religiosa*), raintree (*S. saman* or *A. saman*), banyan (*F. benghalensis*), neem (*A. indica*), tamarind (*T. indica*), gulmohar (*D. regia*), bamboo (*Bambusa* sp.) and devil tree (*A. scholaris*).

The existing tree-based interventions identified by the participants in Vaduthala include home garden, parks with trees, boundary plantations, linear plantation, canal bank plantations and mangrove plantations. Boundary plantation was estimated in 41.81% of the total area, wherein 14.18% and 13.45% were observed in vacant land

Table 11.2 LULC class area (%) against existing interventions based on mapathon

Class	Home garden	Plantation in entire plot	Boundary plantation	Canal bank/riverbank/ mangrove plantation*	Linear plantation
Built-up	27.27	0	13.45	0	0.74
Vegetation	1.09	0	9.45	0	0.73
Roads	0	0	4.73	0	14.92
Vacant land	6.18	4.36	14.18	1.45	1.09
Waterbody	0	0	0	0.36	0

*The mangrove plantation is merged with canal bank/riverbank plantation

Table 11.3 LULC class area (%) under different interventions categories based on mapathon

Class	Home garden	Plantation in entire plot	Boundary plantation	Canal/ riverbank plantation	Mangrove plantation	Avenue/ linear plantation
Built-up	28.85	1.92	7.69	0	1.92	0
Vegetation	9.62	0	3.85	0	0	0
Roads	0	0	0	0	0	1.92
Vacant land	3.85	26.92	11.54	0	0	0
Waterbody	0	0	0	1.92	0	0

and built-up category, respectively (Table 11.2). The linear plantation was estimated in 17.48% area, wherein 14.92% area was associated with roads. The home garden has been estimated in 34.54% of the total areas, wherein 27.27% of the area were built-up area dominated. Moreover, 1.81% area was observed under the canal bank/ mangrove category.

The restoration potential classes for tree-based interventions as obtained via mapathon data analysis are given in Table 11.3. The results indicated maximum potential for home garden (42.32%), followed by plantation in the entire plot (28.84%) and boundary plantation (23.08%). The home garden is recorded in 28.85% of built-up area, followed by vegetation (9.62%) and vacant land (3.85%). The vacant land was mostly preferred for plantation in the entire plot (26.92%) and boundary plantation (11.54%). Participants also suggested potential for avenue/ linear plantation along the roads, canal bank plantation along the waterbody and mangrove plantation nearby built-up area.

11.4.4 Potential for Tree-Based Interventions Based on Spatial Analysis

About 17.76 ha in the Vaduthala region were excluded due to areas unsuitable for tree-based interventions. Potential area for mangrove plantations was identified in the coastal areas having a smaller number of trees. The roads, canal banks and existing parks were manually digitized using Google Earth and the information

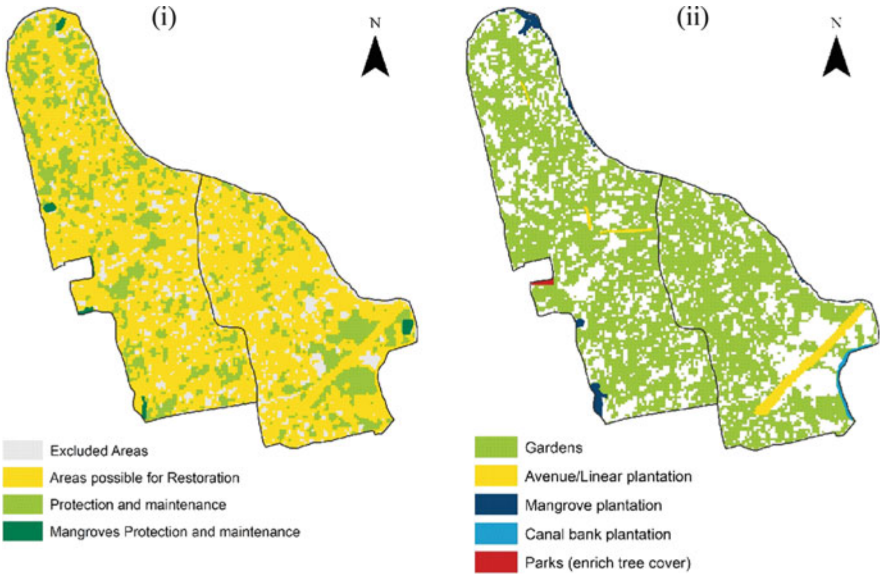


Fig. 11.9 (**a**) Estimated areas for protection and restoration and (**b**) the proposed tree-based interventions for the Vaduthala region, Kochi

collected on the ground. Existing mangrove and tree cover areas were identified using the NDVI threshold-based approach in 0.95 ha and 29.53 ha, respectively. The existing mangrove and tree cover areas can be protected and maintained (Fig. 11.9a). The restoration potential for tree-based interventions was recommended in the remaining 101.44 ha. Out of the total potential area, the maximum area was estimated for home gardens or gardens with trees (96.11 ha), followed by the avenue/linear plantation in 2.97 ha (Fig. 11.9b). About 1.65 ha were observed suitable for mangrove plantation, mostly identified in the coast in the northern boundary and two patches in the western boundary. Canal bank plantation is identified in 0.53 ha in the south-east boundary. Additionally, the ground-based observations indicated that the tree cover in vacant area (dominated with weeds) beside the Greater Cochin Development Authority (GCDA) park, Vaduthala, can be increased through suitable tree-based interventions in the western boundary (Figs. 11.9b and 11.10).

The major challenges in conducting mapathon event in an urban set-up include insufficient data collection due to (i) absence of participants for some wards, (ii) under-representation in some of the wards with respect to ward size and the number of sampling plots and (iii) lesser time spent by the participants in the data collection process. The analysis shows higher restoration potential for built-up and vacant land areas. Results obtained suggest that the tree-based interventions are observed more in built-up areas, along roads and vacant spaces in densely populated Kochi, while the areas preferred for restoration in the built-up and vacant space. A limited additional potential was observed along roads, canal bank and waterbody. In

Fig. 11.10 Location of the Greater Cochin Development Authority (GCDA) park, Vaduthala, identified in Google Maps (LHS) and field photo (RHS)

addition to improving biodiversity, air quality and urban heating, the green infrastructure helps in restoring the pre-development hydrology and mitigating water quality issues in cities (Rai et al. 2019). The lack of joint initiatives between top-level aspirations and on-the-ground implementation causes limited data on restoration activities (Stanturf and Mansourian 2020). The remote sensing and GIS-based data analysis and integration with the citizen science approach are useful for public involvement and awareness (Nilsson et al. 2007). In this purview, the current study and adopted approach may lead bridging the data gaps and land use planners for improving tree cover in urban areas.

11.5 Conclusion

Enabling city led NBS interventions to develop heat mitigation and adaptation strategies for resilient neighbourhoods is the most prudent way forward for resilient cities. Community-led actions to identify potentials for NBS interventions and increased awareness of the need for urban greening as city mitigation and adaptation solutions against climate change and extreme weather events will play a key role in achieving a more liveable and sustainable city. Through mapathon data analysis, we have been able to identify potential areas of tree-based intervention and the typologies in Kochi. Home garden and boundary plantation were observed as the dominant existing interventions, while home garden and plantation in the entire plot were mostly recommended for restoration in Kochi. In addition to mapathon data analysis, spatial analysis was carried out in the focussed region in two wards (31 and 32) of Vaduthala. Home garden (34.54%) and boundary plantations (41.81%) have been observed as the dominant exiting tree-based interventions. In comparison, home garden (42.32%), boundary plantation (23.08%) and plantation in the entire plot (28.84%) have been recognized as the maximum potential interventions in the Vaduthala region. Based on the spatial analysis, tree cover and mangrove were identified in 29.53 ha and 0.95 ha in the Vaduthala region, respectively. These areas have been recommended for protection. Around 101.44 ha was identified potential for restoration, wherein 96.11 ha area was recommended for home garden. The generated data and maps will be useful to build capacities amongst city decision-makers and other stakeholders on the importance of trees for improving liveability and long-term heat resilience.

Acknowledgements We are very grateful to the Kochi Municipal Corporation, the Mayor and councillors, the ward member, Resident Welfare Association (RWA) members and the students from St. Teresa's College, Kochi, and Kerala Agricultural University (KAU), Thrissur, for supporting in the mapathon data collection process. We also acknowledge all the student participants from various institutes (St. Teresa's College, Kochi; Kerala Agriculture University (KAU) Thrissur; School of Architecture Mookambika Technical Campus, Muvattupuzha, Kerala) and others who supported the mapathon process and field data collection. We are thankful to Dr. Nirmala Padmanabhan, Professor, St. Teresa's College, and Dr. Rajan, Director, Centre for Heritage, Environment and Development, for their constant guidance. The authors are also thankful to the WRI India members: Aparna Vijaykumar, Dr. KM Jayahari, Jaya Dhindaw, Dr. Ruchika Singh, Rajeev Malagi, and Raj Bhagat P for their continuous support and encouragement. We are thankful to our donors Norway's International Climate and Forests Initiative (NICFI) for supporting us under the Cities4Forests initiative. The mapathon is part of the Cities4Forests initiative in Kochi. Cities4Forests is a coalition of more than 70+ cities from around the world involving mayors' offices and other city agencies, such as public water utilities and offices of sustainability. Cities4Forests encourages peer-to-peer learning and connects cities with technical support from institutions with expertise in cities, forests, climate crisis, water, communications, finance, policy and social equity. This helps cities recognize their interdependence with the world's forests and use their political, economic and cultural power to protect and manage those forests for human well-being. Cities4Forests shares an aspiration to do what is within our power to reduce deforestation, restore forests (including more trees in cities) and manage forests more sustainably.

Conflict of Interest Statement The authors report no conflict of interest for this publication.

References

Census India (2011) Census of India. Office of the Registrar General and Census Commissioner, Ministry of Home Affairs, Government of India, New Delhi

Chaturvedi R, Duraisami M, Jayahari KM, Kanchana CB, Singh R, Segarin S, Rajagopal P (2018) Restoration Opportunities Atlas of India. Washington, DC: World Resources Institute.

Enzi V, Cameron B, Dezsényi P et al (2017) Nature-based solutions and buildings—the power of surfaces to help cities adapt to climate change and to deliver biodiversity. In: Nature-based solutions to climate change adaptation in urban areas. Springer, Cham, pp 159–183

Food and Agriculture Organization of the United Nations (FAO) (2020) Urban and peri-urban forestry. http://www.fao.org/sustainable-forest-management/toolbox/modules/urban-and-peri-urban-forestry/basic-knowledge/en/. Accessed November 2020

Guidelines for Plantation in the Industrial Parks of Telangana (2015). https://tsiic.telangana.gov.in/wp-content/uploads/2018/02/THH-Guidelines.pdf. Accessed November 2020

Gujarat Forest Department (2012) Status of tree cover in urban areas of Gujarat. Social forestry wing, Gujarat Forest Department, Gandhinagar

Kaplan G, Avdan U, Avdan ZY (2018) Urban heat island analysis using the Landsat 8 satellite data: a case study in Skopje, Macedonia. Proceedings. MDPI, p 358

Kerala Forest Research Institute (KFRI) (2009) The conservation of mangroves in Kerala: economic and ecological linkages. Kerala Forest Research Institute, Thrissur. http://docs.kfri.res.in/KFRI-RR/KFRI-RR353.pdf

Konijnendijk CC, Gauthier M (2006) Urban forestry for multifunctional urban land use. In: van Veenhuizen R (ed) Cities farming for the future: agriculture for green and productive cities. RUAF Foundation, Rome, pp 414–416

McDonald R, Kroeger T, Boucher T et al (2016) Planting healthy air: a global analysis of the role of urban trees in addressing particulate matter pollution and extreme heat. In: Planting healthy air: a global analysis of the role of urban trees in addressing particulate matter pollution and extreme heat. The Nature Conservancy, Arlington, VA

Ministry of Urban Development (2014) Urban Greening Guidelines, 2014

Mohandas M, Lekshmy S, Radhakrishnan T (2014) Kerala mangroves--pastures of estuaries--their present status and challenges. Int J Sci Res 3:2804–2809

Nair AM, Mohanlal L, Nabeela CRA et al (2016) Study on the impact of land use changes on urban hydrology of Cochin, Kerala, India. In: Urban hydrology, watershed management and socio-economic aspects. Springer, Cham, pp 69–82

Nilsson K, Åkerlund U, Konijnendijk CC et al (2007) Implementing urban greening aid projects—the case of St. Petersburg, Russia. Urban For Urban Green 6:93–101

Niyas P, Kunhamu TK, Ali SK et al (2016) Functional diversity in the selected urban and peri-urban homegardens of Kerala, India. Indian J Agrofor 18:39–46

Rai A, Minsker B, Sullivan W, Band L (2019) A novel computational green infrastructure design framework for hydrologic and human benefits. Environ Model Softw 118:252–261

Reytar K, Martin D, Landsberg F, et al (2021) Mapping together: a guide to monitoring forest and landscape restoration using collect earth mapathons. https://www.wri.org/research/mapping-together-guide-monitoring-forest-and-landscape-restoration-using-collect-earth. Accessed November 2020

Salbitano F, Borelli S, Conigliaro M, et al (2016) Guidelines on urban and peri-urban forestry. FAO Forestry Paper

Stanturf JA, Mansourian S (2020) Forest landscape restoration: state of play. R Soc Open Sci 7: 201218

Thomas G, Sherin AP, Ansar S, Zachariah EJ (2014) Analysis of urban heat island in Kochi, India, using a modified local climate zone classification. Procedia Environ Sci 21:3–13

Zhao L, Oleson K, Bou-Zeid E, Krayenhoff ES, Bray A, Zhu Q, Zheng Z, Chen C, Oppenheimer M (2021) Global multi-model projections of local urban climates. Nat Clim Chang 11(2):152–157

Kanchana Balasubramanian is pursuing her doctoral research in Integrative Conservation with emphasis on Forestry and Natural Resources at the University of Georgia.

Sidhtharthan Segarian works as a Research Analyst with the Sustainable Landscapes and Restoration programme at the World Resources Institute (WRI), Bengaluru, India.

Priya Narayanan is the Manager in Urban Forestry and Urban Development at the World Resources Institute (WRI), Bengaluru, India.

Pulakesh Das works as a Senior Project Associate with the Sustainable Landscapes and Restoration programme at the World Resources Institute (WRI), Bengaluru, India.

Changing People-Nature Linkages Around Green Infrastructure in Rapidly Urbanising Landscapes: The Case of a Protected Area in Bengaluru Metropolitan Region of South India

12

B. Dhanya, K. S. Harini, and H. C. Chetan

Abstract

Urban protected areas are vital green infrastructure elements that provide a host of co-benefits ranging from mitigation of urban pollution and heat islands to recreation, in addition to their well-established role in biodiversity conservation. This study uses an ecosystem services framework to understand the transformations in people-nature interactions around a recently established protected area in a fast-urbanising landscape in South India. Data collection involved methods ranging from ecosystem services ranking to key informant interviews with diverse stakeholder groups in the protected area. The study revealed that provisioning services such as grazing land for livestock and water for drinking and irrigation are the most preferred by local communities, while protected area regulations prioritise management for conservation and recreational benefits that benefit urban dwellers. Though the impacts of conservation on the focal species remain uncertain, the repercussions on local livelihoods are immense as forest-dependent communities are pushed out to rely on urban job opportunities. The study calls for careful integration of diverse ecosystem service uses and stakeholder perceptions to manage protected areas as green infrastructure elements for social-ecological benefits in urbanising landscapes.

B. Dhanya (✉)
Faculty of Ecosystem and Environment Management and Centre for Policy Studies, Indian Institute of Forest Management, Bhopal, India
e-mail: dhanyab@iifmbhopal.edu.in

K. S. Harini · H. C. Chetan
The University of Trans-Disciplinary Health Sciences and Technology, Bengaluru, India

S. Dhyani et al. (eds.), *Blue-Green Infrastructure Across Asian Countries*,
https://doi.org/10.1007/978-981-16-7128-9_12

Keywords

Ecosystem services · Social-ecological linkages · Vultures · Conservation · Urbanisation · Livelihoods · Stakeholders

12.1 Introduction

Protected areas (PAs or nature reserves) are a widely recognised strategy for safeguarding biodiversity at multiple levels ranging from species of conservation interest to iconic ecosystems and landscapes (Bruner et al. 2001; Eken et al. 2004; Hannah 2008). Over the 2000–2020 period, the global extent of PAs has increased from about 10% to at least 15% terrestrially (Secretariat of the Convention on Biological Diversity 2020). Globally 32.8% of protected land is under intense human pressure, and 57% of all PAs, concentrated in Western Europe, Southern Asia and Africa, encompass land under intense human pressure (Jones et al. 2018). With the current staggering rates of urban expansion globally, median distance from a nature reserve to an urban area is already less than 50 km in many regions (McDonald et al. 2008), and the extent of urban land within 50 km of PAs is predicted to triple from its 2000 value by 2030 (Güneralp and Seto 2013).

In many fast-urbanising landscapes, PAs have become the last remaining patches of critical green infrastructure providing a multitude of ecosystem services such as mitigation of urban pollution, heat islands and climate impacts, water provisioning and air purification. The role of urban green spaces in enhancing human physical and mental well-being and fostering social cohesion and stewardship is being better appreciated following the COVID-19 pandemic-induced lockdown across the globe (Ugolini et al. 2020; Kleinschroth and Kowarik 2020). Despite their diverse roles as vital green infrastructure elements, management of PAs in urbanising landscapes is fraught with intense conservation-development tensions. Tryzna (2014) describes certain distinctive stressors on urban protected areas, some of which include the large number of visitors who generally lack opportunities to experience wild nature, intense urban development, disproportionate impacts of crime, vandalism, littering, dumping and light and noise pollution and urban edge effects such as frequent and severe fires, air and water pollution and introduction of invasive alien species. Such impacts are more pronounced in urban peripheries of Global South where unplanned urbanisation has been driving astounding transformations of ecological commons and green infrastructure with serious repercussions on ecosystem-dependent communities (Mundoli et al. 2014, 2017).

India is estimated to add 416 million urban dwellers by 2050 and together with China and Nigeria will account for 35% of the projected growth of the world's urban population between 2018 and 2050 (UN 2019). Some of India's densest urban settlements are found just outside PAs (e.g. Sanjay Gandhi National Park in Mumbai and Bannerghatta National Park in Bengaluru) that are increasingly threatened by the growing urban sprawl (Rodary et al. 2018). Changing land use in peri-urban regions has disrupted the rural agricultural-forest continuum, blurring the historically fluid boundaries between human and wild spaces (Vikas 2019). The impact of urbanisation on ecosystem services from blue-green infrastructure elements such as lakes (D'Souza and Nagendra 2011; Mundoli et al. 2014; Derkzen et al. 2017), wooded groves (Mundoli et al. 2017) and agriculture (Patil et al. 2018) in the peripheries of Indian cities is well documented; however, changing people-nature relationships around peri-urban PAs has not received adequate academic attention in the Indian context. This study attempts to understand the transformations in social-ecological interactions around a recently established PA in the vicinity of India's fastest growing metropolis, Bengaluru. We seek to unpack the role of urbanisation in mediating the synergies and trade-offs between biodiversity conservation objectives and the sustainability of local livelihoods with a view to inform the management of the PA as a green infrastructure component for urban resilience.

12.2 Methodology

12.2.1 Study Area

Ramadevarabetta Vulture Sanctuary (RVS), located between the North latitudes 12°45′963″ to 12°45′115″ and East longitudes 77°18′291″ and 77°17′466″ in Ramanagara district in the Bengaluru Metropolitan Region, is a unique landscape with huge granite rocks (Location map in Fig. 12.1). Ramadevarabetta State Forest,

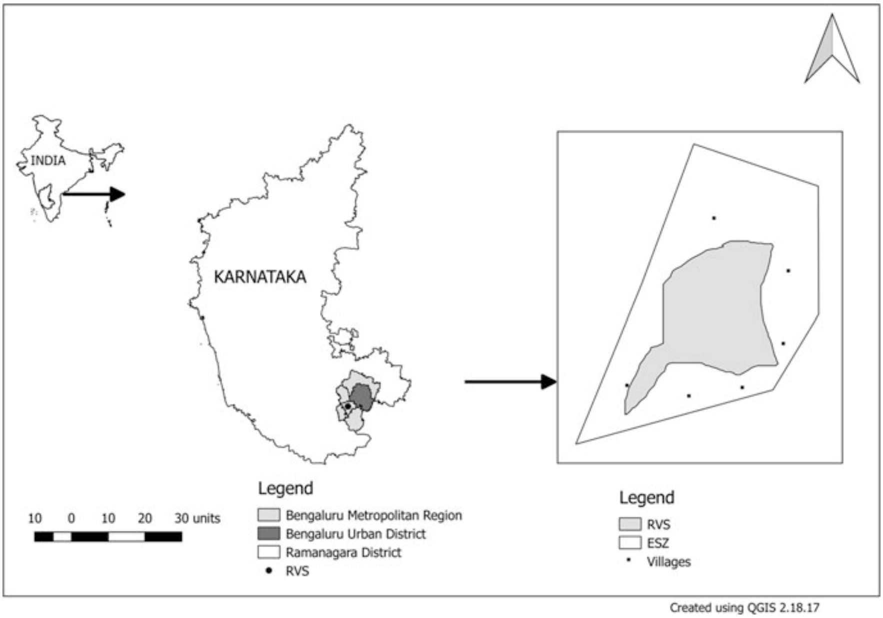


Fig. 12.1 Location map of RVS

originally notified under Section 17 of Mysore Forest Regulation Act in 1917, was declared as a wildlife sanctuary for protecting vultures in 2012.

From over 40 million in 1991–1992, the numbers of India's three vulture species of the genus *Gyps*, viz. the long-billed (LBV-*Gyps indicus* Scopoli), the slender-billed (*Gyps tenuirostris* G.R. Gray) and the white-rumped (*Gyps bengalensis*, J.F. Gmelin), have plummeted by a drastic 97–99.9% by 2007 (Bindra 2018). Social-ecological repercussions of this collapse have been catastrophic; millions of carcasses were left rotting in the absence of nature's most efficient scavengers thereby increasing the transmission potential of diseases such as tuberculosis, anthrax and foot-and-mouth disease, contamination of drinking water and explosion in feral dog population. The human health costs of vulture decline, and subsequent increases in dogs and rabies were estimated to be about $1.5 billion annually in India (Markandya et al. 2008). Cultural practices were also severely hit; for instance, sky burial rituals of Parsi community in India and Tibetan Buddhists, in which corpses are disposed of by vultures, had to be discontinued, and the dead is now burnt using solar power concentrators (Markandya et al. 2008). Extensive veterinary use of the anti-inflammatory drug diclofenac causing renal failure in vultures on ingestion of carcasses of treated livestock has been confirmed as the major reason for decline in Asian vulture populations (Prakash et al. 2012; Swan et al. 2006). In an effort to revive the vulture populations, the governments of India, Pakistan and Nepal withdrew manufacturing licenses for veterinary diclofenac in 2006 (Prakash et al. 2012).

RVS was reported as a unique vulture habitat in 2006, when a local NGO identified four species of vultures (LBV, Egyptian vulture (*Neophron percnopterus* L.), white-rumped vulture and king vulture (*Sarcogyps calvus* Scopoli)) as documented in archival records from the region (Lakshmikantha 2016). In 2012, an area of about 346 ha in Ramadevarabetta State Forest was declared as RVS by state government making it the first vulture sanctuary in India. Supporting around 150 species of birds belonging to over 40 families, RVS is part of the Important Bird Area network in India (Islam and Rahmani 2004). The tropical scrub and dry deciduous vegetation of RVS harbours fauna including sloth bear (*Melursus ursinus*, Shaw.), leopard (*Panthera pardus* L.), striped hyena (*Hyaena hyaena* L.) and jackal (*Canis aureus* L.) and flora such as ivory tree (*Wrightia tinctoria R. Br.*), used extensively in the local wooden toy-making industry. The famous Ramadevarabetta temple within RVS and the popularity of the hills as the shooting location of the blockbuster Bollywood movie *Sholay* draw large flocks of tourists year-round.

To further buffer the vulture habitat, an area of 708 ha within a radius of 130 m to 1.80 km around the boundary of RVS was declared as Eco-Sensitive Zone (ESZ) in 2017 (MoEFCC 2017). Stone quarrying, polluting industries, veterinary use of diclofenac, establishment of meat processing units and rock climbing and allied activities are prohibited within the ESZ, while commercial establishment of hotels and resorts and construction activities are regulated. Despite these measures, the vulture populations of RVS have dwindled considerably, with only two species, the LBV and the Egyptian vulture now found in the region, from the four species reported earlier. Partying at the hills leaving over liquor bottles and meat, movie crews flying drones (Chetan 2016), poaching of hatchlings and adult birds (Khanna 2015), influx of photographers trying to capture the birds and tourist traffic to the temple during festivals along with lack of animal carcasses and nesting trees in the surrounding urbanising landscape (Abhisheka et al. 2011) have been reported to have driven away vultures from RVS. There are six villages in the ESZ (Fig. 12.1 and Table 12.1) with a total population of around 11,000 (MoEFCC 2017). Local livelihood options including livestock grazing in forests (prohibited in PAs under Wildlife Protection Act (WPA), 1972), forest produce collection (banned under Wildlife (Amendment) Act 2002) and quarrying activities (prohibited in ESZ notification) have been curtailed following sanctuary and ESZ notifications. At the same time, urban developmental projects such as construction of a 4 km bypass for the Bengaluru-Mysuru highway through the ESZ and Satellite Town Ring Road within 200 m of the ESZ (Rao 2018) are being proposed and implemented. Recognising the role of urban growth in further complicating the conservation-livelihood interactions in this landscape, we traced the transitions triggered by these drivers in people-nature linkages around RVS.

12.2.2 Data Collection

Data collection involved multistage interactions with stakeholder groups including local communities around RVS, conservationists and government officials over March–December 2019, as described below.

12.2.2.1 Exploratory Interactions in Villages

Preliminary exploratory interactions were held with groups of eight to ten members in eight locations in the six villages located in the fringes of RVS (inside the ESZ) using a checklist to collect information on land use, cropping, livelihood options, dependence on forests and perceptions on the impacts of the conservation project and urban expansion. Each interaction lasted for 80–90 min, and multiple discussions were conducted in two villages to capture the variations in perceptions based on caste composition. All interactions happened in the local language.

12.2.2.2 Focus Group Discussions (FGD) for Participatory Ranking of Ecosystem Services and Disservices from Forests

Four villages where communities depend closely on forests at RVS, as identified in the preliminary explorations, were selected for further detailed ESS assessment. FGDs for ESS ranking were conducted in total six sites in the four villages, following Schreckenberg et al. (2016) and Drekzen et al. (2017). Each discussion lasted for around 2 h and was conducted in common gathering places such as *kattes* (a social gathering place under a tree, usually of *Ficus* species), schools, etc. Before the actual meeting, visits were made to the villages to meet people and invite them for discussion. It was ensured that people who have lived in these villages for more than 30 years and those belonging to all important caste groups are represented in the meeting. In villages with deep caste divisions, separate sessions were conducted for

Table 12.1 Profile of villages in the ESZ of RVS

Village number	Distance from PA (km)[a]	Area (ha)[b]	Population[b]	Major religions and castes[a]	Net sown area (ha)[b]	Major crops[a]	Irrigated area (% of net sown area)[b]	Livestock numbers[c]			
								Cattle	Buffalo	Sheep	Goat
1	2	151	978	*Iruligas*, *Vokkaligas*, *Bovi*, Muslims, *Bale banjegas*, *Koravas* and *Lingayats*	83.6	Ragi, mulberry and vegetables	42.11	131	10	22	47
2	2	588	1596	*Adi Karnataka*	361.2	Mulberry, papaya and banana	35.33	353	7	204	156
3	3	1581	3483	*Vokkaligas* and *Iruligas*	1026.4	Ragi, mulberry and vegetables	29.36	1074	29	357	558
4	5	234	1224	*Vokkaligas* and *Adi Karnataka*	122.2	Mulberry, ragi, mango and coconut	19.48	257	19	207	112
5	8	394	1286	*Vokkaligas*, *Kurubas*, *Lingayats* and *Madiwalas*	239	Paddy, vegetables, banana	29.57	327	5	30	57
6	11	588	2404	*Vokkaligas* and Muslims	346.8	Mulberry and vegetables	23.81	607	58	113	332

[a]Primary survey
[b]Ministry of Home Affairs 2011
[c]Department of Animal Husbandry and Dairying 2019

Table 12.2 ESS and disservices listed for participatory ranking exercises

Section	Group	Class type
Provisioning (biotic)	Wild plants/animals for nutrition, materials or energy	• Grazing livestock in forests • Fodder for stall-fed livestock • Fuelwood • Wild fruits and leaves • Medicinal plants • Other NTFPs
Provisioning (abiotic)	Surface/ground water for nutrition, materials or energy	• Surface/ground water for drinking and agricultural uses
Regulation and maintenance (biotic)	Regulation of baseline flows and extreme events	• Soil erosion control
	Atmospheric composition and conditions	• Temperature regulation • Air quality moderation
	Lifecycle maintenance, habitat and gene pool protection	• Habitat for useful or iconic flora and fauna • Pollination
Cultural (biotic)	Intellectual and representative interactions with natural environment	• Aesthetic benefits
	Spiritual, symbolic and other interactions with natural environment	• Tree worship and religious values

Source: Modified from Haines-Young and Potschin (2018)

different groups. Male and female group sessions were conducted separately in each site to assess the gender differences in the use of ESS from forests. Thus, a total of 11 discussions were conducted in the six locations to capture the changes in peoples' use of ecosystem services in the context of urban growth and the launch of the conservation project.

We used Ecosystem Services Approach to portray social-ecological interlinkages, following the Common International Classification of Ecosystem Services or CICES (Haines-Young and Potschin 2018). From each section of the CICES classification, types of ESS that were appreciated by participants in the exploratory interactions were selected for the ranking exercise. Fourteen ecosystem services were thus considered (Table 12.2), and additionally seven ecosystem disservices (conflicts with leopards (*Panthera pardus* L.), wild boars (*Sus scrofa* L.), sloth bears (*Melursus ursinus*, Shaw.) and snakes (Serpentes L.) and nuisance from mosquitoes, forest fire and antisocial activities due to increased tourist influx) that were highlighted in the interactions were also ranked. Important ESS benefits from PAs such as recreation and education did not figure in the ranking exercise as these were not found relevant for the local communities in the exploratory discussions.

Participants were asked to rank the services/disservices based on their relevance in two periods: present and past (20 years back when urbanisation pressure started mounting around Bengaluru). Picture cards depicting each service/disservice were used to facilitate people's understanding, considering that most of them are illiterate.

Each group arrived at a unanimous ranking of ESS after debating the relevance within the group and ordered the cards in columns based on the ranks, with the number one ranked service placed at the topmost position and lower ranks below that. After the ranking exercise, reasons for changes in preferences between the two time periods were elicited qualitatively in the group discussions.

12.2.2.3 Key Informant Interviews

Semi-structured interviews were conducted with seven key informants from the four selected villages using an interview guide consisting of open-ended questions. People who have lived in the village for more than three decades and members of local institutions like panchayats were selected as key respondents, taking care to include both genders and the major caste groups in the villages. Personal perceptions on the past and present land uses and livelihoods in their villages, experiences about changes in the use of ecosystems and impacts of the conservation project and urban growth were elicited in these interviews. Further three vulture conservationists were interviewed to understand the status of LBV—the focal species of conservation in RVS. A wildlife sanctuary official was interviewed to garner information on the management strategies for the sanctuary. Respondents were interviewed in locations convenient for them (house, office, etc.) for durations ranging from 90 to 120 min, except for the international vulture conservation expert who was interviewed over email.

12.2.3 Data Analysis

Data collected from interviews and ranking sessions were analysed using simple statistics such as percentages and averages wherever possible. Rank 1 was considered as the highest rank for both ESS and disservices with higher numbers indicating lower preferences. Ranks were converted to scores using the formula Score = 1/Rank. For instance, rank 2 was scored 0.5 (1/2) and so on. For both ESS and disservices, the lowest score was 0 (not considered for ranking indicating no relevance), while the highest rank was 1 for both groups. Spearman's correlation coefficient was worked out using SigmaStat 3.5 to assess the association of preference scores with gender and variation of scores with respect to the two time periods and distance of the village from the PA boundary.

12.3 Results and Discussion

12.3.1 Shift in the Use of ESS and Disservices from the Forests

Participatory ranking exercises revealed that provisioning services such as grazing land for livestock, water for drinking and irrigation and fodder for livestock are the most preferred by local communities across villages, followed by cultural and regulatory services, both in the past and present time periods (Fig. 12.2). Other

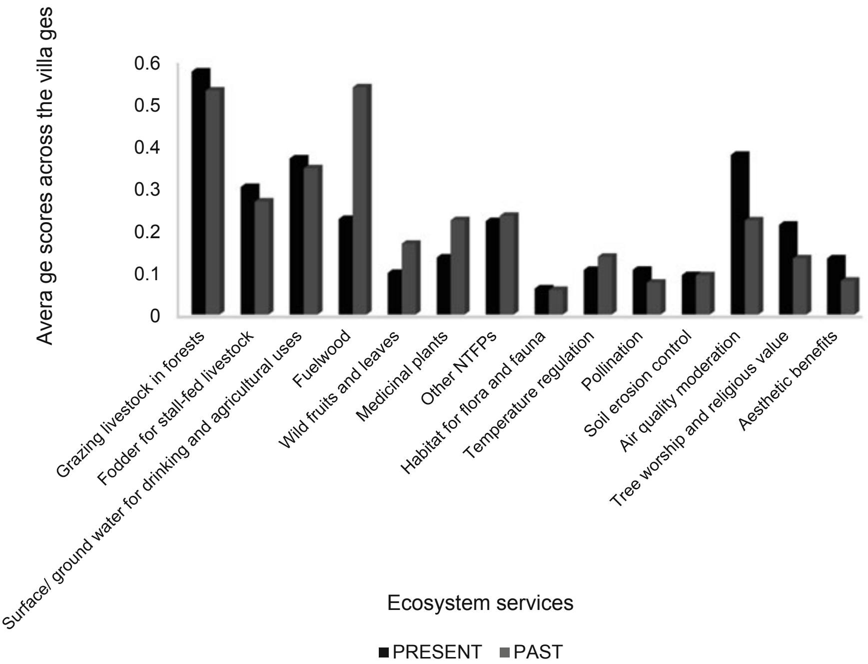


Fig. 12.2 Changes in ecosystem services from forests

studies also have shown stakeholders attributing higher relevance for provisioning services over regulatory and cultural services from forests (Agbenyega et al. 2009; Hartter 2010). Grazing livestock remains the highest ranked option across time periods. This is a crucial use of forests, especially for the socially marginalised and landless groups such as *Iruligas* whose prominent livelihood options have been forest produce collection and livestock rearing. The role of forest in water provisioning is also being acknowledged better now as indicated by the improved ranking—second position now—from third in the past. However, harvesting fruits and medicinal plants from forests has reduced as food from farms or markets and modern medicines, respectively, substitute these produces. Similarly, fuelwood collection which was the second most preferred use in the past is not ranked high in the present due to replacement by liquefied petroleum gas (LPG) as cooking fuel. But local communities continue to collect produce such as broom sticks for which there are no better replacements yet.

Preferences for the regulatory service—air quality moderation—and cultural services, religious and aesthetic benefits, have increased from past to present corollary to the decreasing subsistence use of forests. Shift in preference from provisioning ESS towards cultural services such as recreation in urbanising landscapes is well documented as in the case of ESS uses from lakes in Bengaluru (Derkzen et al. 2017). Growing concerns about air pollution from urbanisation, industrialisation and higher vehicular movement fuelled by increasing tourist visits to RVS have

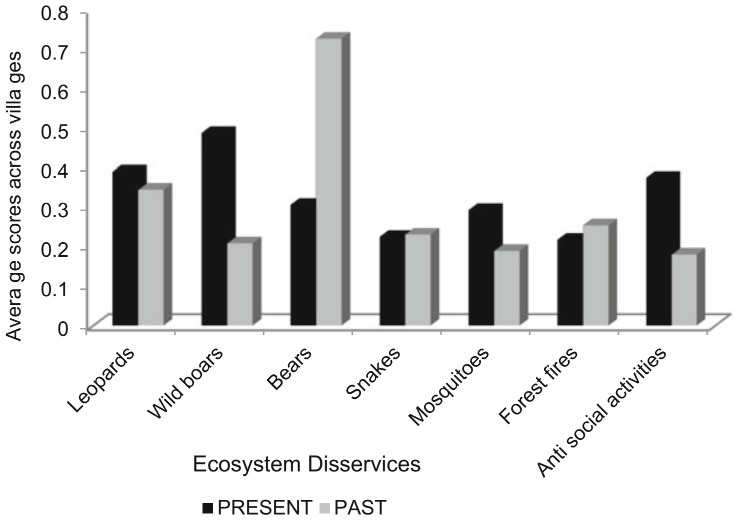


Fig. 12.3 Changes in ecosystem disservices from forests

sensitised people on the role of trees and green spaces in maintaining air quality, propelling this ESS to the third preferred position now. Other regulatory services—habitat for wildlife, pollination, soil erosion control and temperature moderation—were ranked consistently low in both present and past time periods.

ESS preferences also reflected the spatial and social locations of the stakeholders. Scores for the most appreciated service, grazing showed a significant positive correlation with the distance of the village from RVS (Spearman's rank correlation, rho $= 0.6$, $p < 0.05$). Communities in locations farther away from the forest tend to feel the negative impacts of grazing ban more severely in the absence of other grazing commons, while those close to the forest boundaries still use the peripheries for grazing as and when opportunities arise, when forest guards are absent or in some cases bribing the guards for gaining access. Absolute lack of access to forests for grazing resulted in higher appreciation of this service for respondents who live farther.

Men and women have distinct leanings in ranking the services; men preferred regulatory services like air quality moderation, while women preferred provisioning services like grazing and fuelwood collection. No significant correlation could be found between the ranks assigned by men and women for all services. Caste positions also influenced preferences, reflective of diverse livelihood dependencies on forests, e.g. landless scheduled tribes (*Iruligas*) value services such as NTFP collection and livestock grazing, while landowning agricultural castes consider water provision for irrigation as the major service. In villages with homogenous caste composition, preference is mostly tilted towards a single service.

Among the various disservices, attacks by sloth bear were the most prevalent in the past (Fig. 12.3). But in the present, bear raids have reduced, and wild boar and leopard attacks have increased. The key informant from FD attributed this change to improved food sources for bears inside the forest following planting of fruit trees such as *Tamarindus indica* L., *Ficus religiosa* L. and *Ficus benghalensis* L. (Manjunatha 2016). Community members pointed out loud music and noise from tourist resorts and quarrying activities as deterrents for bears from approaching human habitations. Higher food availability in forests led to an explosion in population of wild boars that now raid agricultural crops. Change in cropping pattern in response to crop depredation was also revealed in the exploratory interactions and FGDs. Sugarcane (*Saccharum officinarum* L.) and groundnut (*Arachis hypogaea* L.) which attracted bears were replaced by horticultural crops that are now prone to wild boar attacks. The major conflict currently is with leopards that raid on livestock, especially sheep. Up to 25–30 sheep were lost annually in some villages from leopard attacks, as reported in the FGDs. During 2010–2014, there were 355 cases of crop damage, 75 cases of cattle kills, 19 human injuries and 2 human deaths from wildlife conflicts in Ramanagara division for which compensations of INR 7,12,778, INR 3,17,250, INR 2,93,187 and INR 10,000,00 were paid by the Forest Department, respectively (Manjunatha 2016).

The use of forests as spaces for antisocial activities such as alcohol consumption is another disservice that has increased from past to present. Tourists who visit RVS party at the hills and leave over the liquor bottles and other trash (Chetan 2016). Both men and women expressed dissatisfaction over such activities, which they consider are consequences of urbanisation and changing cultural values. But women complained about local men also indulging in such activities, whereas men spoke about this as a disservice from outsiders. People found loud music played from tourist resorts on weekends and continuous vehicular movement in village roads disturbing. No trend was discernible with respect to distance of the village from the PA in ranking of the disservices.

12.3.2 Impacts of Urbanisation and Conservation on Livelihoods

Our research unravelled the multifarious impacts of the conservation project and urban expansion on livelihoods of local communities. Urban expansion was revealed to have mixed outcomes, for certain groups exacerbating the livelihood vulnerabilities created by the conservation project and for certain others ameliorating them, hinging on the resource endowments of the stakeholders. The ramifications were particularly acute on traditional livelihood activities such as animal husbandry and forest produce collection.

12.3.2.1 Impacts on Livestock Rearing

Both urbanisation and the conservation project has equally impacted livestock rearing, an important livelihood option for local communities such as *Adi Karnataka* and *Iruliga*. Spiralling urban demand for exotic crop produce, land, water and labour has been creating new agroecologies in peri-urban Bengaluru (Patil et al. 2018).

Within the ESZ of RVS, between 2009 and 2018, plantations of horticultural crops such as mango and coconut and timber species such as teak and *Melia dubia* grew by 47% and built-up area expanded by 14%, replacing agriculture and fallow lands (Harini 2019). In Ramanagara district, the extent of area under mulberry (*Morus* spp.) for sericulture jumped by 59% during 2008–2014 tied to the branding of Ramanagara as sericulture hub of Karnataka, while area under traditional rain-fed crop of groundnut (*Arachis hypogaea* L.) decreased by 53%, castor (*Ricinus communis* L.) by 43% and black gram (*Vigna mungo* (L.) Hepper) by 73%, during the same period. Such changes were facilitated by expansion of irrigation; irrigated area as percentage of net sown area increased by 20–200% in villages in ESZ between 2002 and 2011 (Ministry of Home Affairs 2001, 2011). Urban growth transforms traditional agriculture and animal husbandry practices on account of (a) conversion of grazing lands for low-cost housing or developmental projects and (b) shift to perennial cropping patterns such as horticultural orchards to cater to urban demand, precluding the grazing of livestock during non-cropping seasons. In these circumstances, forests continued to support the grazing needs of poorer communities. While landowning communities have responded to loss of grazing areas by shifting to hybrid breeds of cattle that are stall-fed, for landless people, maintaining such exotic cattle is not possible. High urban demand for milk also promoted dairying activities using exotic high-yielding breeds by resourceful groups. Those who could not afford such shifts have completely discontinued livestock rearing and now rely on itinerant wage labour and other urban job opportunities.

In 2012, exotic breeds constituted only 48% of the total cattle population in the district, whereas in 2019, 78% of all cattle raised were exotic. Sheep population declined by 65% during the same period (Department of Animal Husbandry and Dairying 2012, 2019). *Iruligas* have reduced or completely moved away from sheep rearing on account of loss of access to forests, other grazing commons and livestock depredation by wildlife. Around PAs in India, livestock depredation by carnivores is reported to have driven the shift from native to hybrid breeds of cattle, as hybrids are usually stall-fed avoiding conflicts with wildlife during grazing in forests (Bhardwaj 2018). Such changes also lead to declining tolerance from community for injury and death caused by carnivores in view of the enormous financial damage that farmers are likely to face on the loss of hybrid cattle (Bhardwaj 2018). But around RVS, livestock raid by wildlife was not highlighted as a reason for shift to hybrid cattle by dairy farmers; rather growing urban demand for milk was reported to have spurred intensive dairying activities.

12.3.2.2 Impacts on NTFP Collection

During FGDs and key informant interviews, people reported collection of diverse produces ranging from honey, fuelwood, bamboo, broomsticks to wild greens such as *seege* (*Acacia concinna* (Willd.) DC.), *bade* (*Foeniculum vulgare* Mill.), *thonde* (*Coccinia grandis* (L.) Voigt), fruits of *bel* (*Aegle marmelos* (L.) Correa), *elche* (*Ziziphus jujube* Mill.), *nerale* (*Syzygium cumini* (L.) Skeels), *amla* (*Phyllanthus emblica* L.), tamarind (*Tamarindus indica* L.), custard apple (*Annona squamosa* L.)

and roots of *magali* (*Decalepis hamiltonii* Wight Arn.) before the initiation of conservation project, but at present, occasional collection of honey, greens and firewood only is reported.

*Iruliga*s (also known as *kadupujararu* or the priests of the forests) the traditional hunter-gatherer community have been extremely forest-dependent, foraging on wild tubers, fruits and honey and hunting rats to meet dietary requirements. Sales of honey, *magali* roots and firewood were the mainstay of their livelihoods. *Iruligas* possess rich traditional knowledge on wild medicinal herbs and sustainable harvesting of honey from shrubs, hollow trees and rocks. The beehives are smoked to harvest honey in a process that doesn't harm the bees (Iyer 2016). The extensive ethnobotanical knowledge of *Iruligas* also comes in handy to avoid beestings using herbal repellents while collecting honey (Krishna 2020). If the hive is small with less honey, small amount is consumed in forests, and if large amounts are available, honey collected is brought back home and shared with others. Honey collected from shrubs is considered the tastiest and is consumed with wild tubers, dug from forests using a sharp stick and boiled and seasoned with forest peppers. Green leaves of several edible species are also cooked this way (Radhamani 2014). With restricted access to wild food sources, the community is now dependent on free supply of rice through food security programmes, and the low-quality food leads to poor health and nutritional outcomes including high rates of infant mortality and maternal mortality (Mutharaju and Kodandarama 2019). After PA declaration, some *Iruliga* community members were purportedly arrested for collecting and selling *Magali* roots.

Loss of access to natural resources from exclusionary conservation has been reported to cause severe impoverishment among poor, indigenous rural (Brockington and Igoe 2006; Dowie 2009) who depend heavily on "subsidy from nature" in the form of fodder, water, wild food and other forest produce to meet basic consumption and livelihood needs (West et al. 2006; Angelsen et al. 2014). Conservation displacement increases the importance of wage labour as communities whose traditional livelihood and labour opportunities are disrupted find themselves exposed to networks of capitalist exchange (Brockington and Duffy 2011), a trend visible around RVS.

12.3.2.3 Community Perceptions on Livelihood Impacts of the PA

Community involvement in the management of RVS and livelihood benefits from the PA has been minimal, as reported in our interactions. Community members are provided wage labour in pre-monsoon tree planting and plantation maintenance programmes of FD. FD has also organised training programmes on controlling forest fires, but community participation in the programme was underwhelming as reported by a key informant who is member of Panchayat. A few families in the *Iruliga* settlement near the entry gate of RVS run small shops for tourists, and one of them is employed as a guard with FD. This group had a positive outlook towards the conservation project despite its impacts on their customary livelihoods. Larger landscape level and socio-economic changes have been rendering traditional occupations non-viable even before the conservation project, in their opinion. For instance, FGD participants among *Iruligas* noted that honey resources in forests have dwindled as a consequence of intensive chemical use in surrounding mango orchards decimating honeybees. At the same time, people also acknowledged the importance of labour opportunities that mango orchards provide when forest-dependent livelihoods are declining. Thus, the urban demand for food produce has both positive and negative impacts on *Iruliga* livelihood sustainability. In fact, most respondents from this settlement portrayed urban growth as beneficial since amenities including road, electricity connection and accessibility to cities that facilitate exploration of wage labour opportunities have improved. However, *Iruligas* in other settlements away from the PA boundary expressed anguish against the conservation project on account of declining access to forests. Thus, the attitude towards and benefits from conservation is heavily determined by spatial location, i.e. proximity to the sanctuary, besides the social hierarchy in terms of caste position.

The landowning class that comprises of upper castes found opportunities in urbanisation in terms of higher sales and rental value of land and improved access to education and jobs. Land was acquired by government from villages for highway construction and other developmental projects including the proposed textile park for which 50 ha of land in one village has been identified (Department of Industries and Commerce G 2016). Land value has skyrocketed from INR 5000 per hectare to INR 1.75–2.5 million in the past decade depending on availability of irrigation and proximity to highway. The attitude towards conservation project was mostly neutral among upper castes except for concerns over the possibility of ESZ regulations restricting land sales, land use changes and further agricultural expansion.

Discontent was apparent among the Scheduled Caste group of *Adi Karnataka* with both urbanisation and conservation project. Urbanisation has made life more expensive and the community less cohesive in their opinion, with sociocultural practices such as collective celebration of festivals fast-disappearing. This community has been leasing out agricultural land from landowning groups, but with rampant land sales and conversion, it has become difficult to avail land on lease for farming, while the conservation measures ban the use of forests for livestock rearing.

The impacts of displacement created by protected areas are spread unevenly across diverse actors within local communities, and community responses are contoured around age, caste, class, gender and ethnicity (Hall et al. 2015; Dao 2016). Kabra (2019) while examining contestations within and between different caste groups to corner resource flows associated with state welfare in a conservation displacement site in central India argues that the distribution of risks and opportunities among the affected population tends to enhance existing socio-economic inequalities and power imbalances. Around RVS, both the landowning class and sections of the scheduled tribe community who expect economic gains from the conservation project expressed positive attitude towards it, while the subaltern caste group of *Adi Karnataka* perceive themselves as losers in the tussle between conservation and livelihoods, accentuated by urbanisation.

12.3.3 Impacts of Conservation on the Status of Vultures in the Urbanising Landscape

Our interactions with multiple stakeholders showed that RVS faltered in the stated objective of conserving critically endangered LBVs. LBV populations at RVS have plummeted from 22 to just 4 between 2011 and 2020, and since 2014, there has been no breeding success (2019 email from Mr. Shashi Kumar and Mr. Darshan, Karnataka Vulture Conservation Trust). At the same time, Egyptian vultures have become more abundant over years, from 5–6 to 30–35 facilitated by increased availability of silk pupae from sericulture units and chicken waste in the surrounding region (Kaggare 2019). LBVs feed only on medium- to large-sized carcasses like those of cattle and other large mammals and have not adapted to the decreasing availability of such food in the landscape.

12.3.3.1 Community Perceptions on Vulture Conservation

In group discussions and interviews with local community, respondents unanimously observed that vulture population in RVS had decreased from the past (from 50 to 100 a decade back to only 10–12 now); however, there were seasonal variations in their abundance, ranging from as low as 3 in summer up to 15 during monsoon season. Respondents related the reduction in vulture population to dwindling food and water sources, radiation from mobile towers, construction projects, decline in tree populations in the landscape and poaching by some traditional hunting communities. Though there is a general awareness about decline of vulture population, their ecological role as scavengers and the need of establishment of a sanctuary for vulture conservation were not recognised by local community. However, respondents were aware of and concerned about the change in rules about using the forests after declaration of sanctuary, especially restrictions on grazing.

Though ecological role was not appreciated, local communities want vultures to be conserved due to cultural values. Key respondents spoke about cultural practices such as offering food to vultures during death-related rituals on the belief that the deceased soul would enter heaven. This practice, according to them, is not followed now as vultures have become rare. Activating such cultural links therefore would be a crucial step towards building positive perceptions and a sense of ownership of the community towards conservation project. Markandya et al. (2008) and van Dooren (2010) recognise the role that Hindu mythology associated with a revered vulture God, *Jatayu*, has played in vulture conservation in Indian subcontinent.

12.3.3.2 Perceptions of Vulture Conservationists and the FD Official

As grazing ban was highlighted as the major negative impact of conservation project in community interactions, we solicited the opinion of conservationists on the usefulness of banning livestock grazing in the PA. There were contradictory opinions: some found the ban necessary because disturbance from any human movements, especially during feeding, could lead vultures to abandon the food and fly off, whereas others opined that grazing ban is not particularly beneficial to vulture population. Heavy tourist influx and ongoing construction of a highway bypass in the ESZ were recognised as huge threats to vultures by both the local community and conservationists. Noise from vehicular movement close to the nesting site of the vultures and from blasting of explosives to crack boulders for road construction could threaten the chicks or the just migrated vultures that are new to the landscape. Shift in animal husbandry practices from native breeds to exotic breeds with higher milk yield was recognised as a major driver of vulture decline in RVS by experts. Hybrid cattle are expensive to maintain and are therefore insured, and on death, burial of carcasses is mandatory to claim the insurance, leading to scarcity of cattle carcasses for LBV to feed on. Conservationists thus agree with the community perceptions of decrease in vulture numbers from food shortage.

There was no consensus between the conservationists interviewed about the best conservation strategy—studies to understand breeding and flying behaviour and establishment of captive breeding centres for vultures were highlighted as urgent requirements by the local vulture conservation group. Suggestions have been put forth to bring carcasses of mammals dying in road kills from PAs in the nearby districts for the vultures to feed on, after testing for presence of diclofenac. Some of the experts were sceptical about a sanctuary as conservation strategy, given that vultures routinely travel 50–100 km, and, in their view, addressing the threats, especially drug contamination of carcasses in areas of feeding potential, to create a safe zone for vultures is a more effective protection measure.

According to the FD official interviewed, vulture populations at RVS are showing an increasing trend, and nesting activity has also been noticed. The official justified the ban on livestock grazing as undisturbed forests are beneficial not just for the vultures but also for other wild fauna. FD has carried out afforestation projects in RVS, and consequently between 2009 and 2018, forest area has increased by 19.25% within the ESZ of RVS (Harini 2019). However, experts point out that barren landscapes are conducive for vultures as their huge wingspan demands large open spaces for landing. Afforestation therefore is not likely to have any direct positive impact on the area as a vulture habitat. LBV nests exclusively on rock cliffs, while Egyptian vultures could occasionally nest and roost on coconut trees. A growing area under horticultural plantations of coconut may marginally promote nesting and roosting of Egyptian vultures.

12.4 Conclusions

Several positive and negative feedbacks are conspicuous between vulture conservation, local livelihood sustenance and urbanisation process around RVS (as depicted in a driver-pressure-state-impact-response or DPSIR diagram in Fig. 12.4); for instance, expanding cultivation of coconut trees to cater to urban demand for the produce and waste from chicken shops and sericulture units enhancing EV population is a positive feedback, while the shift to hybrid cattle for meeting demand for milk from the city has led to shortage of cattle carcasses and high use of veterinary drugs negatively impacting vultures. Thus, as the vulture experts suggested,

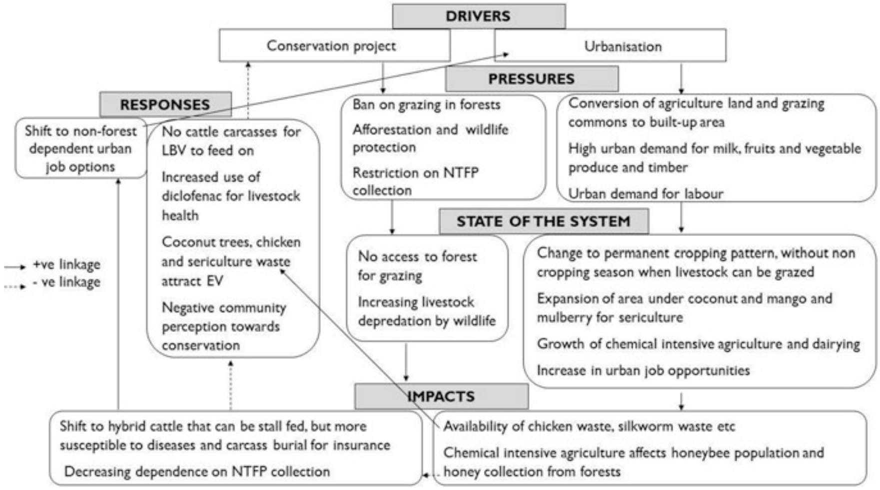


Fig. 12.4 DPSIR framework depicting conservation-livelihoods-urbanisation interactions

declaring a limited area as a sanctuary without acknowledging these larger landscape level social-ecological linkages might not lead to revival of LBV population.

Though the conservation outcome of establishing RVS remains uncertain as far as the focal species is considered, the repercussions on local livelihoods are conspicuous as forest-dependent livelihoods are pushed out to rely on urban job opportunities. While changing cultural preferences brought about by proximity to urban centres might also have influenced such shifts, restrictions on forest use is the major trigger. Diclofenac, the well-known driver of vulture extinctions, does not appear to be the major risk factor as of now owing to the shortage of cattle carcasses for vultures in this landscape. Social-ecological transformations including land use transitions, changes in agriculture and animal husbandry practices and alienation of the forest-dependent communities from fortress conservation approaches are bigger threats to the sanctuary and the vulture population. Under the intense influence of a metropolis, cultural and aesthetic values of green infrastructure for urban visitors are prioritised overlooking the local provisioning needs. It is ironic that while the local community is criminalised for minor livelihood use of forests, several ecologically devastating state-sponsored development schemes such as expansion of highways are carried out undeterred.

Conflicts of interests in and perceptions towards the conservation project are evident between stakeholder groups; local people clearly recognise grazing as the most preferred ecosystem service from the forest, whereas some conservationists and FD consider grazing as a threat for the vultures and other fauna. Recreational uses of the forests were not valued by local people; for FD, this is an important service as a potential revenue generator. Negative preference of local people towards PAs is triggered by the restriction of access to forests and lack of involvement in its management, and the probability of positive preference decreases with increasing dependence on provisioning services (Amin et al. 2015). The ecological impacts of excluding livestock have been often disastrous in other PAs in India; colonisation by invasive species and consequent changes in vegetation composition resulting in biodiversity decline have been reported in the absence of other herbivores to fulfil the functional role that livestock play in human-influenced ecosystems (Nautiyal and Kaechele 2007; Zeeshan et al. 2017).

12.5 Implications and Recommendations

The study clearly reveals the need for inclusive approaches of planning for green infrastructure—the PA in this case—in urbanising areas. A socially just approach of conservation should carefully craft mechanisms to integrate local livelihood needs as part of the conservation plan while remaining cognisant of the differential impacts of conservation on local populace. Buscher and Fletcher (2019) outline a new future of conservation that is "convivial" instead of exclusionary and preserves integrated spaces of diverse landscapes and governance systems within which multiple human stakeholders and other species can coexist equitably. An inclusive model of conservation that allows sustenance of livelihood activities of forest dwellers and leverage indigenous knowledge for protection of the ecosystem and its iconic raptors could be the way ahead for a robust conservation strategy in RVS. Cultural links with vultures enshrined in rituals, myths and folklore that were extolled during our interviews could be invigorated to ignite community's interest in the conservation project thereby creating integrated spaces of coexistence.

It is important to recognise that "community" is a heterogeneous entity with intrinsic power asymmetries that are further worsened by alienation created by conservation. Dispossessed communities are left dependent on the vagaries of urban wage labour markets that are highly volatile, accentuating livelihood vulnerability as has happened during the COVID-19 pandemic. India witnessed large-scale reverse migration from cities to rural areas in the wake of the pandemic. At this critical juncture, maintaining the historic linkages of communities with forests and even encouraging communities to forge sustainable linkages with forests should be a priority for conservation plans. Restoring the community's right to forest produce and traditional forest management practices is crucial for sustaining people's participation in conservation. Envisioning PAs as pathways for sustainability goals beyond biodiversity conservation and as part of wider social-ecological systems helps foster sustainable human-nature relationships, environmental health and livelihood and landscape resilience (Loos 2021).

While most of these recommendations hold true for many PAs in the Global South, in the case of a peri-urban PA, tele-couplings with macro level factors such as global- and national-level socio-economic changes and policies arising from the proximity to an urban centre are to be recognised as unique pressures. In the present case, such pressures are evident in the form of the post liberalisation economic changes in India that accelerated real estate boom, population growth, densification and sprawl in urban peripheries. These factors are manifested as different direct stressors on the landscape such as extensive conversion of rural land, changes in cropping practices to produce certain commodities for urban food consumption, increased recreational demand from urban centres, etc. Governance challenges are also rampant, with multiple urban planning agencies and institutions responsible for the management of the PA. In the present case, parastatal agencies including the Bangalore Metropolitan Region Development Authority, Ramanagara Urban Development Authority and Satellite Town Ring Road Planning Authority are all responsible for landscape planning, while the Forest Department is responsible for management of the PA, and coordination between these agencies for devising an integrated approach of planning and management are often lacking. Planning for nature reserve as urban green infrastructure should be mindful of such challenges that are quite different from conservation issues in rural areas. Both urban growth and the area designated for biodiversity conservation to meet commitments set under Aichi targets and other biodiversity frameworks are predicted to intensify in the coming decades in the Global South, so are the conflicts between urbanisation and conservation. Preserving PAs as protected islands devoid of human pressure in a sea of urban growth might not lead to sustainable outcomes, if the intense social-ecological interactions around urban PAs that are amplified by urbanisation are not factored in. A deliberate reorientation of current conservation planning approaches to reimagine the role of PA as urban green infrastructure with multiple ecosystem service uses to diverse stakeholders is undoubtedly vital for inclusive and sustainable urbanisation in the Global South.

Acknowledgements We thank local community members in RVS for participating in the interviews and group discussions as part of this study. Karnataka Forest Department, Ramanagara Division, and Karnataka Vulture Conservation Trust, Ramanagara, supported this research by sharing data on vulture ecology and status at RVS. Samudyatha R., The University of Trans-Disciplinary Health Sciences and Technology, Bengaluru, assisted us in data collection. The financial support from Azim Premji University, Bengaluru, for this study is gratefully acknowledged.

Conflict of Interest Statement The authors report no conflict of interest for this publication.

References

Abhisheka K, Aravind NA, Ganesh T (2011) Of the hunter and the hunted. Deccan Herald. http://www.deccanherald.com/content/154620/ofhunterhunted.html. Accessed 12 Sep 2020

Agbenyega O, Burgess PJ, Cook M, Morris J (2009) Application of an ecosystem function framework to perceptions of community woodlands. Land Use Policy 26:551–557

Amin A, Zaehringer J, Schwilch G, Koné I (2015) People, protected areas and ecosystem services: a qualitative and quantitative analysis of local people's perception and preferences in Côte d'Ivoire. Nat Res Forum 39(2):97–109. https://doi.org/10.1111/1477-8947.12069

Angelsen A, Jagger P, Babigumira R, Belcher B, Hogarth N, Bauch S, Börner J, Smith-Hall C, Wunder S (2014) Environmental income and rural livelihoods: a global-comparative analysis. World Dev 64(1):S12–S28

Bhardwaj M (2018) Preference for hybrid cattle breads increasing man- carnivore conflict. The New Indian Express. http://cms.newindianexpress.com/cities/bengaluru/2018/sep/04/preference-for-hybrid-cattle-breeds-increasing-man-carnivore-conflicts-1867280.html. Accessed 03 Sep 2020

Bindra PS (2018) Declining vulture population can cause a health crisis. Mongabay. https://india.mongabay.com/2018/02/declining-vulture-population-can-cause-a-health-crisis. Accessed 08 Sep 2020

Brockington D, Duffy R (2011) Introduction: capitalism and conservation: the production and reproduction of biodiversity conservation. In: Brockington D, Duffy R (eds) Capitalism and conservation. Wiley-Blackwell, Hoboken, pp 1–16

Brockington D, Igoe J (2006) Eviction for conservation: a global overview. Conserv Soc 4(3): 424–470

Bruner A, Gullison R, Rice R, da Fonseca G (2001) Effectiveness of parks in protecting tropical biodiversity. Science 291(5501):125–128. https://doi.org/10.1126/science.291.5501.125

Buscher B, Fletcher R (2019) Towards convivial conservation. Conserv Soc 17(3):1–14

Chetan R (2016) Shoot at Sholay site threatens Ramanagara vultures. Bangalore Mirror. https://bangaloremirror.indiatimes.com/news/state/big-demand-in-asian-nations-for-mlurus-mud-crabs/articleshow/52980466.cms. Accessed 06 June 2020

D'Souza R, Nagendra H (2011) Changes in public commons as a consequence of urbanization: the Agara Lake in Bangalore, India. Environ Manag 47:840–850

Dao N (2016) Political responses to Dam-induced resettlement in Northern Uplands Vietnam. J Agrarian Change 16(2):291–317

Department of Animal Husbandry & Dairying. (2012, 2019). Basic animal husbandry statistics. Karnataka (India), http://dahd.nic.in/about-us/divisions/statistics. Accessed 08 Sep 2020

Department of Industries and Commerce G (2016) Ramanagara district profile. Karnataka (India). Slideshare.net. https://www.slideshare.net/InvestKarnataka/ramanagara-district-profile. Accessed 26 Aug 2020

Derkzen ML, Nagendra H, Van Teeffelen AJA, Purushotham A, Verburg PH (2017) Shifts in ecosystem services in deprived urban areas: understanding people's responses and consequences for well-being. Ecol Soc 22(1):51. https://doi.org/10.5751/ES-09168-220151

Dowie M (2009) Conservation refugees: the hundred-year conflict between global conservation and native peoples. MIT Press, Cambridge, MA

Eken G, Bennun L, Brooks T, Darwall W, Fishpool L, Foster M et al (2004) Key biodiversity areas as site conservation targets. Bioscience 54(12):1110–1118

Güneralp B, Seto KC (2013) Futures of global urban expansion: uncertainties and implications of biodiversity. Environ Res Lett 8:014025

Haines-Young RH, Potschin M (2018) Proposal for a common international classification of ecosystem goods and services (CICES) for integrated environmental and economic accounting. European Environment Agency

Hall R, Edelman M, Borras S, Scoones I, White B, Wolford W (2015) Resistance, acquiescence or incorporation? An introduction to land grabbing and political reactions 'from below'. J Peasant Stud 42(3–4):467–488

Hannah L (2008) Protected areas and climate change. Ann N Y Acad Sci 1134(1):201–212. https://doi.org/10.1196/annals.1439.009

Harini KS (2019) Conservation challenges in Ramadevarabetta vulture sanctuary: understanding the role of legal status change and urbanization. Dissertation, University of Trans-Disciplinary Health Sciences and Technology

Hartter J (2010) Resource use and ecosystem services in a Forest Park Landscape. Soc Nat Resour 23(3):207–223. https://doi.org/10.1080/08941920903360372

Islam MZ, Rahmani AR (2004) Important bird areas in India: priority areas for conservation. Bombay Natural History Society, BirdLife International, & Oxford University Press, Mumbai, U.K. & Mumbai

Iyer S (2016) Urban legend: the rat-eaters of Ramanagara. Deccan Chronicle. https://www.deccanchronicle.com/lifestyle/viral-and-trending/270316/urban-legend-the-rat-eaters-of-ramanagara.html. Accessed 20 Oct 2020

Jones KR, Venter O, Fuller RA, Allan JR, Maxwell SL, Negret PJ, Watson EM (2018) One-third of global protected land is under intense human pressure. Science 360:788–791

Kabra A (2019) Caste in stone? Exploring caste and class dimensions of conservation displacement in Central India. J Contemp Asia Pages 50(5):785–805

Kaggare N (2019) Ramadevara Betta fails long-billed vultures. Karnataka (India). Deccan Herald. https://www.deccanherald.com/state/ramadevara-betta-fails-long-billed-vultures-759846.html. Accessed 08 Sep 2020

Khanna B (2015) Ramanagar hillock now home to 25 long-billed vultures. https://www.deccanherald.com/content/499176/ramanagar-hillock-now-home-25.html. Accessed Sep 2015

Kleinschroth F, Kowarik I (2020) COVID -19 crisis demonstrates the urgent need for urban greenspaces. Front Ecol Environ 18(6):318–319. https://doi.org/10.1002/fee.2230

Krishna N (2020) 'People of the night' left in the dark. Deccan Herald. https://www.deccanherald.com/spectrum/people-of-the-night-left-in-the-dark-854224.html. Accessed 21 Oct 2020

Lakshmikantha BK (2016) Ramanagara youths establish trust to protect vultures. https://timesofindiaindiatimescom/city/mysuru/Ramanagara-youths-establish-trust-to-protect-vultures/articleshow/54011674cms. Accessed 21 Oct 2020

Loos J (2021) Reconciling conservation and development in protected areas of the Global South. Basic Appl Ecol 54:108–118

Manjunatha D (2016) Working plan for Ramanagara territorial division 2012-13 to 2021-22. Karnataka Forest Department. https://aranya.gov.in/new/newdownloads/WP/Ramanagara%20WP.pdf. Accessed 2019 Jan 21

Markandya A, Taylor T, Longo A, Murty MN, Murty S, Dhavala K (2008) Counting the cost of vulture decline—an appraisal of the human health and other benefits of vultures in India. Ecol Econ 67(2):194–204

McDonald R, Kareiva P, Forman R (2008) The implications of current and future urbanization for global protected areas and biodiversity conservation. Biol Conserv 141(6):1695–1703. https://doi.org/10.1016/j.biocon.2008.04.025

Ministry of Environment, Forest and Climate Change (2017) Gazette Notification on Ramadevara Betta Vulture Sanctuary. Karnataka (India). http://www.moef.gov.in/sites/default/files/Sree%20Ramadevarabetta%20Vulture%20Sanctuary%2C%20Karnataka.pdf. Accessed 22 Jan 2019

Ministry of Home Affairs (2001, 2011) District census handbook, Ramanagara. Karnataka (India)

Mundoli S, Manjunatha B, Nagendra H (2014) Effects of urbanisation on the use of lakes as commons in the peri-urban interface of Bengaluru, India. Int J Urban Sustain Dev 7(1):89–108

Mundoli S, Manjunatha B, Nagendra H (2017) Commons that provide: the importance of Bengaluru's wooded groves for urban resilience. Int J Urban Sustain Dev 9:184–206

Mutharaju H, Kodandarama (2019) A study on Iruliga tribal community political awareness and cultural condition with special reference to Ramanagara Karnataka. Int J Appl Res 5(12): 355–358. Retrieved 21 October 2020

Nautiyal S, Kaechele H (2007) Adverse impacts of pasture abandonment in Himalayan protected areas: testing the efficiency of a Natural Resource Management Plan (NRMP). Environ Impact Assess Rev 27(2):109–125. https://doi.org/10.1016/j.eiar.2006.10.003

Patil S, Dhanya B, Vanjari RS, Purushothaman S (2018) Urbanisation and new agroecologies: the story of Bengaluru's peripheries. Rev Environ Dev 53(41):71–77

Prakash V, Bishwakarma M, Chaudhary A, Cuthbert R, Dave R, Kulkarni M et al (2012) The population decline of Gyps vultures in India and Nepal has slowed since veterinary use of diclofenac was banned. PLoS One 7(11):e49118. https://doi.org/10.1371/journal.pone.0049118

Radhamani T (2014) Struggle life of Iruliga Tribe in Karnataka. Oldrorlbpworld http://oldror.lbp.world/ColorArticle/1150.pdf. Accessed 21 Oct 2020

Rao MR (2018) The Hindu. https://www.thehindu.com/news/cities/bangalore/satellite-town-ring-road-may-claim-30000-trees/article25093311.ece. Accessed 01 Oct 2018

Rodary E, Bruno- Lézy L, Landy F, Morokawa M, Swanepoel J (2018) The history of the four parks: favouring or protecting from urban growth, different successive conservation policies. In: Landy F (ed) Urban national parks to natured cities in the global south: the quest for naturbanity. Springer Nature Singapore Pte Ltd., Singapore, pp 35–62

Schreckenberg K, Torres- Vitolas C, Willock S, Shackelton C, Harvey C, Kafumbata, D (2016) Participatory Data Collection for Ecosystem Services Research—A Practitioner's Manual ESPA Working Paper Series No: 003

Secretariat of the Convention on Biological Diversity. (2020) Global biodiversity outlook 5. Montreal https://wwwcbdint/gbo/ 21 October 2020

Swan G, Cuthbert R, Quevedo M, Green R, Pain D, Bartels P, Cunningham A, Duncan N, Meharg A, Lindsay Oaks J, Parry-Jones J, Shultz S, Taggart M, Verdoorn G, Wolter K (2006) Toxicity of diclofenac to Gyps vultures. Biol Lett 2(2):279–282

Trzyna T (2014) Urban protected areas: profiles and best practice guidelines. Best practice protected area guidelines. IUCN, Gland, Switzerland. xiv :(22):110

Ugolini F, Massetti L, Calaza-Martínez P, Cariñanos P, Dobbs C, Ostoić S et al (2020) Effects of the COVID-19 pandemic on the use and perceptions of urban green space: an international exploratory study. Urban For Urban Green 56:126888. https://doi.org/10.1016/j.ufug.2020.126888

UN (2019) World Population Prospects 2019. https://population.un.org/wpp/Publications/Files/WPP2019_Highlights.pdf. Retrieved 6 June 2021

van Dooren T (2010) Vultures and their people in India: equity and entanglement in a time of extinctions. Manoa 22:130–146

Vikas M (2019) Conservation in Urban Spaces-People-Wildlife interactions and management of Delhi's forests. In: Shahabuddin G, Sivaramakrishnan K (eds) Nature conservation in the new economy: people, wildlife and the law in India. Orient BlackSwan, Hyderabad

West P, Igoe J, Brockington D (2006) Parks and peoples: the social impact of protected areas. Annu Rev Anthropol 35(1):251–277

Zeeshan M, Prusty B, Azeez P (2017) Protected area management and local access to natural resources: a change analysis of the villages neighboring a world heritage site, the Keoladeo National Park, India. Earth Perspectives 4(1). https://doi.org/10.1186/s40322-017-0037-3

Dhanya Bhaskar is the Chairperson, Centre for Policy Studies and Associate Professor of Ecosystem and Environment Management at the Indian Institute of Forest Management, Bhopal, India.

K. S. Harini is a postgraduate in Conservation Science, Bengaluru, India.

H. C. Chetan is an Associate Professor at Centre for Conservation of Natural Resources at the University of Trans-Disciplinary Health Sciences and Technology, Bengaluru.

Remodelling Urban Spaces in the Light of Blue-Green Infrastructure: A Case Study of Guwahati, India

13

Arup Kr. Misra and Tanvi Hussain

Abstract

Guwahati, the fastest-growing metropolis of North East India, is surrounded by beautiful hillocks and the mighty River Brahmaputra flowing through the north. The city is endowed with rich biodiversity and blessed with pleasant weather. But since the 1990s, migration from rural Assam started; unplanned growth and expansion of the city soon followed. Unforeseen problems, like urban floods, landslides, land and water quality degradation, heat island effects and scarcity of basic amenities, are now quite common in Guwahati. The only Ramsar site of the state, the Deepor Beel, as well as other wetlands in Guwahati is under severe threat due to the encroachment and exploitation. The city falls in most vulnerable seismic zone V, but preparedness to combat big earthquakes and similar disasters is not in place. The present study has been carried out to assess the decadal changes over a period, starting from first spell of population influx, senseless expansion to environmental degradation. Data used for the study comprised of Landsat TM, ETM+, OLI and TIRS, ASTER Digital Elevation Model (DEM) and Survey of India Topomap. Data classification, analysis and mapping were carried out in GIS environment using ESRI ArcGIS 10.1 and Hexagon ERDAS 2014 software. It was found that urban expansion increased by 11.53% in 2000–1990, 16.31% in 2010–2000 and 13.64% in 2020–2010. But open spaces reduced by 14.47% in 2010–2000, waterbodies have shrunk and forest cover have reduced considerably. Based on these, suggestions have been made for restoration of existing natural resources and remodelling the city using blue-green infrastructure.

A. K. Misra (✉)
Pollution Control Board Assam, Guwahati, Assam, India

T. Hussain
Assam Science Technology and Environment Council, Guwahati, Assam, India

S. Dhyani et al. (eds.), *Blue-Green Infrastructure Across Asian Countries*,
https://doi.org/10.1007/978-981-16-7128-9_13

Keywords

Urban expansion · Grey infrastructure · Flood hazard · Urban migration · Guwahati · Blue-green infrastructure

13.1 Introduction

Rapid urbanization and unplanned growth have led to urban sprawl, water and air pollution, environmental degradation and exposure to natural and man-made hazards in many countries (Li et al. 2015; Zhang 2016). Fifty four percent of the world's population resided in urban areas in 2014, which is projected to rise to 66% by 2050. Asia and Africa will urbanize at a greater pace than all other regions of the world, where increase will be from 48 and 40% to 64 and 56%, respectively, by 2050. The world urban population has grown from 746 million in 1950 to 3.9 billion in 2014, which further will reach 6.3 billion by 2050. Africa and Asia combined will account for 90% of this rise. Though high-income developed countries have undergone urbanization for several decades, this process started much later in upper middle class countries, mainly due to collapse of rural economy, extreme climate events, people displaced by mega projects and lack of basic civic amenities in rural areas. The 57% urban population in developed countries in 1950 is expected to rise to 86% by 2050, while the same data for upper middle class countries would be from 20% in 1950 to 79% in 2050 (UN 2014).

Among the developing countries, India possesses the most characteristic features of urbanization. In 1951, India's total population was over 361 million, with 17.29% urban population which increased by 13.87% in 2011. The growth of urban population started gaining momentum after 1980. Post 1991, economic growth of the country due to Liberalization-Privatization-Globalization (LPG) brought into sharp focus the economic role of cities (Sadashivan and Tabassu 2016). Urbanization in India is referred to as pseudo-urbanization because people migrate to cities due to rural push factors and not due to urban pull (Breese 1969). Continuous concentration of population and activities in cities marks the pattern of urbanization in India (Jaysawal and Saha 2014). An example of this was the mass migration of marginal workers from cities during the nationwide lockdown period from March to June 2020 owing to COVID-19 pandemic. Urbanization in India is involuted (Mukherji 1991) and has been characterized by weak economic base and poor industrialization. Such lopsided urbanization has given rise to class I cities with massive growth of slums and denial of shelter, basic amenities such as potable water, hygiene, sanitation, electricity, etc., along with misery, poverty, unemployment, inequalities, exploitation and degradation of the environment and quality of urban life (Bhagat 1992; Kundu 1994). During the last 50 years, the urban population of the country has grown five times (Chakrabarti 2001), and the number of mega cities has increased from three (Delhi, Mumbai, Kolkata) to six including Bengaluru, Hyderabad and Chennai. As urbanization takes place and urban population increases, demand for land also increases resulting in unprecedented changes in land use-land cover, draining and filling of wetlands either to house the growing population or build urban infrastructure for industrial and commercial purpose or expansion of transport and communication, felling of trees in the forest, ploughing or grazing of grasslands and conversion of agricultural lands for other purpose.

Indian cities report of steady land cover erosion due to intense urbanization. Between 1973 and 2007, built-up area in Bengaluru has increased by 46% leading to a sharp decline from 68% to 25% in vegetation and 61% in waterbodies (Kumar et al. 2009). Disposal and management of solid waste is another matter of concern because in most of the cities there are no effective mechanisms to collect and dispose wastes. Similar evidence of urban progression from Delhi reflects that the city is developing very fast in the west, south-west and eastern sides. Urban expansion in the fringe areas has engulfed 17% of agricultural land in the Union Territory of Delhi. Considered as the lungs of Delhi, there has been considerable decrease in the famous Kamala Nehru Ridge area from 6.7% in 1992 to 5.5% in 2004 because of continuous felling of trees, construction and quarrying (Sherbinin et al. 2007).

North East (NE) India comprises of eight states, viz. Assam, Arunachal Pradesh, Meghalaya, Nagaland, Mizoram, Manipur, Tripura and Sikkim. Compared to the rest of India, NE is least urbanized where only 18% of the population reside in the 414 towns of various sizes. The only "million city" in the region is Guwahati in Assam, the gateway of the region, located on the left bank of Brahmaputra. Of the half dozen towns with population of more than 100,000, the largest number of towns falls in the group having population of 5000–10,000 people. Many of these towns are administrative or service centres with few industrial towns. The important cities or towns in the region are Guwahati, Jorhat, Dibrugarh, Tezpur and Silchar in Assam; Shillong and Tura in Meghalaya; Dimapur and Kohima in Nagaland; Agartala in Tripura; Imphal in Manipur; Aizawl in Mizoram; and Tawang and Ziro in Arunachal Pradesh. Digboi with a petroleum refinery and several hydrocarbon industries is the oil town of Assam; Itanagar is the newly planned town of Arunachal Pradesh and Agartala an upcoming urban hub. The number of towns in the NE India has increased from 30 in 1951 to 414 in 2011, and urban population has increased by 3.5% only of which highest urban pollution of 52.44% resides in Assam followed by 11.48% in Tripura, 9.82% in Manipur, 7.11% in Meghalaya, 6.85% in Nagaland, 6.71% in Mizoram, 3.74% in Arunachal Pradesh and 1.81% in Sikkim (Dikshit and Dikshit 2014).

13.1.1 Grey Infrastructure and the Challenges Within

Grey infrastructure refers to the traditional methods of managing water using man-made or constructed drainpipes, curb inlets, minor channels, manholes, roadside ditches and culverts designed or installed to remove storm water as fast as possible from sites to avoid or reduce on-site flooding. Grey infrastructure is often designed to avoid any type of ecosystem to grown on it. The grey infrastructure sewer system is of two types: combined or separate. The combined sewer system is the one in which storm water and wastewater are collected in the same pipe network, and then the mixed water is taken to wastewater treatment plant before being discharged into the nearest large waterbody or main river channel. On the other hand, in the separate sewer system, the storm water and wastewater are collected separately, and the wastewater is transported for treatment, whereas the storm water is directly discharged in nearest large waterbody or river channel if it does not contain pollutants (Jha et al. 2012; Opperman 2014).

This traditional grey infrastructure has been proved to be quite effective in collecting storm water run-off and draining it until unintended negative consequences related to quality and quantity of water started emerging in the form of changes in hydrological cycles, increased peak flows, downstream flooding risks, changes in groundwater and surface water levels causing increased climate change-related flood risks and flash floods, enhanced delivery of nutrients and toxins causing eutrophication threatening aquatic habitats in urban waterways and combined sewer overflows (CSOs) during heavy downpour or wet conditions, exposing urban populations to health risks from waterborne pathogens and toxins (Driscoll et al. 2015).

13.1.2 Dual Impacts of Urbanization and Grey Infrastructure on Urban Ecosystem

Combined impact of urbanization and grey infrastructure has pushed urban ecosystem to the edge of vulnerability. Under natural conditions, only a limited portion of the ground surface is covered by impervious layer. So, most rainwater goes down to recharge groundwater resources, filling rivers and lakes and taken up by plants and trees through the process of rainfall interception, infiltration, evapotranspiration and soil retention (Wagner et al. 2013). But in the cities, sealed surfaces like buildings, squares, sidewalks and pavements act as barriers, and instead of infiltration through the soil, the rainwater simply flows over the impervious surfaces. Secondly, urban expansion, particularly in flood-prone areas, alters the natural path of the flowing waterbodies and reduces rainwater infiltration, again increasing overland flows exceeding the capacity of drainage systems. Although urban drainage systems are designed to prevent local flooding by draining out storm water as fast as possible from the vulnerable sites, many a times urban flooding in the downstream is also observed (Jha et al. 2012). Such downstream flood risks may be amplified by ageing systems causing sewers to overflow, blocked natural flow paths and increase run-off (Grant 2010). This issue is severe in cities like Guwahati, which are facing financial challenges of developing new infrastructure, at the same time operating, maintaining, rehabilitating and ensuring environmental compliance of the current ageing infrastructure (Ozment et al. 2015).

Due to impervious surfaces and storm water systems, infiltration and evaporation are reduced in urban areas causing rise of ambient temperature resulting in urban heat island (UHI) effect (Chetia et al. 2020). This also changes the local climate parameters resulting in low precipitation, slower groundwater recharge rates and less water for the citizens. The lower groundwater levels in the urban areas can potentially lead to lower streambase flows, decreasing habitats and cover available for instream inhabitants, therefore increasing competition and vulnerability to predators. With reduced flow, there is also the likelihood of increased water temperatures and lower dissolved oxygen levels, both of which will create additional stress to stream inhabitants (Howe et al. 2011; Knight 2003).

Run-off from roads and highways frequently washes pollutants like dirt, oil, grease, toxic chemicals, heavy metals, road salts, wintertime salting and sanding deposits, sodium chloride and calcium chloride on the roads, nitrogen and phosphorus, rubbish from roadside vehicle repairing centres (brake pads, wear-related deposits include copper and zinc) and pathogens into nearby waterways including rivers, streams and lakes. Fertilizer application on agricultural strips is a source of nitrogen and phosphorus. Urban run-off also reduces visibility of water with outbreaks of blue-green algae, fish kill, piles of foam, cloudy and coloured water and oil slicks. In addition, the degradation of roads and pavements also generates pollutants, and floating inorganic debris and litter (bottles and aluminium cans, car tyres, oil drums, etc.) raises community concern. The decomposition of organic debris like leaves, twigs, timber, paper, cardboard and food waste reduces visibility of water, and nutrients released can form rich organic sediment resulting in algal blooms (Lloyd et al. 2002). The effect of these pollutants from road run-off is harmful for the human ecosystem as well as flora and fauna. Urban storm water run-off also significantly contributes to thermal pollution of waterways and waterbodies. Increased temperatures can threaten survival of aquatic species by interfering with spawning and migration patterns, promote harmful algal blooms producing toxins, raise treatment costs for drinking water and harm industries that rely on clean water, besides creating dead zones in water (Brears 2018; Stuart and Stanford 1978; Qian et al. 2019).

13.1.3 Blue-Green Infrastructure and Its Advantages

Blue-green infrastructure (BGI) is a network of strategically planned natural and semi-natural areas encompassing green spaces and blue areas concerning aquatic ecosystems and other environmental features. BGI is designed and managed to protect biodiversity and deliver a wide range of ecosystem services (Brears 2018). It is supposed to utilize natural processes to improve and manage water quality and quantity by restoring the hydrological function of any urban landscape. Spatial planning is the most effective way of implementing BGI. This allows interactions between different land use patterns over a large geographical area. Spatial planning at strategic level helps to pinpoint the best locations for habitat enhancement projects to house the increasing population load and reconnect healthy ecosystems, improve permeability of landscape and connectivity between protected areas and guide infrastructural developments away from sensitive natural areas to more robust areas that in addition may contribute to recreating and restoring green infrastructure features in the development proposal. It also helps to identify multifunctional zones where compatible land uses are favourable and support healthy ecosystems over single focus development (Foster et al. 2011).

13.1.4 Footprints of Urbanization in Guwahati City

Guwahati, the largest city of North East India, has witnessed influx of people since 1972 when the capital of Assam was shifted from Shillong to Dispur. The population of the city increased at a compound annual growth rate of 4.0% from 293,219 to 646,169 between 1971 and 1991. By the last decadal census in 2011, its population reached 968,549, and at present, the city probably has about one and a half million people. The city is of strategic and geographical significance, located at the banks of the mighty Brahmaputra River, with few tributaries flowing through the city nurtures biodiversity (Figs. 13.1 and 13.2). But rapid and unplanned urban growth has changed the land use pattern of the city. Like numerous Indian cities, Guwahati also faces problems of land use-land cover (LULC) change due to inadequate planning efforts, uncontrolled development activities compounded by urban population growth and expansion with adverse impacts on the ecology and environment of the city. The only Ramsar site of the state, the Deepor *Beel* (wetlands, lakes and ponds are commonly called "beel" in Assamese language), located in Guwahati is under severe threat due to the encroachment and unplanned urban developmental activities. The city is located on the seismic belt (Zone V) and prone to floods and

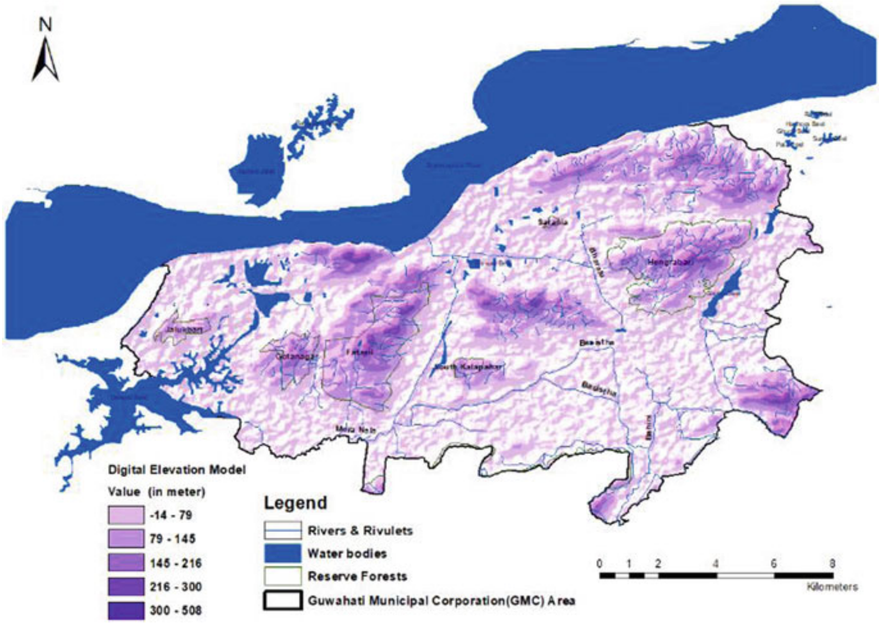


Fig. 13.1 Base map of Guwahati Municipal Corporation (GMC) area

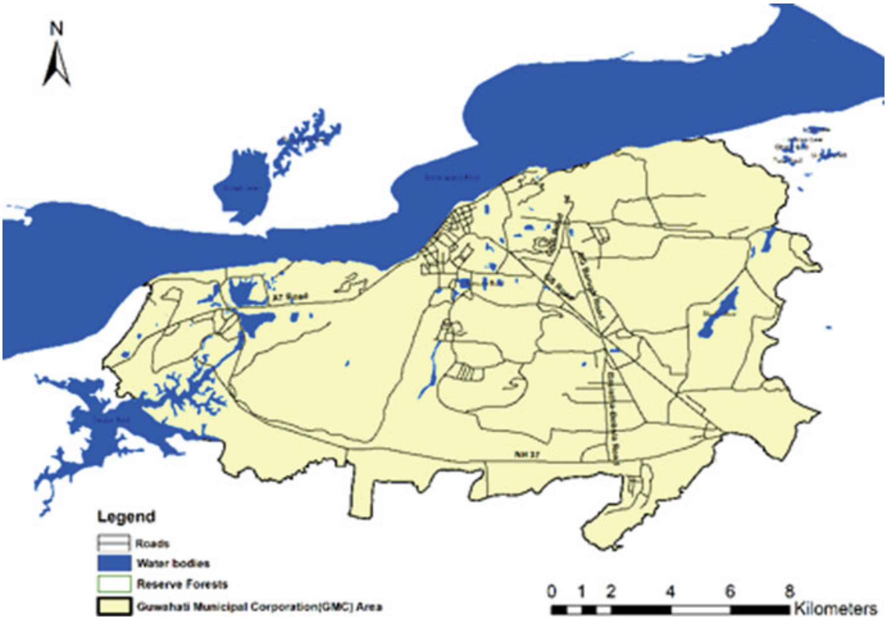


Fig. 13.2 Road network map of GMC area

landslide. The capacity and preparedness of the city to combat with such disasters and deal with its impacts are not up to the mark, which make its residents quite vulnerable.

On 25 June 2015, the Ministry of Urban Development (MoUD), Government of India under its Smart City Mission, launched an ambitious initiative to develop 100 smart cities and 500 small medium towns under Atal Mission for Rejuvenation and Urban Transformation (AMRUT). Guwahati is the only city from NE India among the top 20 cities (Round 1) to be developed as a smart city (Kaushik et al. 2015). The city is extolled as lynch pin to the gateway to Southeast Asia and India's Act East Policy (Pawe and Saikia 2018; Sarma 2012). The vision for smart city includes Solar City Guwahati Mission, Integrated Command and Control Center (ICCC) with smart electric poles for smart lightning, robust IT connectivity, skill development centres, Deepor *Beel* development project, strengthening eco-tourism in the city, flag construction at Gandhi Mandap, special road which connects Guwahati to AIIMS (Guwahati), round-the-clock electricity supply, smart metering, wastewater recycling, smart parking, etc.

This has pressed upon the need for efficient urban planning and proper environmental management of the city. Planning and management necessitate advanced methodologies like space technologies and spatial mapping which aids urban planners, environmentalists, ecologist, economists and resource managers to solve problems accompanied with urban growth (Maktav and Erbek 2005). Traditionally, in the field of geography and planning, there is research on description, characterization, mapping and measurement, understanding the morphology, form and evolution of urban environment (Taubenböck et al. 2009). The classical theories of urban morphology defined urban patterns as concentric rings with different land use types as sectors (Burgess 1935), modification of concentric zones pattern based on transportation network (Hoyt 1939) and the multiple nuclei theory model of urban patches with specialized multiple centres of land use (Harris and Ullman 1945). Meanwhile, techniques of remote sensing (RS) have been proved effective in mapping urban areas at various scales acquiring data for urban LULC analysis (Batty and Howes 2001; Donnay et al. 2001; Herold et al. 2002).

In this study, a spatiotemporal analysis of Guwahati city's LULC and its changes using time series of Landsat data has been carried out to detect the pressure of urban population growth and expansion on the forests, rivers and rivulets, and its increasing vulnerabilities.

13.2 Methodology

Methodology adopted for the study has been shown in Fig. 13.3.

13.2.1 Data

Primary Data for the study comprised of Landsat time series data (TM, ETM+, OLI and TIRS) and ASTER Digital Elevation Model (DEM) were downloaded from United States Geological Survey's interface Earth Explorer, Survey of India (SOI)

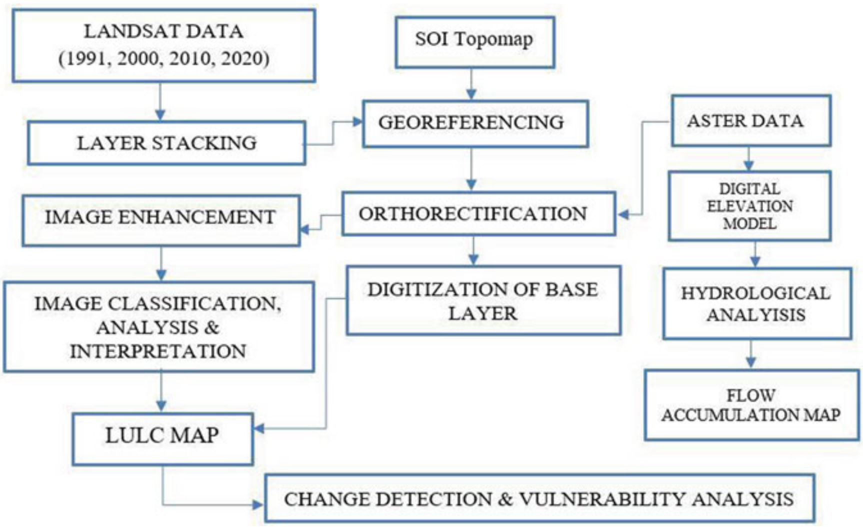


Fig. 13.3 Flowchart of methodology adopted in the study

Table 13.1 Details of satellite data used in the study

Data	Bands	Resolution	Path and row	Year
Landsat TM[a]	7	30 m	137/42	1990
Landsat ETM+[b]	8	30 m	137/42	2000, 2010
Landsat OLI and TIRS[c]	11	30 m	137/42	2020
ASTER[d]	14	30 m	–	2011

[a]Landsat Thematic Mapper
[b]Landsat Enhanced Thematic Mapper
[c]Landsat Operational Land Imager and Thermal Infrared Sensor
[d]Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER)

Topomap for Guwahati city and secondary data for the consisted of flood and landslide hazards maps for Guwahati city developed by Assam State Disaster Management Authority (ASDMA), Government of Assam. Data classification, analysis and mapping were carried out in GIS environment using ESRI ArcGIS 10.1 and Hexagon ERDAS 2014 software (Table 13.1).

13.2.2 Image Classification and Accuracy

The LULC characteristics of Guwahati Municipal Corporation (GMC) were generated using supervised classification technique through maximum likelihood classifier for the Landsat time series data, while classifying it ensured that different clusters do not overlap and at least 30 numbers of observations per cluster were maintained (Saikia et al. 2013; Janssen et al. 2001). Based on the spatial resolution of the Landsat data and the multifunctional LULC pattern of Guwahati city (Borah and Bhagabati 2015), the datasets were classified into eight LULC categories. The LULC scheme adopted in this study complies with the land cover classification scheme designed by the Food and Agriculture Organization (Gregrio and Jansen 1998; Latham et al. 2002). An accuracy assessment was performed for each decade (1990, 2000, 2010 and 2020) with a set of 40 random ground points for each LULC class. Overall accuracies and Cohen's kappa coefficient (κ) for 1990, 2000, 2010 and 2020 images were 96.80% ($\kappa = 0.95$), 96.88% ($\kappa = 0.96$), 94.31% ($\kappa = 0.92$) and 92.96% ($\kappa = 0.92$), respectively. An overall accuracy of 85% is generally regarded satisfactory (Anderson 1976). The value of kappa coefficient ranges between 0 and 1, and over 0.75, it is deemed excellent (Fleiss 1981).

13.3 Results and Discussion

13.3.1 Spatiotemporal Analysis of Guwahati City

From the LULC classification of Guwahati Municipal Corporation areas for the decades 1990, 2000, 2010 and 2020, it is evident that natural areas (closed forest, open forest, aquatic vegetation, open space, riverine sand) and agriculture were the

Table 13.2 Decadal LULC statistics of GMC area (in ha)

LULC categories	Area under different LULC categories (in ha)			
	1990	2000	2010	2020
Urban built-up	3711.85	5733.71	8594.16	10986.71
Waterbodies	652.73	761.46	512.90	341.98
Aquatic vegetation	2085.00	693.24	396.24	432.92
Closed forest	1114.43	1308.12	1273.27	1255.76
Open forest	5700.47	3454.10	5788.1	4048.58
Open space	1353.49	3547.22	968.08	468.90
Agriculture land	2891.64	2030.72	0.00	0.00
Riverine sand	27.77	8.84	4.61	2.56
Total	**17,537**	**17,537**	**17,537**	**17,537**

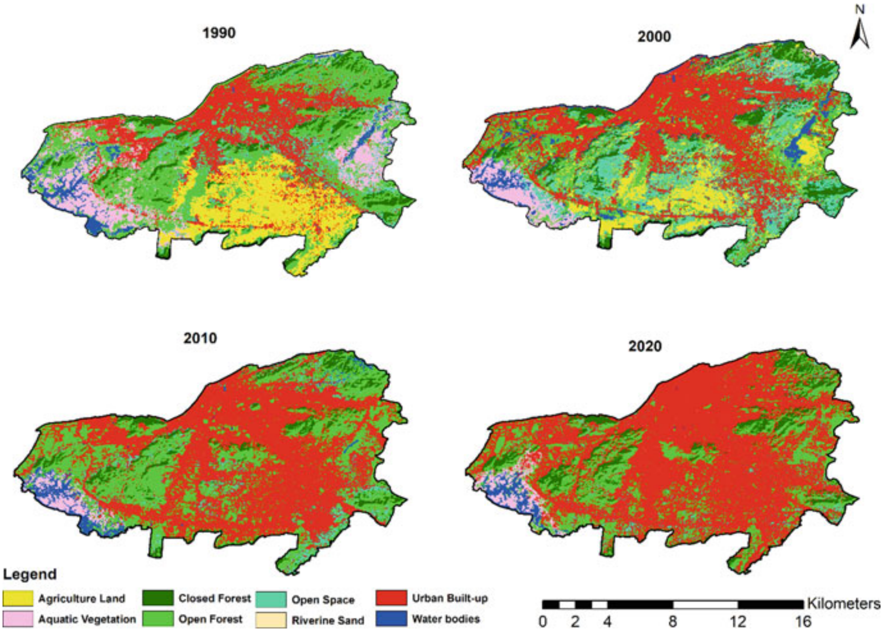


Fig. 13.4 Decadal LULC map of GMC area

predominant LULC categories during 1990 and 2000. However, with increasing urban pressure and population growth, these areas have largely been replaced by built-up areas in 2010 and 2020 (Table 13.2; Fig. 13.4).

Over the four decades under study, urban built-up increased by 11.53% in 2000–1990, by 16.31% in 2010–2000 and by 13.64% in 2020–2010 (Table 13.3). Although waterbodies have increased by 0.62%, this increase can be linked with the decrease of aquatic vegetation by 7.94% which helped the signature of water to be visible. However, both waterbodies and aquatic vegetation decreased by 1.42 and

Table 13.3 Decadal LULC change statistics of GMC area

LULC categories	Decadal LULC change (in ha)			Rate of decadal LULC change (in %)		
	2000–1990	2010–2000	2020–2010	2000–1990	2010–2000	2020–2010
Urban built-up	2021.86	2860.45	2392.55	11.53%	16.31%	13.64%
Waterbodies	108.73	−248.56	−170.92	0.62%	−1.42%	−0.97%
Aquatic vegetation	−1391.76	−297	36.68	−7.94%	−1.69%	0.21%
Closed forest	193.69	−34.85	−17.51	1.10%	−0.20%	−0.10%
Open forest	−2246.37	2334	−1739.52	−12.81%	13.31%	−9.92%
Open space	2193.73	−2579.14	−499.18	12.51%	−14.71%	−2.85%
Agriculture land	−860.92	−2030.72	0	−4.91%	−11.58%	0.00%
Riverine sand	−18.93	−4.23	−2.05	−0.11%	−0.02%	−0.01%

1.69% between 2010 and 2000. Aquatic vegetation grew by 0.21% in 2010–2000, but waterbodies continued to decrease by another 0.97%. Closed forest increased by 1.10% in 2000–1990 but continued to decline by 0.20 and 0.10% in 2010–2000 and 2020–2010, respectively, due to human pressure. Open forest reduced by 12.81% in 2000–1990 and then increased by 13.31% in 2010–2000 to witness decline again by 9.92% in 2020–2010. Clearance of open forest in the city led to the rise of open space by 12.51% in 2000–1990 which later continued to decline by 14.71 and 2.85% in 2010–2010 and 2020–2010, respectively. Rapid urbanization and need to house the growing population have created tremendous pressure on the agriculture land which reduced by 4.91% in 2000–1990 and by 11.58% in 2010–2000 which got wiped out from the land use pattern of the city (Fig. 13.5). The emergence and submergence of the riverine sand is a continuous dynamic annual episode.

13.3.2 Encroachment of the Reserve Forest by Urban Built-Up

The city is surrounded by 18 hills of which 8 are reserve forests (RF), and 6 of them are in the city, namely, Fatasil RF, Gotanagar RF, Hengrabari RF, Jalukbari RF, Sarania RF and South Kalapahar RF. Primarily, the vegetation of the city is tropical deciduous. Over the years, expansion of built-up areas occurred inside the notified reserved forests (RFs) and on the hills within the jurisdiction of GMC (Table 13.4 and Figs. 13.6 and 13.7). Such encroachments are predominantly made by the urban poor. In 2001, nearly 170,000 people were residing in the city hills (Borah and Gogoi 2012). Besides the urban poor, some pockets of land have been encroached of by commercial entities and wealthy urbanites (Borthakur and Nath 2012). Urban poor residing in informal settlements on the tenuous hill slopes of the RFs often face the problem of soil erosion or rainfall-induced landslide (Forman 2014). During 2000–2007, around 60 people lost their lives due to mudslide in the hills of Guwahati (Dutta et al. 2017). These makeshift houses often lack access to basic

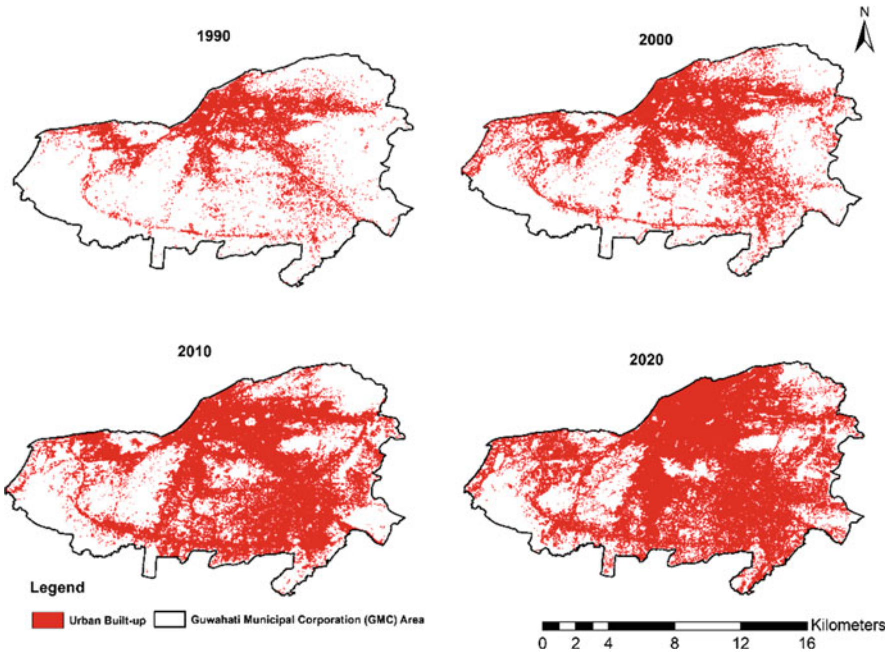


Fig. 13.5 Decadal urban expansion in GMC area

Table 13.4 Urban expansion in the reserve forests of Guwahati city

Reserve forests	Area under urban built-up in the RFs (in ha)				Decadal growth of built-up in RFs		
	1990	2000	2010	2020	2000–1990	2010–2000	2020–2010
Fatasil	9.80	26.59	79.20	132.31	16.79	52.61	53.11
Gotanagar	2.42	5.97	8.70	18.53	3.56	2.73	9.83
Hengrabari	79.09	188.80	385.12	396.73	109.72	196.32	11.61
Jalukbari	0.00	0.94	0.71	1.17	0.94	–0.23	0.46
Sarania	2.12	2.16	0.96	8.69	0.04	–1.20	7.73
South Kalapahar	1.58	2.99	7.93	45.47	1.41	4.93	37.54
Total	**2085.00**	**2227.46**	**2492.62**	**2622.89**	**132.46**	**255.16**	**120.27**

amenities such as all-weather or drivable roads, electricity and water supply and sanitation. Ever increasing population and lack of space have forced humans to settle in the vulnerable locations of the city (Forman 2014), thereby increasing pressure on the slopes, natural domain of the rivers and rivulets, wetlands and flood plains. Urban expansion changes a city's seven basic factors—natural vegetation, water, agricultural land, housing, communities, jobs and transport (Forman and Wu 2016),

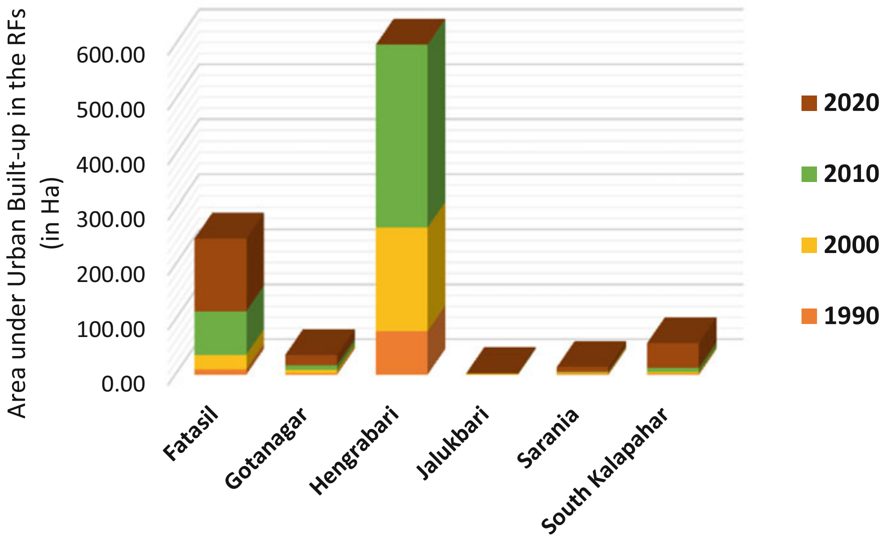


Fig. 13.6 Showing urban built-up in the reserve forests within GMC area

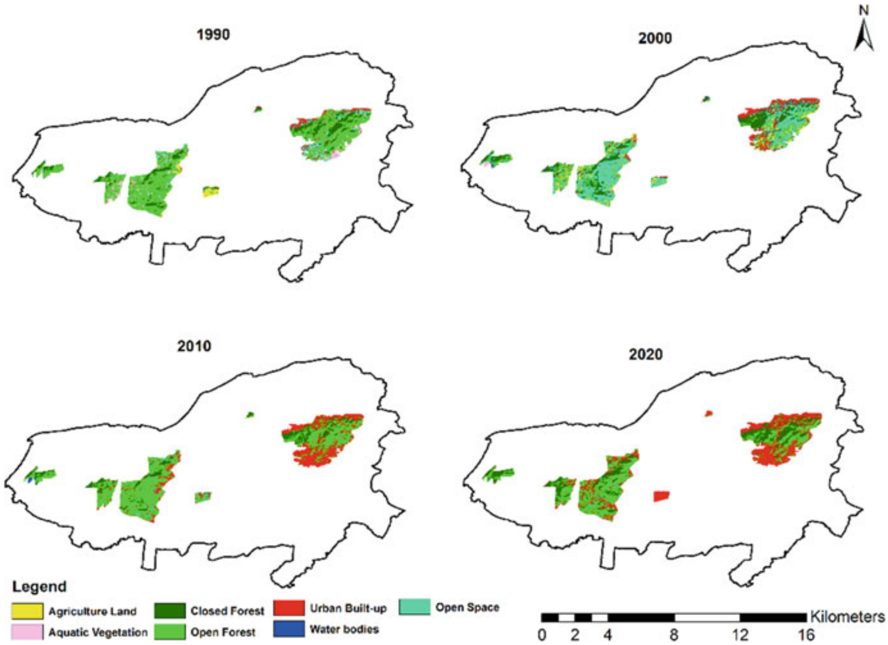


Fig. 13.7 Decadal expansion of urban built-up and reduction of forest cover in the RFs of Guwahati

although unequally on the basis of economic strata. Changes in all these have been quite significant in the case of Guwahati as well.

13.3.3 Impacts of Urban Growth in Guwahati

Change in the land use pattern and fast pace of urbanization during the past four decades has resulted in significant depreciation of the environment and ecology of the city. Growing urban settlement in and around the hills and reserve forests of the city at the cost of forest or vegetation cover have exposed the surface to landslide, soil erosion and rise in air pollution. Urban expansion and human settlement along the flood plains of Brahmaputra River and banks of other rivulets within the city and around the wetlands have led to decrease in the water retention capacity of the waterbodies exacerbating problems of flooding and water logging (Gogoi 2013). Degradation of wetlands is a notable problem of Guwahati due to shrinkage of the Ramsar Site Deepor *Beel* and complete encroachment and conversion of Silsako *Beel* and Borsola *Beel*. Water contamination and bacterial pollution in Brahmaputra River and Bharalu River have increased due to direct and untreated discharge from combined sewer systems, and biological oxygen demand (BOD) of Bharalu River has increased due to presence of various oxygen demanding organic and inorganic matter (Girija et al. 2007; Hussain et al. 2015). Deforestation and cutting of hill slopes for earth filling of low-lying areas have increased the risk of sheet-wash, slope failure, high rate of soil erosion, increased siltation and choking of drainage channels. Soil erosion and heavy siltation have raised the riverbeds, and the capacity of natural and artificial drainage network to discharge storm water has drastically reduced. Backflow of water from rivers, rivulets and wetlands also causes frequent floods during monsoons and occurrence of heavy rainfall. The growing urban population and its need of potable water has put tremendous pressure on the groundwater resources leading to lowering of groundwater table and scarcity of water (Nath et al. 2021). The groundwater of the city reports moderate mineral content with slightly higher concentration of iron and toxic elements (Das et al. 2003; Singh et al. 2019).

13.3.4 Vulnerability of Flood Hazard in Guwahati

Other than the mighty Brahmaputra River flowing through the north of the city, a number of other rivers and rivulets, namely, Bharalu, Basistha and Bahini, originating from the Khasi Hills of Meghalaya flow through the city. The river Bharalu drains into Brahmaputra River and river Basishta into the Deepor *Beel* through the Mora Bharalu channel. Besides the city is also known for its numerous wetlands such as Deepor *Beel*, Silsako *Beel* and Borsola *Beel* which sustain significant flora and fauna in the heart of the city. Based on its physiography, the city is divided into six natural drainage basins, ultimately discharging into the mighty Brahmaputra River with different drainage lines and reservoirs (Baruah and Naik

2020). These are Silsako basin, Deepor basin, Bharalu basin, Kalmoni basin, Foreshore basin and North Guwahati basin:

- Bharalu basin: Bharalu is the major river running across the city. It is heavily degraded due to haphazard construction on the natural domain of the river, unplanned commercial developmental, sewage and solid waste disposal, etc. Decline in water-holding capacity during heavy rainfall or monsoon season causes flood in the city due to backflow from Brahmaputra River. City life comes to a standstill, with frequent loss in life and property. The river has been marked as one of the most polluted rivers of the country by the Central Pollution Control Board (CPCB), New Delhi.
- Deepor basin: With a respectable tag of Ramsar site, this wetland was the storm water storage of the city. Basishta river drains into this wetland, and it is the single largest basin located in the southernmost part of the city. The basin is again subdivided into two sub-basins, viz. Bijubari and Deepor sub-basin. Deepor *Beel* used to act as a sponge retaining the excess storm water during heavy rainfall and then slowly releasing it into the Brahmaputra river.
- Silsako basin: Silsako *Beel* is located in the eastern part of Guwahati city. This basin consists of industrial estate of Bamunimaidam, IOC refinery (Noonmati) and military (Narengi) area. Silsako *Beel* is connected to Brahmaputra river through Bondajan rivulet.
- Kalmoni basin: Although the entire basin lies outside the Guwahati Municipal Corporation (GMC) area, it discharges into Brahmaputra river through Deepor *Beel* and Khanajan rivulet indirectly.
- Foreshore basin: This basin mainly consists of residential, institutional and commercial areas of the city. Due to the shallow bowl-like physiography of the city, water logging and urban floods are regular features in Guwahati during monsoon.
- North Guwahati basin: This basin discharges into the Brahmaputra river directly or indirectly through the Ghorajan rivulet.

The city suffers from the worst impact of urban floods every time after heavy rainfall with worst consequences on and in the fringes of Guwahati-Shillong (GS) Road, RG Baruah Road, GNB Road and Beltola-Basistha Road (Fig. 13.9) due to lack of planned drainage system; ageing water channels and feeder drains with reduced holding capacity due to siltation and solid waste accumulation (Sarmah and Das 2018); encroachment along the edges of the rivers, rivulets and wetlands; or blocking of the channels for construction and settlement and backflow from the channels on occasion or heavy downpour. During incidents of incessant or heavy downpour, the wetlands cannot retain storm water resulting in blockage of waterways and flooded streets with sewage water. On the other hand, clearing of slopes in an around the hills and RFs of Guwahati for settlement and other activities has either blocked or concealed the streams discharging rainwater leading to slope failure induced by downpour. This is another geoenvironmental hazard other than floods that affects the city every year (Dutta et al. 2017). Guwahati Metropolitan

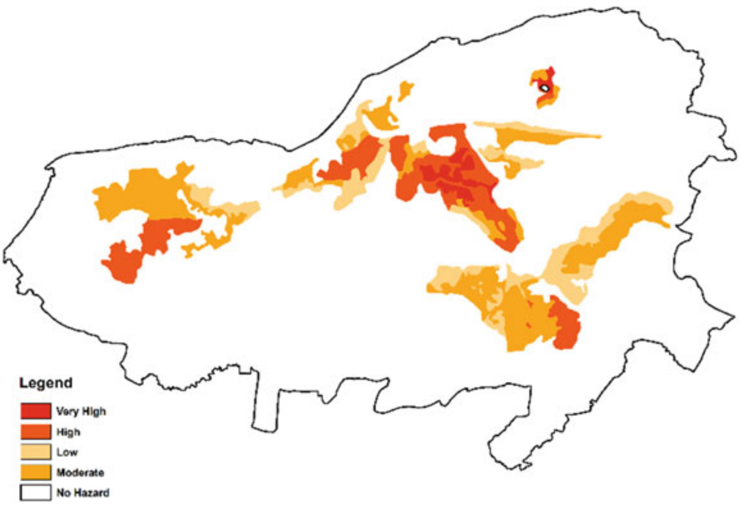


Fig. 13.8 Flood hazard map of Guwahati city (source: ASDMA)

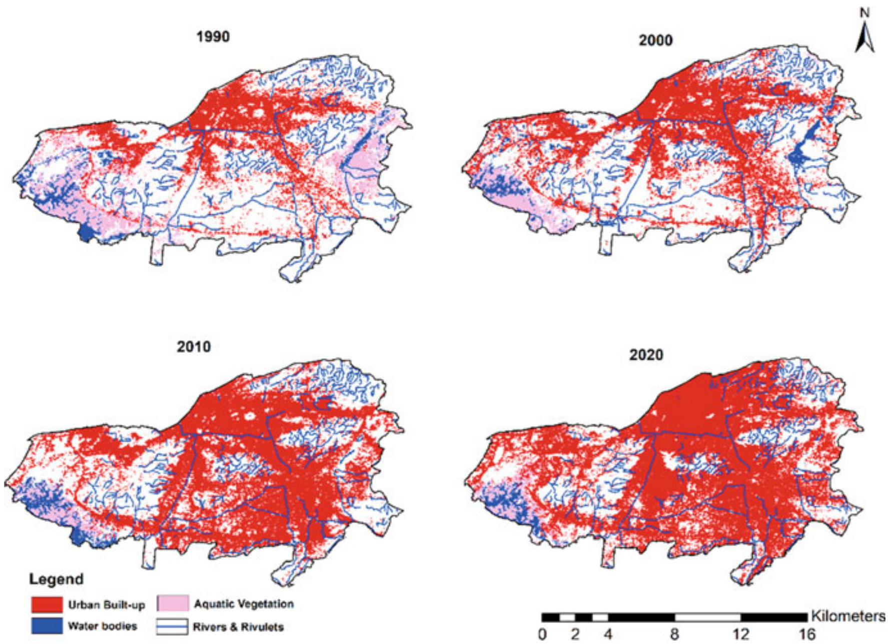


Fig. 13.9 Expansion of urban built-up in Guwahati city

Development Authority (GMDA) identified mushrooming slums as the root cause of urban floods in the city (Sarmah and Das 2018). Figures 13.8 and 13.9 shows the flood hazard zones of Guwahati city, pressure of urban built-up and population on the natural waterways of the city. Apart from Deepor *Beel*, other important wetlands of the city "Silsako *Beel*" and "Borsola *Beel*" have been gradually squeezed by urban built-up. Silsako *Beel* spreads over an area of 87.67 ha in 1990, 127.00 ha (the waterbodies spread over a considerable area due to reduction of aquatic vegetation and inundation of the nearby agriculture land by the waterbody) and 11.62 in 2010, and in 2020, it has no existence. Similarly, Borsola *Beel* was 2.86 ha in 1990, 2.63 ha in 2000 and 0.87 ha in 2010 and was wiped out in 2020. From this it is evident that the non-existence of wetlands in the city has exacerbated the vulnerability of flood hazard.

13.4 Role of Blue-Green Infrastructure in Remodelling Guwahati City

Remodelling Guwahati city in the light of BGI is the solution to reduce the risks and vulnerability to flood and landslide hazards, improve drainage network for storm water discharge and water ways, enhance green cover of the RFs and open spaces, restore and improve the existing waterbodies of the city and aid GMDA in adopting compatible and favourable building bye-laws to enrich the urban ecosystem. Some of the BGI measures proposed, based on the present study, are as follows:

- **Storm water detention and retention basin:** This is a system to store run-off storm water temporarily, which includes detention or retention basins, bioretention basins or swales that capture run-off from roadways and buildings. Unlike the traditional urban storm water pathways, this system does not interrupt the upstream storm water sewer inlets. The detention basins are systems to temporarily store storm water run-off during incidents of downpour and later release it at a controlled rate to the drainage system. Retention basin again holds permanent pool of water which is designed for peak run-off control and pre-treatment (Driscoll et al. 2015). Since the city has different depths and pockets of shallow areas, both in the plain and hill slopes, therefore, strategic configuration of these areas into retention and detention systems and connecting them with the storm water drainage will capture inflows and overflows from external and internal conveyance respectively. This will mitigate the flooding of streets and downstream localities and reduce incidents of slope failure.
- **Revival of the concealed or dilapidating rivers, rivulets and streams:** Revival of the existing, blocked or concealed rivers (Bharalu, Basistha, Bondajan), rivulets and streams (Bahini, Mora Bharalu, Khanajan) through dredging, desiltation and networking all the waterways will aid in restoring the aquatic ecosystem of the city (Fig. 13.10). Apart from, conservation of the existing wetlands and cleaning (Deepor*Beel*), desilting and restoring the dying wetlands (Borsola*Beel* and Silsako*Beel*) and reviving its connections with the drainage waterways network like Bharalu river—BorsolaBeel—Brahmaputra River, Basistha—Bahini—Mora Bharalu—Deepor*Beel*—Khanajan—Brahmaputra River and Silsako*Beel*—Bondajan will also bring back the natural retention

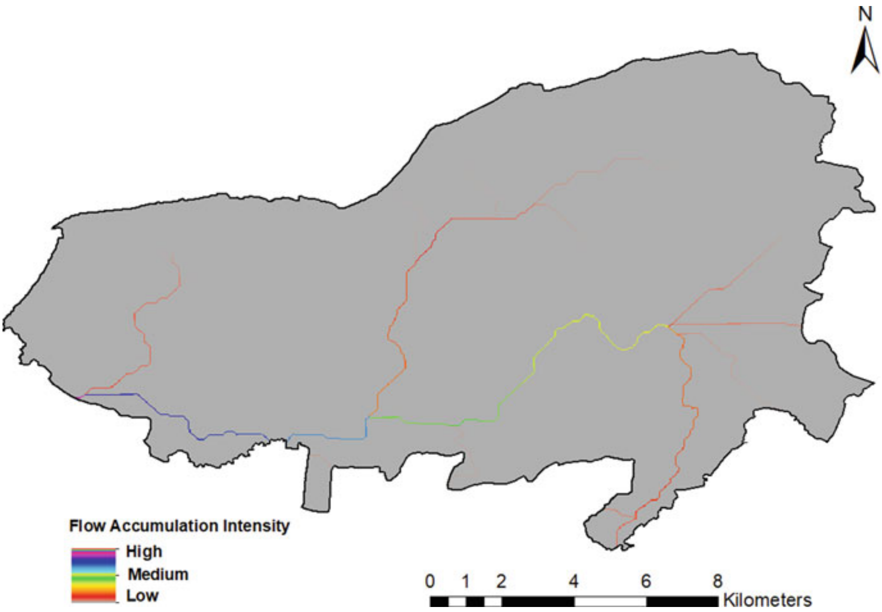


Fig. 13.10 Map showing flow accumulation intensity in the rivers and rivulets of Guwahati city

capacity of the water bodies to hold excess water, improve micro-climate, enrich the natural flora and fauna of the urban landscape, enhance groundwater recharge. During the rain-free periods, these areas can be utilized for recreational purposes (Wang et al. 2018).

- **Riparian buffers:** Riparian buffers are biological filters of vegetation between catchments and receiving pathways, preventing a significant amount of nutrients, toxins and solid wastes from entering into the water system. The vegetation and humus layers hold significant volume of water and directly uptake the contaminants; hence, the storm water run-off is slowed and filtered, allowing infiltration into the soil and releasing the run-off over a longer time period (Wagner et al. 2013). Riparian buffers also reduce erosion and preserve the function and form of the channel (Wang et al. 2021). Riparian buffers along the rivers, rivulets and wetlands of the city will not only reduce the run-off velocity of storm water but will also replenish groundwater and address to its scarcity during lean season, enhance water quality of the natural bodies, conserve the urban biodiversity, reduce man-animal conflicts and add to the aesthetic value of urban landscape.
- **Urban forests and vegetation:** The city already has eight reserve forests. Enhancing forest cover of these RFs will increase green cover of the city, absorb pollutants, improve air quality, act as windbreaks protecting urban infrastructure from wind damage, regulate urban heat island (UHI) effect, control ambient air temperature through evapotranspiration, shelter wildlife and mitigate effects of climate change by carbon sequestration.

- **Green roofs:** Flat rooftops are conducive to rainwater capture. Green roofs are permeable fabric of a growing vegetation grown on flat roofs, capable of treating storm water through retention or bioretention. Green roofs reduce storm water run-off by 50–60% and capture nearly 85% of pollutants. These also filter air pollutants, absorb carbon dioxide and reduce ambient air temperature by about 5 °C and surface temperature by 22 °C preventing UHI effect (Brears 2018; Meerow et al. 2021). Adopting green roofs in the residential housing complexes, government buildings, prestigious buildings and other flagship buildings will provide boost to the concept.
- **Downspouts and rain barrels:** In many commercial buildings and residential complexes, the rainwater is directly passed to the sewage system. Downspout disconnects the route of rainwater from the sewage system and redirects the water towards permeable areas. Besides, downspouts can be connected to rain barrels or cisterns (Foster et al. 2011). Rain barrels are small above-ground water receptacles which usually hold 50 gallons, best suited for small parcels of land as the water captured can be used for irrigation, whereas cisterns are large and can be either above or below ground. Size of the cistern range from 300 to 1000 gallons and are mostly used in large buildings. Installing rain barrels and downspouts in the commercial and residential buildings can solve the groundwater crisis of Guwahati city and improve its water regime.
- **Pervious pavement and depaving:** Pervious pavements are specially designed pavements that let water to percolate through the pavement, preventing it from becoming run-off. There are various types of porous surface such as pervious concrete, pervious asphalt and interlocking. These pavements are made of a porous surface with an underground stone reservoir. The underground reservoir stores the water temporarily before the water infiltrates into the soil. Function of interlocking pavers is different from pervious concrete and asphalt. Interlocking pavers are spaced apart with grass or gravel in between allowing water to infiltrate through the paving. Installing such pavers in the parking lots, sidewalks, front-wards and backwards or urban infrastructure has obvious advantages. On the other hand, depaving of concrete areas will liberate underutilized paved surfaces for vegetation, allowing storm water to infiltrate into the ground where it falls instead of carrying pollutants into waterways, as well as providing a habitat for insects, birds and other wildlife (Jalali and Rabotyagov 2020).

13.5 Conclusion

The present study has unfurled certain problems of Guwahati and its degrading environment and ecosystem. Urban evolution has been expeditious in the past two decades and taken the citizens by shock and surprise. But there are still scope to undertake restructuring and remodelling activities for its recovery, one major approach being building resilience to existing urban hazards by promoting urban infrastructure in the light of BGI. Urban settlement along the slopes of the hills and RFs cannot be uprooted now, but the remaining green patches, rivers, rivulets and waterbodies can be conserved. Rather than putting all loads of urban infrastructure development and settlement on the bowl shape physiography of Guwahati, the neighbouring areas of the metropolis beyond eastern and western limits should be developed into a few satellite townships to decongest the city. Financial endowments should not pose problems in this context because Guwahati is one of the 100 "smart cities" in first phase of AMRUT. Guwahati's strategic location and its importance for the country, as well as Southeast Asian countries, will be an advantage for future projects so far as government or international funding is concerned. Success of all restoration projects will largely depend on mainstreaming BGI with the masterplan for the city and going back to the basics.

Conflict of Interest Statement The authors report no conflict of interest for this publication.

References

Anderson JR (1976) A land use and land cover classification system for use with remote sensor data. US Government Printing Office 964:1–34. https://doi.org/10.3133/pp964

Baruah P, Naik PRP (2020) Masterplan for Guwahati Metropolitan Area-2025 and Sustainable Environment. MuktShabd J 9:7400–7412

Batty M, Howes D (2001) Predicting temporal patterns in urban development from remote imagery. In: Donnay JP, Barnsley M, Longley P (eds) Remote sensing and urban analysis. Taylor & Francis Inc., New York, pp 169–188. https://doi.org/10.1201/9781482268119

Bhagat RB (1992) Components of urban growth in India with reference to Haryana: findings from recent censuses. Nagarlok 25:10–14

Borah P, Bhagabati AK (2015) Effect of river environment on the land use of Guwahati city: perspectives from nature-culture relationship. Clarion-Int Multidiscip J 4:27–33. (https://www.indianjournals.com/ijor.aspx?target=ijor:cla&volume=4&issue=1&article=006)

Borah J, Gogoi B (2012) Growth of slum areas and changing land use pattern in Guwahati city, India. Clarion-Int Multidiscip J 1:189–195. (https://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.1023.25&rep=rep1&type=pdf)

Borthakur M, Nath BK (2012) A study of changing urban landscape and heat island phenomenon in Guwahati metropolitan area. Int J Sci Res Publ 2:1–6. http://www.ijsrp.org/research-paper-1112/ijsrp-p1127.pdf

Brears RC (2018) Blue-green infrastructure in managing urban water resources. In: Brears RC (ed) Blue and green cities. Palgrave Macmillan, London, pp 43–61. https://doi.org/10.1057/978-1-137-59258-3_2

Breese G (1969) Urbanization in newly developing countries. Prentice Hall, New Delhi

Burgess EW (1935) The growth of the city: an introduction to a research project. Ardent Media, London, pp 47–62

Chakrabarti PD (2001) Urban crisis in India: new initiatives for sustainable cities. Dev Pract 11:260–272. https://doi.org/10.1080/09614520120056397

Chetia S, Saikia A, Basumatary M, Sahariah D (2020) When the heat is on: urbanization and land surface temperature in Guwahati, India. Acta Geophys 68:891–901. https://doi.org/10.1007/s11600-020-00422-3

Das B, Talukdar J, Sarma S et al (2003) Fluoride and other inorganic constituents in groundwater of Guwahati, Assam, India. Curr Sci 85:657–661. http://www.jstor.org/stable/24109107

Dikshit KR, Dikshit JK (2014) North-east India: land, people and economy. Springer, Dordrecht, pp 61–90. https://doi.org/10.1007/978-94-007-7055-3

Donnay JP, Barnsley M, Longley P (2001) Remote sensing and urban analysis-introduction. In: Donnay JP, Barnsley M, Longley P (eds) Remote sensing and urban analysis. Taylor & Francis Inc., New York, pp 2–14. https://doi.org/10.1201/9781482268119

Driscoll CT, Eger CG, Chandler DG et al (2015) Green infrastructure: lessons from science and practice. Science Policy Exchange:1–32. https://science-policy-exchange.org/sites/default/files/documents/Green%20Infrastructure%20Report%20Final.pdf

Dutta PJ, Sarma S, Laskar JJ (2017) Predicting the spatial distribution of rain-induced shallow landslides by applying GIS and geocomputational techniques: a case study from North East India. Int J Recent Innov Trends Comput Commun 5:1306–1319. https://www.researchgate.net/profile/Parag-Dutta-3/publication/317889953_Predicting_the_Spatial_Distribution_of_Rain-Induced_Shallow_Landslides_by_applying_GIS_and_Geocomputational_Techniques_A_Case_Study_from_North_East_India/links/5950f03645851543383c5dec/Predicting-the-Spatial-Distribution-of-Rain-Induced-Shallow-Landslides-by-applying-GIS-and-Geocomputational-Techniques-A-Case-Study-from-North-East-India.pdf

Fleiss JL (1981) The measurement and control of misclassification error. In: Statistical methods for rates and proportions. John Wiley & Sons, New York, pp 140–154

Forman RT (2014) Urban ecology: science of cities. Cambridge University Press, New York, pp 31–58

Forman RT, Wu J (2016) Where to put the next billion people. Nature 537:608–611. https://doi.org/10.1038/537608a

Foster J, Lowe A, Winkelman S (2011) The value of green infrastructure for urban climate adaptation. Center Clean Air Policy 750:1–52. (http://www.ggi.dcp.ufl.edu/_library/reference/The%20value%20of%20green%20infrastructure%20for%20urban%20climate%20adaptation.pdf)

Girija TR, Mahanta C, Chandramouli V (2007) Water quality assessment of an untreated effluent impacted urban stream: the Bharalu tributary of the Brahmaputra River, India. Environ Monit Assess 130:221–236. https://doi.org/10.1007/s10661-006-9391-6

Gogoi L (2013) Degradation of natural resources and its impact on environment: a study in Guwahati City, Assam, India. Int J Sci Res Publ 3:321–327. http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.402.8546&rep=rep1&type=pdf#page=322

Grant L (2010) Multi-functional Urban Green infrastructure. A CIWEM briefing report. Saffron Hill, London, pp 5–39. https://www.ciwem.org/assets/pdf/Policy/Reports/Multifunctional-Green-Infrastructure.pdf

Gregrio A, Jansen J (1998) Land cover classification system (LCCS); classification concepts and user manual. UN FAO, Rome, pp 1–32. file:///C:/Users/Outreach/Downloads/Land_Cover_Classification_System_LCCS_Classificati.pdf

Harris CD, Ullman EL (1945) The nature of cities. Ann Am Acad Pol Soc Sci 242:7–17. https://doi.org/10.1177/000271624524200103

Herold M, Scepan J, Clarke KC (2002) The use of remote sensing and landscape metrics to describe structures and changes in urban land uses. Environ Plan A: Econ Space 34:1443–1458. https://doi.org/10.1068/a3496

Howe CA, Butterworth J, Smout IK, et al (2011) Sustainable water management in the city of the future: findings from the SWITCH Project 2006–2011. UNESCO-IHE, pp 69–108. https://rke.abertay.ac.uk/en/publications/sustainable-water-management-in-the-city-of-the-future-findings-f

Hoyt H (1939) The structure and growth of residential neighborhoods in American cities. United States, Federal Housing Administration, Washington, pp 81–112. https://books.google.co.in/books?hl=en&lr=&id=VtjZdGSOWhgC&oi=fnd&pg=PR1&dq=Hoyt+H+(1939)+The+structure+and+growth+of+residential+neighborhoods+in+American+cities.+US+Government+Printing+Office.&ots=QY1qJKuDkS&sig=ZJWfd7W4FiM2aYF-tVsbpt9SjHk&redir_esc=y#v=onepage&q=Hoyt%20H%20(1939)%20The%20structure%20and%20growth%20of%20residential%20neighborhoods%20in%20American%20cities.%20US%20Government%20Printing%20Office.&f=false

Hussain K, Balachandran S, Hoque RR (2015) Sources of polycyclic aromatic hydrocarbons in sediments of the Bharalu River, a tributary of the River Brahmaputra in Guwahati, India. Ecotoxicol Environ Saf 122:61–67. https://doi.org/10.1016/j.ecoenv.2015.07.008

Jalali P, Rabotyagov S (2020) Quantifying cumulative effectiveness of green stormwater infrastructure in improving water quality. Sci Total Environ 731:138953. https://doi.org/10.1016/j.scitotenv.2020.138953

Janssen LLF, Huurneman GC, Kerle N, Tempfli K (2001) Principles of remote sensing. International Institute for Aerospace Survey and Earth Science (ITC), Netherlands, pp 289–300. (https://webapps.itc.utwente.nl/librarywww/papers_2009/general/principlesremotesensing.pdf)

Jaysawal N, Saha S (2014) Urbanization in India: an impact assessment. Int J Appl Soc 4:60–65. https://doi.org/10.5923/j.ijas.20140402.04

Jha AK, Bloch R, Lamond J (2012) Cities and flooding: a guide to integrated urban flood risk management for the 21st century. The World Bank, Washington, DC, pp 488–581. https://books.google.co.in/books?hl=en&lr=&id=n6NoKiWglh0C&oi=fnd&pg=PA6&dq=Jha+AK,+Bloch+R,+Lamond+J+(2012)+Cities+and+flooding:+A+Guide+to+Integrated+Urban+Flood+Risk+Management+for+the+21st+Century.+The+World+Bank.&ots=iB9qbyNvbl&sig=FJxwAZYGNXlIPLtldyPgKap7CxM&redir_esc=y#v=onepage&q&f=false

Kaushik A, Dhingra M, Singh MK, Parikh JK (2015) Indian cities towards smartness: a case study of Guwahati City. Smart City Expo World Congress, pp 1–10. https://www.researchgate.net/profile/Asha_Kaushik2/publication/298703643_Indian_Cities_towards_Smartness_A_Case_Study_of_Guwahati_City/links/56ea7a2a08ae25ede831aff8/Indian-Cities-towards-Smartness-A-Case-Study-of-Guwahati-City.pdf

Knight S (2003) Integrating stormwater management with economic, social, cultural and ecological goals in Christchurch, New Zealand. Aust J Environ Manage 10:181–191. https://doi.org/10.1080/14486563.2003.10648589

Kumar U, Mukhopadhyay C, Ramachandra TV (2009) Spatial data mining and modeling for visualisation of rapid urbanisation. SCIT J 9:1–9. http://wgbis.ces.iisc.ernet.in/energy/discussion_meeting/SCIT.pdf

Kundu A (1994) Pattern of urbanisation with special reference to small and medium towns. In: Chadha GK (ed) Sectoral issues in the Indian economy. Har-Anand Publications, New Delhi

Latham JS, He C, Alinovi L et al (2002) FAO methodologies for land cover classification and mapping. In: Walsh SJ, Crews-Meyer KA (eds) Linking people, place, and policy. Springer, Boston, MA, pp 283–316. https://doi.org/10.1007/978-1-4615-0985-1_13

Li Y, Li Y, Qureshi S et al (2015) On the relationship between landscape ecological patterns and water quality across gradient zones of rapid urbanization in coastal China. Ecol Model 318:100–108. https://doi.org/10.1016/j.ecolmodel.2015.01.028

Lloyd SD, Wong THF, Chesterfield CJ (2002) Water sensitive Urban design-a stormwater management perspective (industry report). In: International Conference on Water Sensitive Urban Design. Cooperative Research Centre for Catchment Hydrology, pp 1–38. https://ewater.org.au/archive/crcch/archive/pubs/pdfs/industry200210.pdf

Maktav D, Erbek FS (2005) Analysis of urban growth using multi-temporal satellite data in Istanbul, Turkey. Int J Remote Sens 26:797–810. https://doi.org/10.1080/01431160512331316784

Meerow S, Natarajan M, Krantz D (2021) Green infrastructure performance in arid and semi-arid urban environments. Urban Water J 18:275–285. https://doi.org/10.1080/1573062X.2021.1877741

Mukherji S (1991) The nature of migration and urbanization in india: a search for alternative planning strategies. In: Srinivasan K, Pathak KB (eds) Dynamics of population and family welfare. Himalaya Publishing House, Bombay, pp 203–245

Nath B, Ni-Meister W, Choudhury R (2021) Impact of urbanization on land use and land cover change in Guwahati city, India and its implication on declining groundwater level. Groundw Sustain Dev 12:100500. https://doi.org/10.1016/j.gsd.2020.100500

Opperman JJ (2014) A flood of benefits: Using green infrastructure to reduce flood risks. The Nature Conservancy, Arlington, VA, pp 1–24. https://www.conservationgateway.org/ConservationPractices/Freshwater/HabitatProtectionandRestoration/Documents/A%20Flood%20of%20Benefits%20-%20J.Opperman%20-%20May%202014.pdf
Ozment S, DiFrancesco K, Gartner T (2015) The role of natural infrastructure in the water, energy and food nexus. Nexus Dialogue Synthesis Papers, IUCN Switzerland, pp 15–22. https://iwa-network.org/wp-content/uploads/2019/02/1438744856-Natural-Infrastrucure-in-the-Nexus_Final-Dialogue-Synthesis-Paper-2015.pdf
Pawe CK, Saikia A (2018) Unplanned urban growth: land use/land cover change in the Guwahati Metropolitan Area, India. GeografiskTidsskrift-Danish J Geograh 118:88–100. https://doi.org/10.1080/00167223.2017.1405357
Qian Q, Sun B, Li X et al (2019) Water quality evaluation on an Urban stormwater retention pond using wireless sensor networks and hydrodynamic modeling. J Irrig Drain Eng 145:05019011. https://doi.org/10.1061/%28ASCE%29IR.1943-4774.0001434
Sadashivam T, Tabassu S (2016) Trends of urbanization in India: issues and challenges in the 21st century. Int J Inform Res Rev 3:2375–2384. http://www.dspmuranchi.ac.in/pdf/Blog/TrendsofUrbanizationinIndiaIssuesandChallengesinthe21stCentury.pdf
Saikia A, Hazarika R, Sahariah D (2013) Land-use/land-cover change and fragmentation in the Nameri Tiger Reserve, India. GeografiskTidsskrift-Danish J Geograh 113:1–10. https://doi.org/10.1080/00167223.2013.782991
Sarma A (2012) Northeast as gateway to Southeast Asia: Big dreams and home truths. In: Deka S (ed) Population development and conflicts in Northeast India. EBH Publishers, Guwahati, pp 1–20
Sarmah T, Das S (2018) Urban flood mitigation planning for Guwahati: a case of Bharalu basin. J Environ Manage 206:1155–1165. https://doi.org/10.1016/j.jenvman.2017.10.079
Sherbinin AD, Carr D, Cassels S, Jiang L (2007) Population and environment. Annu Rev Env Resour 32:345–373. https://doi.org/10.1146/annurev.energy.32.041306.100243
Singh A, Patel AK, Deka JP et al (2019) Prediction of arsenic vulnerable zones in the groundwater environment of a rapidly urbanizing setup, Guwahati, India. Geochemistry 80:125590. https://doi.org/10.1016/j.chemer.2019.125590
Stuart TJ, Stanford JA (1978) A case of thermal pollution limited primary productivity in a southwestern USA reservoir. Hydrobiologia 58:199–211. https://doi.org/10.1007/BF02346956
Taubenböck H, Wegmann M, Roth A et al (2009) Urbanization in India–spatiotemporal analysis using remote sensing data. Comput Environ Urban Syst 33:179–188. https://doi.org/10.1016/j.compenvurbsys.2008.09.003
Wagner I, Krauze K, Zalewski M (2013) Blue aspects of green infrastructure. Sustain Dev Appl 4: 145–155. https://www.researchgate.net/profile/Kinga-Krauze/publication/261638072_Blue_aspects_of_green_infrastructure/links/00463534e6c87333d2000000/Blue-aspects-of-green-infrastructure.pdf
Wandl A, Magoni M (2017) Sustainable planning of peri-Urban areas: introduction to the special issue. Plan Pract Res 32:1–3. https://doi.org/10.1080/02697459.2017.1264191
Wang M, Zhang D, Adhityan A et al (2018) Conventional and holistic urban stormwater management in coastal cities: a case study of the practice in Hong Kong and Singapore. Intl J Water Resources Dev 34:192–212. https://doi.org/10.1080/07900627.2016.1258355
Wang Y, van Roon M, Knight-Lenihan S (2021) Opportunities and challenges in water sensitive industrial development: an Auckland case study, New Zealand. Int J Sustain Dev World Ecol 28:143–156. https://doi.org/10.1080/13504509.2020.1783717
Zhang XQ (2016) The trends, promises and challenges of urbanisation in the world. Habitat Int 54: 241–252. https://doi.org/10.1016/j.habitatint.2015.11.018

Arup Kumar Misra is the Head of the Department at the Department of Chemical Engineering, Golaghat Engineering College, Assam, India.

Tanvi Hussain is a Project Scientist in the Climate Cell of Assam Science Technology and Environment Council (ASTEC), Science & Technology Department, Govt. of Assam, Assam, India.

Part IV

BGI for Sustainable Water Management

Nature-Based Solutions for the Restoration of the Abukuma River Basin (Japan) After Typhoon Hagibis

14

Naoko Kimura

Abstract

In October 2019, Typhoon Hagibis hit many areas of Japan, including the Abukuma River Basin. It brought enormous precipitation and caused many river banks to break, resulting in serious flood disasters. In the Abukuma River Basin, there is a structure called the Hamao flood retention reservoir, which was constructed in 2004 as an environmentally friendly means of flood control. However, its sluice gate was broken by the river's increased flow of water causing a serious flood in the neighboring area. Having previously experienced such floods, such as those which followed heavy storms in July 2020, national and local authorities changed the direction of flood management policy to a basin-wide approach (*ryuiki-chisui* in Japanese). With this policy change, the reconstruction of the river banks has been conducted. The concept for reconstruction employs modern engineering flood control techniques as well as traditional ones, effectively depending on the characteristics of given sites. This chapter clarifies how officials are integrating nature-based solutions or ecosystem-based disaster risk reduction. Also, it discusses the future tasks in the implementation of basin-wide approach flood management integrating NbS.

Keywords

Nature-based solutions · Flood management · Typhoon Hagibis · Disaster risk reduction · Japan

N. Kimura (✉)
Laboratory of Rural Planning, Graduate School of Agriculture, Kyoto University, Kyoto, Japan
e-mail: kimura.naoko.2x@kyoto-u.ac.jp

S. Dhyani et al. (eds.), *Blue-Green Infrastructure Across Asian Countries*,
https://doi.org/10.1007/978-981-16-7128-9_14

14.1 Nature-Based Solutions in Flood Management in Japan

The issues of disaster prevention with hard infrastructure have had to be reconsidered regarding the increasingly extreme climate and meteorological events that have become unprecedented in frequency and extreme level. A report by leading scientists calls this weather extreme "a new normal" (Pihl et al. 2019, p. 17). Floods have increased and measures have been called for, introducing a concept of "nature-based solutions (NbS)" in a broader sense, which is different from the protection of specific species and communities in the narrow sense and the ecosystem conservation approach (IUCN 2020). Since around 2008, the definition of a new nature conservation gear has been studied, in which clear discussions and brute force processes are not always sufficient in Japan. Estrella and Saalismaa (2013) define "ecosystem disaster mitigation" as "the sustainable management, conservation and restoration of ecosystems to reduce disaster risk, to achieve sustainable and resilient development (p. 30)" citing Sudmeier-Rieux and Ash (2009), "sustainable management, protection and restoration." With this definition, it can be understood that ecosystem disaster mitigation envisions two possible practices: conservation and protection of existing natural ecosystems and a new restoration of lost natural ecosystems. Meanwhile, the International Union for Conservation of Nature (IUCN) has addressed NbS as societal issues and tasks such as climate change, food security, water security, human health, natural disasters, and social and economic development in a highly adaptable and effective manner. It is defined as "actions to protect, sustainably manage and restore natural or modified ecosystems that address societal challenges effectively and adaptively, simultaneously providing human well-being and biodiversity benefits" (Cohen-Shacham et al. 2016).

Floods larger than the planned scale are called "excess floods" but as long as it is premised on intensified rainfall due to climate change. If the location of the collapse is in a densely populated residential area, the damage is only for continuous embankments where the precise location of the collapse is unknown. The damage will be enormous. Even if equal safety is ensured up to the planned scale, it is necessary to determine in advance areas which can be flooded intentionally to prevent excessive flooding and damage can be minimized. This is a rebellion-tolerant hydraulic control measure, and we can learn the basics of this feeling from the traditional NbS technologies such as *Kasumi-tei* (open levees), *etsuryu-tei* (overflow levees), flood-protecting forests, etc.

Kasumi-tei (open levees), *etsuryu-tei* (overflow levees), and flood protection forests, which are traditional hydraulic control methods for rivers, are traditional green infrastructures that first appeared in the sixteenth century and remain today. Unfortunately, since the enactment of the River Act in 1896, the need for high-water construction has been called for, and the idea of Western European technology to flush floods with embankments has been adopted, resulting in that the traditional hydraulic technology has gradually become less recognized. However, in the time of "a new normal" as mentioned above, more attention has been paid to such traditional flood control techniques as an approach of NbS. The following sections introduce a few representations of traditional flood control methods used from early times in Japan.

14.1.1 Traditional Nature-Based Solutions in Japan

In late nineteenth-century Japan, the flood control experts of the time, Odaka Junchu and Nishi Moromoto, said “river banks are like as armor” in their books (Takahashi 1971). It means that the damage may be more severe when one wearing armor is hit by bullets. Thus, they warned people about placing too much emphasis on building strong banks, as we build much stronger and higher banks expecting more security once we build it. Also, they pointed out that stormwater level gets higher by building riverbanks or dikes. This precisely tells us about the vulnerability of modern society that has depended much on “gray” infrastructures, such as dams, paved embankments, and roads.

14.1.1.1 Kasumi-Tei

Kasumi-tei is a type of discontinuous levee system that was used from the seventeenth to mid-nineteenth centuries in Japan to mitigate the impact of river flooding (Sendo and Ishikawa 2018). The Kasumi-tei levees are funnel-shaped, and the openings allow stormwater exceeding the river channel capacity to spread backwards, reducing the river discharge, and return to the channel when the floods withdrew (Fig. 14.1). Sendo and Ishikawa (2018) elucidated that the funnel-shaped levee openings effectively help a portion of stormwater exceeding the river capacity

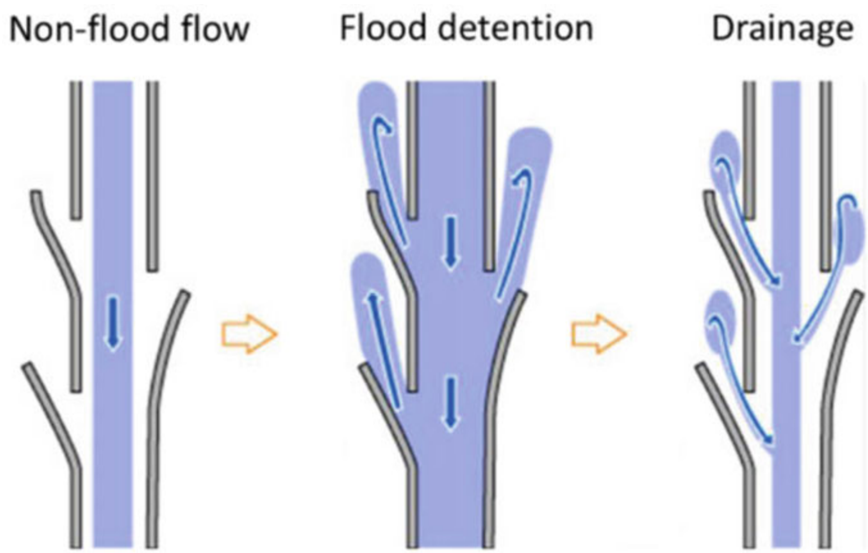


Fig. 14.1 Typical Kasumi-tei levee arrangement (source: Sendo and Ishikawa, 2018)

to spread when flooding and return to the main river through computational simulation.

According to Okuma (1987), who has been studying the arrangement and function of Kasumi-tei levees for many years, it is carried out in steep alluvial fan-shaped gravel rivers of 1/500 or more, and in gentle low-flat sandy rivers of 1/1000 or less. It has been pointed out that the purpose is different upon implementation. The former is designed to return floods that have overflowed and flooded to river channels and to eliminate inland waters. It is thought that the flood control function is dependent on backflow, which is often said to be limited by steep terrain and therefore slight. In the Tedori River, in southern Ishikawa Prefecture and other areas, some Kasumi-tei levees overlap over 1 to 2 km and even above the water levels that rise during floods. First of all, the embankment facing the river prevents flooding, and if the embankment alone fails and collapses, the idea of defense in detail is to minimize flooding with the overlapping rear embankment.

14.1.1.2 Nokoshi (Overflow Levee)

Nokoshi is another example of flood damage mitigation used from early times in Japan (Fig. 14.2). In the Jobaru River in Saga Prefecture, many overflow levees called "Nokoshi" remain to this day, which provides valuable knowledge for understanding the effects of overflow levees. A pair of "Nokoshi" levees was set up along the river, protecting nearby villages from flooding, which played an important role in reducing damage to the inland area of the embankment. Unfortunately, the importance of the embankment's function has not been well understood, and like the Kasumi-tei levee, many levees have been removed for field maintenance and road construction (Tanabe and Okuma 2001). Residential land development is progressing around the Jobaru River Basin and retarding basins, and the risk of exposure to disasters is increasing during overflows. Currently, hydraulic control by the Jobaru River Dam is being considered, and a plan to eliminate Nokoshi has emerged, but it is clear that the dam has its limits in preventing excessive floods. Inundation-tolerant basin hydraulic control should be considered by utilizing Nokoshi and Kasumi-tei levees. Some flood inundation simulations have been

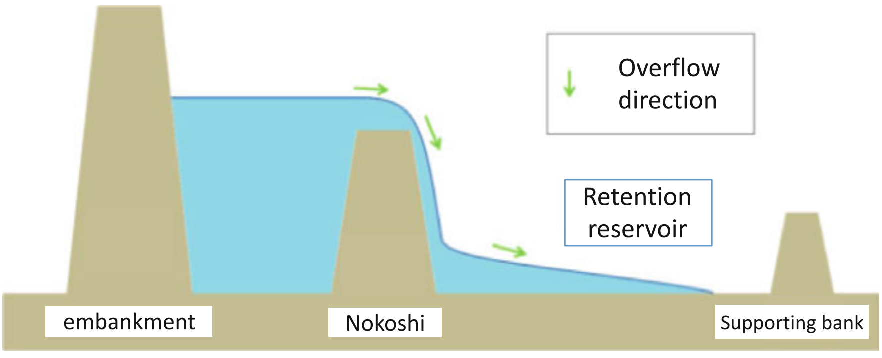


Fig. 14.2 A cross section of "Nokoshi" (modified Nakajima and Ogushi, 2012)

conducted to verify the effects of Nokoshi and Kasumi-tei levees on the Jobaru River, if the flow rate of the main river increases, causing overflow from Nokoshi and Kasumi-tei levees (e.g., Nakajima and Ogushi 2012; Teramura and Shimatani 2021). If there ever were such a case, the water level of the main river would hardly rise at all.

14.1.1.3 Etsuryu-Tei (Overflow Levee)

Due to flood control, the structure is such that floods flow over the embankment. When a part of the embankment is lowered and the flood exceeds the height of the overflow embankment, a part of the flood flows over the overflow embankment into a retention reservoir or a regulating pond. The surface of the overflow dike must be covered with concrete or asphalt so that it will not be damaged by the flow of the water, and it must have a strong structure (MLIT 2012). The zone between the levees can be a floodwater retention reservoir, hence a green infrastructure.

14.1.1.4 Bobirin (Protecting Forests)

Bobirin is an artificial forest created to prevent and mitigate damage to residential land, roads, agricultural land, etc. from disasters caused by natural phenomena or human causes. Although these forests may be built by the private sector or individuals, they are often designated as “protection forests,” based on the public interest functions stipulated in the Forest Law. Of the various protection forests, the following 11 types correspond to disaster prevention forests established to prevent disasters: (1) sediment runoff protection forests (for preventing sediment runoff and erosion by roots and fallen leaves), (2) sediment collapse defense protection forests (for the prevention of unstable ground collapse), (3) flying sand protection forests (for preventing flying sand), (4) windbreak protection forests (for prevention of damage caused by strong winds), (5) flood protection forests (prevention of flooding of rivers and mitigation of water force), (6) tidal damage protection forests (to prevent damage caused by tsunami and storm surge), (7) snow protection forests (protecting roads and railroads from snowstorms), (8) fog-proof protection forests (protecting cultivated land from sea fog), (9) avalanche protection forests (to prevent avalanches and to act as a buffer zone when they occur), (10) rockfall prevention protection forests (to control the danger of rockfall), and (11) fire protection forests (to prevent the spread of fire with fire-resistant tree species) (Watanabe 1998). In the Japanese context, *satoyama* forests prevent and mitigate sediment disasters from hitting nearby villages and help in mitigating crop damage by wild animals (MoE 2016).

14.2 Abukuma River Basin Restoration

The Abukuma River is 239 km long, and its basin area is 5400 km^2, located in the southern part of the Tohoku Region (the northeastern area) in Japan (Fig. 14.3). Its headwater is located at Mt. Asahi (1835 m above sea level) in Tochigi Prefecture and runs through Fukushima Prefecture and Miyagi Prefecture, from south to north,

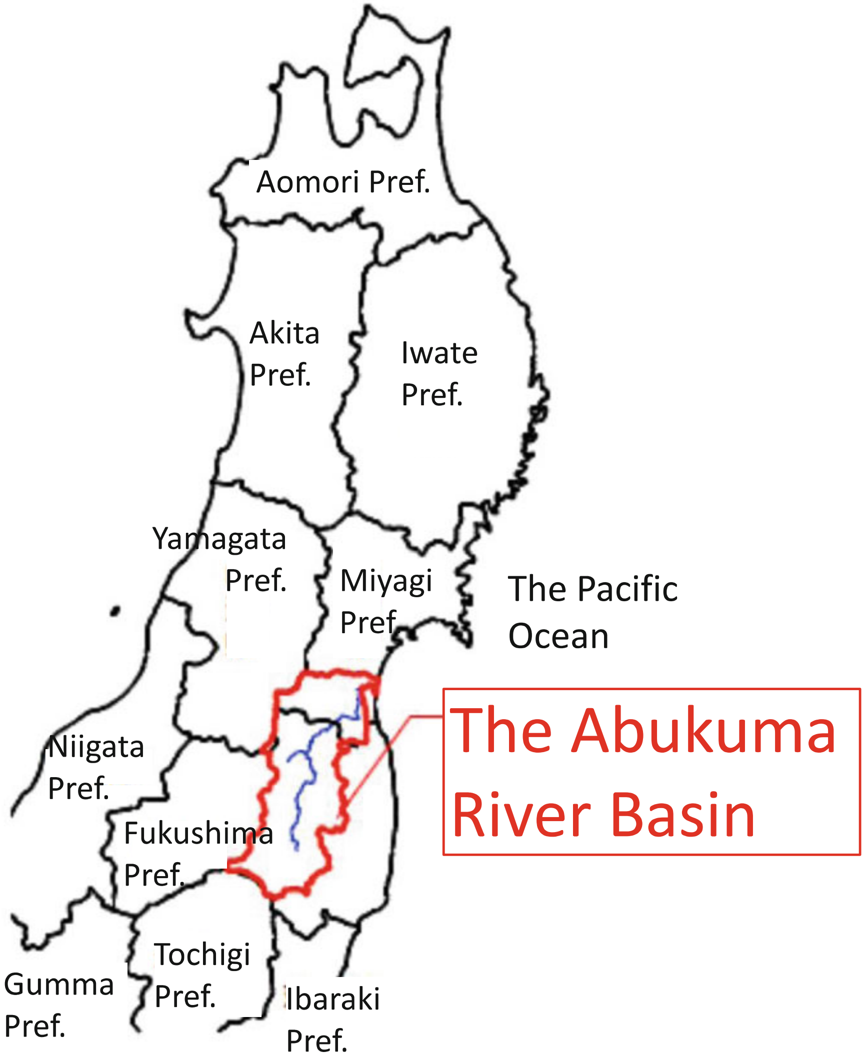


Fig. 14.3 Location of the Abukuma River Basin (modified from MLIT 2012)

emptying into the Pacific Ocean. The basin has a population of 1.3 million. The average annual precipitation is 1100 mm in the plains and 1200–1500 mm in the mountain areas. The river improvement project using modern techniques started in 1919 (MLIT 2021).

14.2.1 Hamao Retention Reservoir

Construction of the Hamao Retention Reservoir began in 2004 as an environmentally friendly method of flood control, and the retention reservoir was completed in 2012 (MLIT Tohoku Region Development Bureau 2012). In addition, to formulate a utilization plan for the retention reservoir, the Ministry of Land, Infrastructure, Transport and Tourism (MLIT) held workshops in which residents also participated and carried out in collaboration with the local community.

The Abukuma River system was severely damaged by a flood in August 1998. For this reason, various studies have been conducted so that even if a similar flood occurs in the future, the flood can be safely mitigated. The Hamao Retention Reservoir temporarily stores part of the water that flows through the river during floods, reducing the amount of water that flows downstream. The traditional technique of etsuryu-tei (overflow levee) has been employed at the Hamao Retention Reservoir. In addition, the improvement of the embankment and the excavation of the river channel and the Hamao Retention Reservoir, which is to be carried out in the "Great Heisei Renovation," will aim to reduce the flood damage downstream. Thus, urgent maintenance was carried out to reduce flood damage caused by floods on the same scale as the August 1998 flood. The area size of the Hamao Retention Reservoir is 75 hectares. The retention capacity was improved from 1.8 million square meters up to 2.3 million square meters by excavation work (MLIT Tohoku Region Development Bureau 2012). Figures 14.4 and 14.5 show the overview of the Hamao Retention Reservoir and the Abukuma River.

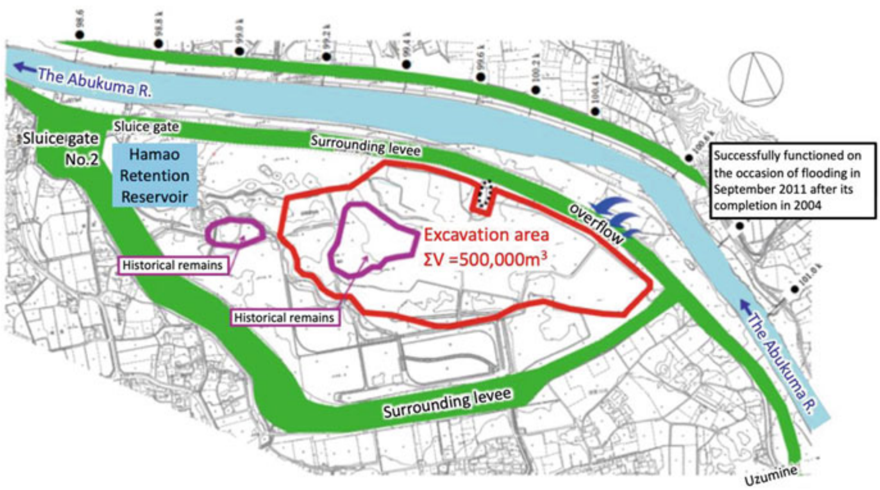


Fig. 14.4 Overview of Hamao Retention Reservoir (modified from MLIT 2012)

Fig. 14.5 Pooling the flood water successfully (2.6 million square meters) at Hamao Retention Reservoir (modified from MLIT 2012)

14.2.2 Typhoon Hagibis Hits Japan

Typhoon Hagibis called "Typhoon No.19" or "2019 East Japan Typhoon" in Japan formed in the central Pacific Ocean on 5 October 2019 and made landfall on mainland Japan on October 12 with a central atmospheric pressure of 955 hPa (at 18:00 on 12 October). The typhoon moved from south to north, across the Kanto and Tohoku Regions until heading out into the Pacific Ocean (Japan Meteorological Agency 2019).

Typhoon Hagibis caused record precipitation and floods in widespread areas of eastern Japan including the Abukuma River Basin in Fukushima Prefecture. As the Abukuma River flows from south to north, the Typhoon Hagibis took its route along the Abukuma River with enormous rainfall from the upper river basin to the downstream basin, bringing such enormous amount of rainfall that exceeded the

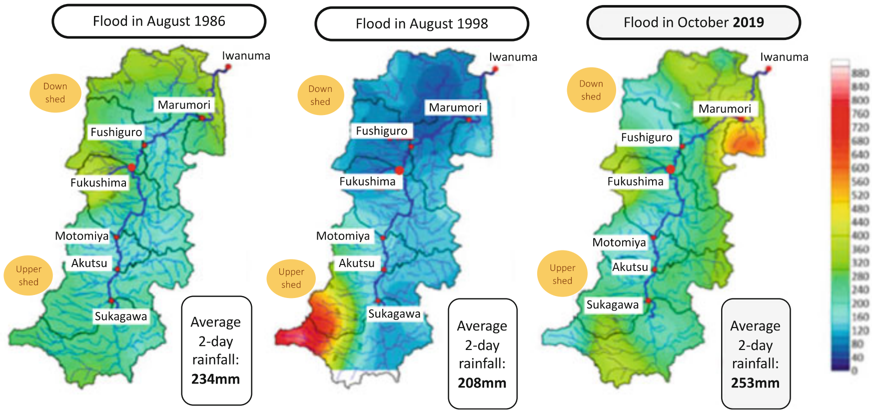


Fig. 14.6 Average 2-day rainfall at Fukushima Observation on the occasions of historical floods in 1986, 1998, and 2019 (modified from MLIT 2020b)

designed discharge of the bank (Kitamoto 2019; The Sankei 2019). Throughout the basin, more than 200 mm rainfall, which is more than double the monthly average in the area, was observed in only 48 h. The characteristics of the rainfall were temporal concentration and spatial distribution. This brought record discharge. At Fukushima Observatory, an estimated actual discharge was 6020 m^3/s, which exceeded both the record of 4310 m^3/s in 1941 and even the interim river improvement goal of 4600 m^3/s (MLIT 2020b). It resulted in a 2-day average rainfall of 253 mm, which exceeded historical record floods in 1986 with 234 mm/2 days or in 1998 with 208 mm/2 days (MLIT 2020b) (Fig. 14.6).

14.2.3 Damages at the Hamao Retention Reservoir

When typhoon Hagibis struck the Abukuma River, various types of infrastructures were damaged, limiting waterway capacity and causing a severe flood disaster throughout the entire basin. The damage of Hagibis in Fukushima Prefecture resulted in 38 deaths (direct, 32; indirect, 6) and left 59 people seriously injured. Damage to houses and other properties resulted in 1434 total collapses, 12,010 semi-collapses, and partial damage to 2005 houses. 1022 houses were inundated higher than the floor, and 432 houses inundated below the floor as of 13:00, 13 July 2021 (Fukushima Prefectural Government 2021).

On 13 October 2019, when the typhoon struck the Abukuma River Basin, the embankment in the Hamao district of Sukagawa City, Fukushima Prefecture, broke for an extension of about 50 m. The surrounding area was flooded. Tohoku Jisei, which manages rivers, established a Committee of Experts on October 14, the following day. After that, the cause of the levee breach and the restoration method were examined three times until December 2 (Nikkei Tech 2020). The Expert Committee investigated the damage situation at the location of the collapse

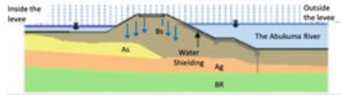
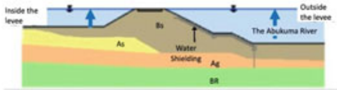
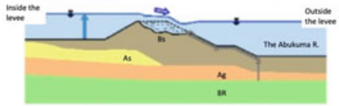
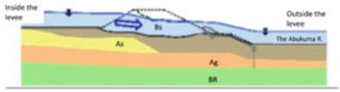
Levels	Process	Cross-section
1 Strom rain Water level rises	- Torrential rain exceeds the designed water level	
2 The water level inside the levee rises and overflows at the upper side of the levee.	- Water levels rise further and the water level inside the levee also rises with overflowing water.	
3 Overflow from inside the levee and corrosion at the top of the levee.	- Water in the reservoir and overflowing water concentrated at the breaking point (sluice gate No.2) which brings the water level inside the reservoir higher than the river water level. - Erosion on the levee surface occurs.	
4 Levee failure (the levee breaks)	- Erosion expands quickly. → The levee breaks.	

Fig. 14.7 Embankment collapse mechanism concluded by the Committee of Experts (source: MLIT Tohoku Regional Development Bureau)

immediately after the typhoon. Upon first inspection, it was thought that there was a possibility that water had overflowed from the embankment side where residential areas and paddy fields are located.

The damage caused by the heavy rainfall above was the inland flood. An additional cause of flooding was due to a large volume of runoff water being stored inside of the levee of the Abukuma River (Kawagoe 2019), and the Hamao Retention Reservoir was not an exception. The embankment in the Hamao district of Sukagawa City, Fukushima Prefecture, was broken for an extension of about 50 m, and the surrounding area was subsequently flooded as mentioned earlier. Due to the record heavy rainfall of the typhoon, the water level of the Abukuma River rose and remained above the designed high-water level for a long period of time. In the Hamao area, the water level on the embankment side rises due to flooding and inland water from upstream. This flood caused overflow to the river to reach beyond the height of the embankment. The top of the flooded area was paved with asphalt. However, when overflowing, a water level difference occurs between the river surface (river) side and the levee inside, and a lifting pressure exceeding its weight acts on the asphalt at the top. In this case, the asphalt was peeled off and washed away, and the embankment near the top was washed away as well. Figure 14.7 shows the mechanism of the main collapse of the levee at the Hamao Retention Reservoir, as reported by the Committee of Experts.

14.3 Basin-Wide Flood Management Approach

High-water construction is planned to suppress the flooding of rivers when the water level of a river is high, that is, in the event of a flood, to temporarily store river water in a dam or to drain it to the sea earlier by the drainage channel construction. It is the basic concept of current river construction. However, in the 2019 Typhoon Hagibis disaster, floods exceeding the planned scale occurred in various parts of the country such as Chubu, Kanto, and Tohoku, the embankments broke at 140 places, and many houses were swallowed by muddy water. While being asked how to adapt to climate change, disaster prevention technologies that keep flood currents in river channels by conventional embankments have exposed their fragility and danger (MLIT 2020c).

14.3.1 Shifting to Basin-Wide Flood Control

The national government agreed with a consensus on the Integrated Flood Management (IFM) project of the Abukuma River on 31 January 2020 (MLIT 2020a). Also, having experienced the floods after Typhoon Hagibis and a heavy rainstorm in July 2020, the national government and several local municipal governments changed their flood control policies to a trans-sectoral, basin-wide approach as a part of IFM (MLIT 2020a). In the future, it will be necessary to systematically carry out the second stage of maintenance, taking into consideration the maintenance status of the entire Abukuma River.

Since the basin-wide approach is regarded as one whole basin including the flooded area, cooperation with all the stakeholders concerned in the entire river basin is required to reduce future flood damage. For this reason, as with the "Urgent Flood Management Project (緊急治水対策プロジェクト)" for nine water systems severely damaged by the Typhoon Hagibis and the heavy rains of July 2020, riverbank restoration was also carried out in Class-A water systems nationwide (MLIT 2020d). Furthermore, for all the Class-A water systems nationwide, MLIT formulates "the basin-wide flood management project (流域治水プロジェクト)" integrating both hardware and software in which maintenance of rivers and rainwater storage facilities, land use regulation and guidance by designating disaster risk areas, as well as preliminary discharge from water-supply dams under the management by municipality governments and private sectors, etc. are all comprehensively included (MLIT 2020d).

Based on the compilation of "full-scale disaster risk reduction (6 July 2020), the "basin-wide flood management project" has been discussed by the basin-wide flood management committee, comprised of the national government, local municipalities, private sectors, etc. "The basin-wide flood management project" in all 109 Class-A water systems nationwide was formulated and announced to the public on 30 March 2021 (MLIT 2021).

14.3.2 Integration of Traditional Flood Management Techniques in the Basin-Wide Flood Management Project

Figures 14.8 and 14.9 illustrate the whole image of the basin-wide flood management project. The basin-wide flood management project includes Kasumi-tei levees, retention reservoirs, and likely overflow levees which will be selected and installed depending on the geographical and demographical conditions in a given area. Artificial forests are also to be included in the mountainside or coastal zone.

In the case of the Hamao retention reservoir, the broken levee (the sluice gate) was restored and reinforced so that the reservoir will keep functioning to pool flood water and prevent large floods in the down shed. Taking the impact of climate change into account, construction of another retention reservoir has been planned, whose capacity will be approximately nine million m^3 in the upper shed area of the Abukuma river (MLIT Tohoku Region Development Bureau 2012). Temporal storage of floodwater in crop fields has been included in the basin-wide flood management project although it is not mentioned in Fig. 14.9. This flood control function of agricultural fields has been long recognized as one of the multifunctional

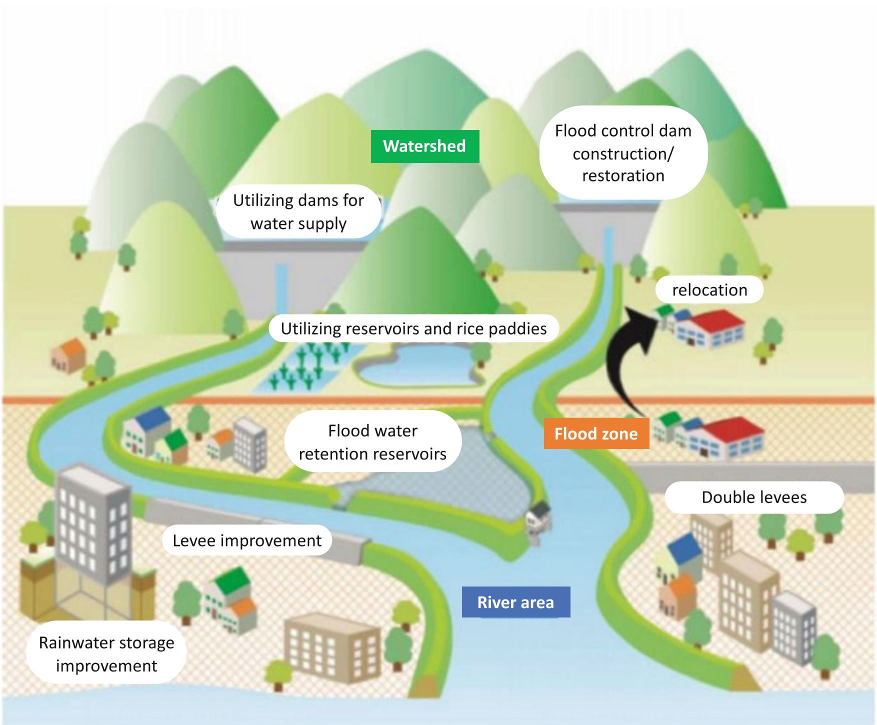


Fig. 14.8 Overall image of basin-wide flood management project (source: MLIT, 2021)

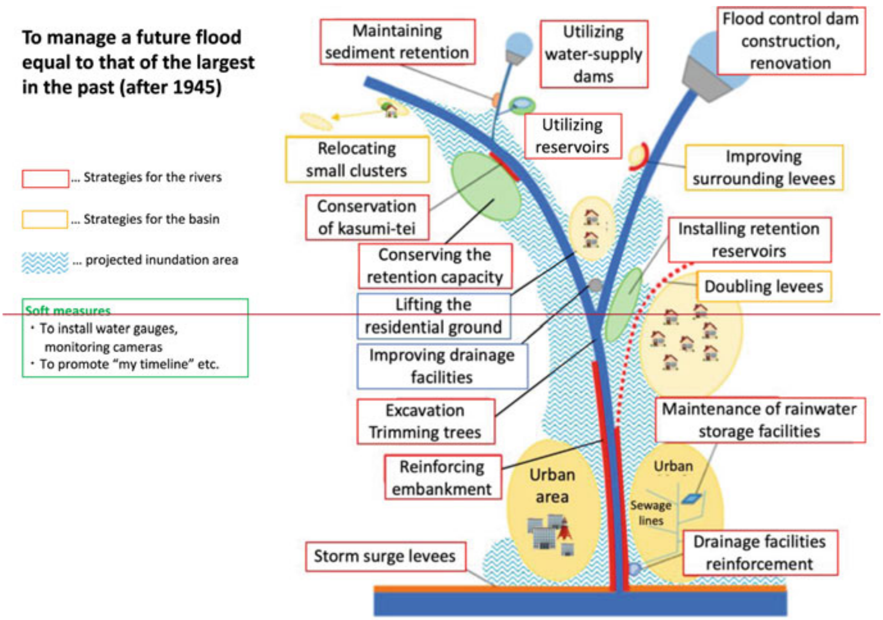


Fig. 14.9 Example measures of a river basin-wide flood management project (Modified from MLIT 2020e)

aspects of agriculture, and there is an institution called Multifunctionality Payment System (MPS) to simultaneously conserve ecosystem services, rural landscapes, etc.

14.3.3 Issues and Future Tasks

Considering climate change impacts and floods in the past, the flood management approach has been shifted to a basin-wide approach. However, the road to social implementation may still have several issues and tasks ahead. NbS for disaster risk reduction has been long discussed; however, not many cases have a proactive introduction, nor do they employ NbS in disaster risk reduction. This section offers a discussion focusing on the following three aspects: technology, economic, and coordination.

14.3.3.1 Technological Issues

The assessment methods for effects and benefits of NbS, including ecosystem-based disaster risk reduction or green infrastructure, have not been established yet (Masuda 2018). In response to these issues, the existing environmental impact assessment system can be used to promote NbS. Environmental impact assessment is the current procedure required when carrying out the development of a certain scale or larger, and businesses need to reduce the impact on the environment as much as possible.

NbS such as green infrastructure utilizes the functions of nature and can be used as an effective tool when consideration for the environment is required. In addition, the evaluation technology for environmental impact assessment and the technology for environmental conservation measures can also be applied to the evaluations and designs when introducing NbS in the future. Furthermore, the introduction of NbS through the procedure of environmental impact assessment will enable the formation of a favorable environment for those who proceed with the project (Masuda 2018).

14.3.3.2 Economic Matters

Concerning the current period of climate change, a hybrid approach integrating conventional civil engineering techniques with NbS is an option for implementation considering the increase of extreme weather patterns (Furuya and Shimatani 2018). However, close attention must be paid to the cost-benefit trade-off in planning and decision-making. The higher the ratio of green infrastructure, the more expensive the cost may become. Prioritizing the cost, it might not only lessen environmental multifaceted functions but also end up a mere excessive gray infrastructure with a hint of green infrastructure as NbS (Onuma and Tsuge 2018). Isaka (2010) pointed out the risks in depending too much on modern civil engineer-based river improvement, or gray infrastructure, which increases the risk of flood and environmental damage in case a flood occurs. This corresponds to claims made by Nishi Moromoto in the nineteenth century.

The price of land and safety can be an important concern for residents as well as private sector enterprises. Results of risk assessment influence land value and may also affect the subjective safety of residents living in the area. When it comes to relocation, it takes longer and involves more steps and processes. In these cases, institution systems for subsidies for residents must be organized. To pursue such processes and avoid unwanted bottlenecks, sufficient risk communication with adequate trust between local government officials, experts, and residents is necessary (Taki 2018). Thus, solutions to economic issues lie in the hands of those who are responsible for implementing budgets, residents, and potential project beneficiaries. Without sound risk communication, the benefit of a basin-wide flood management approach cannot be achieved.

14.3.3.3 Coordination Tasks

Since basin-wide flood management projects by MLIT and NbS involve all the stakeholders in a given basin, conflicts among the stakeholders are likely to occur. Hence, coordination and cooperation are key. Disaster management requires that multilevel governance systems enhance the capacity to cope with uncertainty and surprise by mobilizing diverse sources (Neil Adger et al. 2005). Likewise, there must be cooperation among inter-stakeholder work across boundaries of knowledges, practice, priority, scale, institutional histories, and cultures (Becker 2018).

The number of stakeholders and their interests must not be underestimated when it comes to a basin-wide approach, and various aspects such as disaster risk reduction and regional revitalization are involved. With the variety of stakeholders and aspects involved, the actors who lead the coordination and consensus-making have not been clear in the past and must be clarified especially for multilevel governments, where trans-sectoral information sharing and/or communication in normal time affects emergency responses and support provision (Sakamoto and Yamori 2012).

From the case of the Abukuma River, Konami et al. (2021) assert the significance of preparedness and the role of pre-disaster discussions for consensus-making of IFM after a flood disaster as preparedness for the next occasion, in conjunction with timely, efficient response and recovery. To discuss consensus-making with response and recovery requires all parties to pay attention to local context and knowledge including emergency responses in the past disaster cases. There is no "one-size-fits-all" approach or method in strengthening collaborative mechanisms (Ishiwatari 2019). Also, the structure of flood risk is caused by the risk directly generated by the legal system, and the flood risk is caused by the indirect legal system that exerts a shadow on the rules of behavior and decision-making in political processes and governance (Isaka 2010). It requires improvement of the current systems, which takes additional time. Hence, an optional strategy for applying a basin-wide flood management approach under the current legal system must be adopted to add concepts that come out of discussions rather than denial (Kada et al. 2010). The Shiga Prefectural Government in Japan succeeded in formulating the integrated flood management ordinance in this manner, which was implemented in March 2014.

14.4 Conclusions

This chapter provided the impact of Typhoon Hagibis at the Hamao Retention Reservoir in the Abukuma River Basin as well as some Japanese traditional techniques as NbS for flood mitigation and discussed the policy of the basin-wide approach for flood management and its future tasks through literature reviews. MLIT launched the trans-sectoral-wide basin flood management project in 2020, which integrated some traditional flood mitigation techniques as NbS. The Hamao Retention Reservoir was restored by reinforcing the bank, and construction of another large flood retention reservoir has been planned. However, the tasks of technical, economic, and coordination matters are to be overcome as NbS is related to a variety of issues in many sectors. For the sound implementation of the future NbS in Japan, the following two things are crucial: (1) to make clear which actors lead the coordination and consensus-making, especially among multilevel government officials, and (2) to promote proactive interaction among all the stakeholders in the process of consensus-making.

References

Becker M (2018) The role of intermediaries in flood risk management. Oxford Research Encyclopedias. https://doi.org/10.1093/acrefore/9780199389407.013.318

Cohen-Shacham E, Walters G, Janzen C, Maginnis S (eds) (2016) Nature-based Solutions to address global societal challenges. IUCN, Gland, Switzerland
Estrella M, Saalismaa N (2013) Ecosystem-based disaster risk reduction: an overview. In: Renaud F, Sudmeier-Rieux K, Estrella M (eds) The role of ecosystems in disaster risk reduction. United Nations University Press, Tokyo, pp 26–55
Fukushima Prefectural Government (2021) Damages by the typhoon No.19 (Hagibis) – the 108th. https://www.pref.fukushima.lg.jp/sec/16025b/sokuhou.html. Accessed 31 Jul 2021
Furuta N, Shimatani Y (2018) Integrating ecological perspectives into engineering practices – perspectives and lessons from Japan. Int J Dis Ris Red 32:87–94
Isaka N (2010) Basin-wide approach of flood management and discussion on political and institutional constraints. J Pub Pol Stu 10:104–115. (in Japanese)
Ishiwatari M (2019) Flood governance: establishing collaborative mechanism for integrated approach. Pro Dis Sci 2:100014. https://doi.org/10.1016/j.pdisas.2019.100014
Japan Meteorological Agency (2019) Tropical cyclone tracks (Typhoon Hagibis in 2019). https://www.data.jma.go.jp/fcd/yoho/data/typhoon/T1919.pdf,
Kada Y, Taki K, Nakatani K, Nakanishi N, Nishijima T, Maede H (2010) A study of water policy based on life environmentalism: the position of environmental sociology in government policy. J Env Soc 16:33–47
Kawagoe K (2019) Report on damages by the Typhoon No. 19 (Hagibis) by the Tohoku Region investigation team (Fukushima Prefecture), https://committeesjsceorjp/hydraulic05/system/files/%E4%BB%A4%E5%92%8C%E5%85%83%E5%B9%B4%E5%8F%B0%E9%A2%A8%EF%BC%91%EF%BC%99%E5%8F%B7%E3%81%AE%E6%9D%B1%E5%8C%97%E5%9C%B0%E5%8C%BA%E8%AA%BF%E6%9F%BB%E5%A0%B1%E5%91%8A%28%E7%A6%8F%E5%B3%B6%E7%9C%8C%29%E3%80%80_0pdf. Accessed 30 Jun 2021
Kitamoto A (2019) Digital Typhoon: Typhoon 201919 (HAGIBIS) – Detailed Track Information. http://agora.ex.nii.ac.jp/digital-typhoon/summary/wnp/l/201919.html.en, Tokyo, Japan, National Institute of Informatics. Accessed 30 Jun 2021
Konami T, Koga H, Kawatsura A (2021) Role of pre-disaster discussions on preparedness on consensus-making of integrated flood management (IFM) after a flood disaster, based on a case in the Abukuma River Basin, Fukushima, Japan. Int J Dis Ris Red 53. https://doi.org/10.1016/j.ijdrr.2020.102012
Masuda Y (2018) An overview of green infrastructure. Imp Ass 16(2):2–4
MLIT. (2012) Basins and rivers in the Abukuma water system. https://www.city.koriyama.lg.jp/material/files/group/15/abukumagawagaiyou.pdf. Accessed 30 Jun 2021
MLIT. (2020a) Abukuma River Integrated Flood Management Project. http://www.thr.mlit.go.jp/fukushima/pdf/20201202abukuma_project_English_ad_appendix.pdf, 2020. Accessed 8 Jun 2021
MLIT. (2020b) Overview of flooding on the occasion of Typhoon Hagibis (on 12 October 2019) the 4th report, http://www.thr.mlit.go.jp/fukushima/pdf/20191218_taifu19_syusuigaiyo_vol4.pdf. Accessed 30 Jun 2021
MLIT. (2020c) Overview of flooding on the occasion of Typhoon Hagibis (on 12 October 2019) the final report, https://www.city.koriyama.lg.jp/material/files/group/24/r0206_ks06.pdf. Accessed 30 Jun 2021
MLIT. (2020d) Basin-wide flood management (ryuikichisui) project. https://www.mlit.go.jp/river/kasen/ryuiki_pro/index.html. Accessed 8 May 2021
MLIT (2020e) Full-scale disaster risk reduction – to protect our life. MLIT, Tokyo
MLIT. (2021) Announcement of “Basin-wide flood management project” in the all 109 Class-A water systems. https://www.mlit.go.jp/report/press/mizukokudo05_hh_000128.html. Accessed 8 May 2021
MLIT Tohoku Region Development Bureau (2012) The Abukuma river development plan, http://www.thr.mlit.go.jp/fukushima/kasen_seibi/2012henkou/zenbun.pdf. Accessed 31 Jul 2021

MLIT Tohoku Region Development Bureau (2020) Press release: completion of restoration at the broken levees at the Abukuma River, https://www.thr.mlit.go.jp/bumon/kisya/kisyah/images/81172_1.pdf. Accessed 17 Jun 2021

MoE (2016) Ecosystem-based disaster risk reduction in Japan, https://www.env.go.jp/nature/biodic/eco-drr/pamph04.pdf. Accessed 13 Oct 2016

Nakajima D, Ogushi K (2012) Effect and Numerical simulation of flood water into the retention reservoir at the Jobaru river – Kasumi-tei levees, Civil Engineering Conference, http://library.jsce.or.jp/jsce/open/00074/2012/56-02-0034.pdf. Accessed 29 Jun 2021 (in Japanese)

Neil Adger W, Hughes TP, Folke C, Carpenter SR, Rockström J (2005) Social-ecological resilience to coastal disasters. Science 309(5737):1036–1039. https://doi.org/10.1126/science.1112122

Nikkei Tech (2020) (Levee breakings) Part 1: Reality of 100 years-Abukuma River, https://xtech.nikkei.com/atcl/nxt/column/18/00142/00764/ (accessed 8 June 2021)

Okuma T (1987) Discussion on the function and etymology of Kasumi-tei levee. Japan Civil Eng Conf Proc:259–266. (in Japanese)

Onuma A, Tsuge T (2018) Comparing green infrastructure as ecosystem-based disaster risk reduction with grey infrastructure in terms of costs and benefits under uncertainty: a theoretical approach. Int J Dis Ris Red 32:22–28

Pihl E, Martin MA, Blome T, Hebden S, Jarzebski MP, Lambino RA, Köhler C, Canadell JG, Ebi KL, Edenhofer O, Gaffney O, Rockström J, Roy J, Srivastava L, Payne DR, Adler C, Watts S, Jacobsson L, Sonntag S (2019) 10 New insights in climate science 2019. Future Earth & The Earth League, Stockholm, p 38

Sakamoto M, Yamori K (2012) Understanding mutual assistance coordination among prefectures and municipalities in a multi-location. J Soc Saf Sci 18:391–400

Sendo H, Ishikawa T (2018) Hydraulic function of the kasumi-tei levee system on the Kurobe Alluvial Fan of the 19th century. In: Paquier A, Rivière N (eds) River Flow 2018 – Ninth International Conference on Fluvial Hydraulics, E3S Web Con 40. Lyon-Villeurbanne, France, September 5–8, 2018. https://doi.org/10.1051/e3sconf/20184006032

Sudmeier-Rieux K, Ash N (2009) Environmental guidance note for disaster risk reduction: Healthy Ecosystems for human security. IUCN, Gland, Switzerland. (Revised edition)

Takahashi H (1971) Land transformation and floods. Iwanami-shinsho, Tokyo

Taki K (2018) Research for the implementation of the risk-based floodplain management: a zoning process for the building-regulation in Shiga Prefecture, Japan. Jap J Ris Ana 28(1):31–39

Tanabe T, Okuma T (2001) A study on the roles and effects of "NOKOSHI" on the Jobaru-River Basin: example of flood control that allows overflowing and its future possibility. His Stu in Civ Eng 21:147–158

Teramura J, Shimatani Y (2021) Advantages of the open Levee (Kasumi-Tei), a traditional Japanese River Technology on the Matsuura River, from an ecosystem-based disaster risk reduction perspective. Water 13:480. https://doi.org/10.3390/w13040480

The Sankei (2019) Typhoon Hagibis – "the sequence of breeches" the track of the typhoon along the Abukuma river from south to north. https://www.sankei.com/article/20191017-2DFKNRJQTFLI7NPBLXDGUNHHU4/ Accessed 17 Jun 2021

Watanabe K (1998) Change of the area and factors of the decrease in the flood control forests after World War II. Water Sci 42(1):61–74

Naoko Kimura is a Senior Program Associate for Integrated Lake Basin Management at International Lake Environment Committee Foundation, Japan.

Nature-Based Solutions (NbS) for Sustainable Development of the Resource Base and Ecosystem Services of Marine and Coastal Ecosystems of India

15

Harini Santhanam and Sudip Kumar Kundu

Abstract

The imminent dangers due to increasing anthropogenic stress on the coastal seas, as well as marine pollution in the Anthropocene, have highlighted the need to devise and adopt novel eco-sustainable solutions through the use of technology for India. Special emphasis on the use of scientifically derived marine fishery advisories (MFAs) can have multiple co-benefits with the utilization of nature-based solutions (NbS) for monitoring and management of coastal and marine resource bases. Such co-management options can be effective to realize the targets for Sustainable Development Goals 14 (SDG 14) for 2030. At present, the Indian National Centre for Ocean Information Services (INCOIS) under the Ministry of Earth Sciences (MoES) provides the MFAs on a daily basis by using a combination of data from satellite imageries and ground-based datasets. However, sustainable use of marine and coastal ecosystems services needs to be informed by appropriate technological models of resources usage, including the incorporation of coastal zone management plans as per NbS frameworks for achieving long-term successes. The present study highlights the need to adopt NbS and MFAs as co-management approaches for adaptation and/or mitigation of the impacts of climatic and environmental factors as well as for fostering sustainable fishing initiatives for the Bay of Bengal. Such integrative methodologies are crucial for the development of model-based policy frameworks for sustainable marine resources management. Accordingly, an

H. Santhanam (✉)
National Institute of Advanced Studies, Bengaluru, Karnataka, India
e-mail: harini@nias.res.in

S. K. Kundu
National Institute of Advanced Studies, Bengaluru, Karnataka, India

Manipal Academy for Higher Education, Manipal, Karnataka, India

S. Dhyani et al. (eds.), *Blue-Green Infrastructure Across Asian Countries*,
https://doi.org/10.1007/978-981-16-7128-9_15

assessment of the NbS techniques for deriving a new adaptive framework is presented and discussed in the context of consideration of MFAs as NbS Assisting Technologies (NAT) to obtain significant co-benefits for sustainable development.

Keywords

Marine resources · Coastal zone · Ecosystem services · Nature-based solutions · Marine fishery advisories

15.1 Introduction

The Indian region is characterized by the various landforms forming the unique tapestry of diverse coastal and marine ecosystems along with its 8118 km of long coastline. From the perspective of ecosystem services for India, the coastal regions act as a buffer zone as it links land and ocean together and also creates a system of socio-ecological interactions typical to the Indian subcontinent. On the other hand, the marine ecosystems form the basis of the ecological heritage as well as the source for national, regional and local economies for India. The coastal region of India also plays a vital role in marine fish landings across its 1511 fish landings centres located in 9 maritime states and 2 union territories (UTs). In case of India, marine fishes have been treated as one of the best source of animal protein to remedy malnutrition (Hinds 1992). Further, the fishery sector creates large employment in India, and currently about 16 million fishers are directly dependent on this sector, while the number is double along the value chain (NFDB 2020). In 2019, India has harnessed about 3.56 million metric tons (Mt) of marine fishes with a 2.1% of annual growth rate where Tamil Nadu contributed the highest share among all maritime states and UTs (ICAR-CMFRI 2020). As per the latest statistics, fish capture from the mechanized sectors contributed about 83%, while the contribution is only 1% from the traditional fishing sector. India also exported nearly 1.40 Mt. of seafood worth INR 465.89 billion (USD 6.73 billion) during 2018–2019 (NFDB 2020). In this way, coastal and marine ecosystems have provided the vital basis to support lives and livelihoods by improving the economy of the country and henceforth improved the socio-economic conditions (Nayak 2017). In recent times, various anthropogenic activities along with global warming-derived climate change have been posing major threats for the conservation and sustainable development of the coastal and marine ecosystems in India (Nayak 2017).

Activity-based challenges in coastal and marine area management have enhanced the recognition of the imminent limits for exploitation of the marine resources base. However, the matching of the management approaches requires the expansion of the current technological solutions to meet not just the present but even presumptive challenges to sustainable development. For example, at present, the fishery sector in India faces a wide range of challenges associated with lack of infrastructure, overfishing, water pollution, habitat degradation, insufficient market information, post-harvest losses, weak organizations, a lack of access to financial services, etc. (FAO 2018). In the last two decades, small-scale fishers had also reported the forced displacement of fishes from their traditional fishing grounds as well as reduction in the stocks, as a direct consequence of the impacts of industrialization, pollution, etc. Despite the recognition of the environmental limits and the need for sustainable fishing, overfishing becomes a substantiated activity at local levels to enhance the sources of the incomes of fishers caught in the loop of poverty and indebtedness (Pramod 2010). Such activities in turn lead to the inevitable environmental degradation of unimaginable proportions. Matthew (2015) also reported that small-scale fishers in India suffer from water pollution, destruction of fish habitats, increasing competition and high prices of coastal land. Anthropogenic pollution in the marine environment is the most common threat in achieving sustainable marine resources, i.e. marine fish management (Bradley et al. 2019).

A large part of the management approaches undertaken at national and local levels in dealing with these challenges have been ably supported by several of India's flagship programmes at central and state levels for maritime conservation, supported through the use of spatio-temporal monitoring of the resources. For example, the use of geospatial technologies has contributed to a wealth of data on the coastal and marine environments from various remote sensing satellites such as INSAT, OCEANSAT, RESOURCESAT, CARTOSAT, RISAT, SCATSAT, SARAL-ALTIKA, IRNSS, etc. by enhancing the knowledge on physical structure and conditions, spatial pattern and extent along with its temporal changes of coastal and marine habitats (Nayak 2017, 2020). However, mainstreaming the use of data for managing the critical ecosystems requires three major perspectives:

1. Approaching marine and coastal conservation by adopting nature-inspired and nature-based management options which provide long-term benefits to the environment as well as the society.
2. Planning for infrastructural approaches which reduce and prevent human dependence on pollution-causing materials for achieving livelihood targets through use of sustainable technologies.
3. Use of assistive technologies to plan, establish, monitor and manage the resource base.

In this context, nature-based solutions (NbS) can be considered as effective measures to preserve the coastal and marine ecosystem services especially in the case of a maritime country as India facing the numerous challenges due to accelerated urbanization.

In general, NbS refers to the sustainable use as well as sustainable management of nature to remedy various socio-environmental challenges. The outcomes of NbS are also associated with human welfare and biodiversity enrichment through the sustainable resource management (IUCN 2021). The lives and the livelihoods of the coastal people including marine fishers are highly dependent on the coastal and marine ecosystem; however, they are also exposed to extreme weather events associated with cyclones, storm surges, coastal erosion, etc. (Gajjar 2020). In connection, NbS can play an important role in reducing the effect of weather extremeness through the use of natural resources which is also helpful in the conservation of natural resources. For instance, by increasing the mangroves forest and salt marshes in the coastal areas, it is possible to reduce the strength of wave height and velocity by 31% and 72% along with coastline stabilization by sediment aggregation. In this context, coral reefs, seagrass and sandy beaches are also useful to minimize the coastal erosion, storm surges, etc. (Cohen-Shacham et al. 2016; Kapos et al. 2019). Additionally, Kapos et al. (2019) also mentioned that NbS are beneficial for the improvement of marine fish stocks, marine biodiversity conservation and carbon sequestrations along with tourism and recreation associated with the sea. Table 15.1 shows the list of marine habitats, the ecosystem services rendered by them as well as scope for nature-based management approaches which need to be considered for appropriate blue-green infrastructure development.

In this context, the Sustainable Development Goal 14 ‘Life below water’ imposed by the United Nations places an emphasis on mainly three thematic areas: marine pollution, marine climate and sustainable usages of marine resources by balancing the environmental, social and economical dimensions of the sustainable development. The United Nations Economic and Social Council (2019) reported that marine environment is suffering from unsustainable depletion, environmental deterioration, saturation of carbon dioxide and henceforth oceanic acidification while oceans and marine fisheries are continued to global economic, social and environmental needs. Most significantly, the present efforts to protect the marine environment are yet not been so impressive globally. Further, the sustainability of the global marine fishery resources continues to decrease at a reduced rate, while the contribution of the sustainable marine fishery capture to the GDP remained stable at the global scale with a regional variation in Pacific Small Island developing countries and least developed countries where it largely contributes to the GDP with an average of 1.55 and 1.15, respectively, during 2011–2017. Hence, it is evident that an urgent assessment of the ecosystem services is required, which can support the planning of national policies on sustainable fishing.

15.2 Marine Ecosystem Services: Existing Approaches and Relevance to Resources Modelling

Although oceans, seas and coastal ecosystems support a large population of humans through their multiple ecosystem services, it is difficult to assess these services completely particularly because of the challenges in capturing the dynamics of the marine habitats and owing to the dynamicity of the oceanic processes such as winds, tides and currents (e.g. Townsend et al. 2018). Since the primary goal of planning the assessments is towards producing the desired observation on the socio-economic benefits, the models of resource usages are usually region- or location-specific and cannot be generalized, which make decision-making quite complex. Further, the technical, technological and the implementation capacity of a country can limit the use of decision support tools (Posner et al. 2016). Specifically, in the case of

Table 15.1 Marine and coastal habitats and scope for nature-based (NbS) green management

Marine/coastal habitat component	Ecosystem service rendered	Scope for nature-based (NbS) green management
Estuaries, tidal creeks, backwaters	Fisheries	Sustainable fishing practices using traditional crafts and gears
	Nutrient circulation	Maintenance of natural channels of recirculation; minimizing land-based solid waste and fertilizers run-off
	Navigability	Use of traditional, non-polluting modes of transport
Wetlands and marshlands	Nutrient sequestration	Controlling eutrophication using wetlands
	Water residence and recirculation	Balancing tidal and wind-driven recirculation by protective barriers
	Sediment enrichment	Waterlogging and marshland protection to increase organic content in sediments
Coastal sand dunes	Barriers and embayment	Protective barrier management using natural sluices and gates
Coastal lagoons and mangroves	Fisheries	Sustainable fishing practices using traditional crafts and gears
	Nutrient circulation	Maintenance of natural channels of recirculation; minimizing land-based solid waste and fertilizers run-off
	Bird and protected marine animals sanctuary	Protective areas approaches to preserve biodiversity
	Perpetuation of keystone species	
	Bioshields	Mangrove reforestation
Open sea ecosystems and marine protected areas	Climate regulation	Decrease in anthropogenic emissions of particulates along coast and offshore
	Fisheries	Sustainable fishing practices; using traditional crafts and gears and preventing overfishing
	Nutrient circulation	Maintenance of natural salinity and hydrological cycles, reducing desalination and improved bioavailability by providing regeneration periods

modelling the marine fisheries resource base, it is important to derive the potential reference points for ecosystem-based fisheries management which can characterize the ecosystem status practically (e.g. Link et al. 2002). Thus, the need for planning NbS-based green solutions for management hinges on the use of the ecosystem modelling approaches to optimize the resource usages.

Taking an example of ecosystem-based management (EBM) approaches defined in recent times, it emerges that there are several 'levels' of consideration of the datasets to model the overall efficiency of these approaches (Link and Browman 2014). For example, considering the case of fisheries as major ecosystem services

Table 15.2 Ecosystem services assessment and approaches in the context of marine resources management (adapted from Seppelt et al. 2011)

Marine ecosystem services parameter	Considerations to select appropriate NbS
Biophysical and environmental services	Realism of the ecosystem data and models
Off-site usages	Recognition of the off-site effects
Local resource usages	Accounting for local trade-offs
Stakeholder participation	Evaluate the critical involvement of stakeholders in assessments

component, the ecosystem approach to fisheries (EAF), an integration of the fish stocks with environmental and ecological components such as temperature, predator removals, multispecies interactions, etc., is necessary to select the appropriate NbS strategy. This system accounts not only the interactive elements but also the impacts of the fisheries stock changes on other components of the ecosystem. A typical blueprint for ecosystem services studies thus includes the consideration of four facets which need to be critically evaluated (Seppelt et al. 2011) as shown in the Table 15.2.

In each of the parameters critically considered to model the marine resource base, a degree of normalization needs to be incorporated to achieve the practical implementation of the goals and challenges. A recent approach of using the Multiscale Integrated Model of Ecosystem Services (MIMES) incorporates the integration of multiple ecological processes with human dynamics to simulate the interactions between coupled human and natural systems (Boumans et al. 2015). Such integrative framework often requires inputs of datasets from multiple platforms and sources including varied spatial and temporal databases, to match with the intangible and tangible benefits of the use of an appropriate NbS.

From the perspective of mainstreaming the NbS, it is also observed that the ecosystem services are not readily linked to market values and economic assessments, which put a huge pressure on deriving truthful representations of these services themselves. However, there exists huge scope to improve the supply chain assessments and their relationships with the demand side as inherent processes for sustainable development of marine resources. These require a higher level of involvement with computational regime that incorporates local- to regional-level considerations for regional development. Another perspective in the sustainable development of marine resource base includes accounting for the challenges to the achievement of the targets due to indirect drivers such as extreme weather events, sea level rise and invasive species. These multiple drivers and pressures need to be linked to the adaptive management plans and bring the experiences in dealing with these stressors into operationalizing the ecosystem-based management approaches. The computational challenges of integrating these datasets become huge considerations while deriving assessments of the impacts of the NbS-based policy frameworks.

Incorporating the NbS frameworks into marine resources management will hence require the integration of different pathways considering the ecological interactions including impacts, the services rendered as well as the administrative and governance challenges. The flow across these pathways is aligned with the use of the correct NbS strategies which will alleviate the impacts, improve the services and reduce the governance challenges across the long-term temporal scales. At the end of the process, it is important to integrate these experiences into the database to provide the blueprint for futuristic development. In order to do so, data transparency, as well as flow pathways, has to be logically and intuitively reorganized to present the inherent scenarios for futuristic development. The computational advantages can be interlinked to the decision support tools using inference-based modelling frameworks. These aspects are discussed in the role of technology in adopting NbS for coastal and marine systems.

15.3 Examples of Coastal and Marine NbS Options in Global and Indian Contexts

Globally, the NbS adopted for coastal and marine environments can be divided into four categories – fully natural solution, i.e. natural coral reefs, mangroves, etc.; managed natural solution, i.e. planted mangroves, artificial coral reefs and renourished sea beach; hybrid solution, i.e. combination of engineering structure and natural features like dune-dyke system, etc.; and environment-friendly engineering structure, i.e. bamboo sediment fences (Pontee et al. 2016; Fig. 15.1).

Pontee et al. (2016) also highlighted that the implementation of NbS also depends on some factors, e.g. types of habitat, water depth as well as habitat characteristics related to the effective coastal protection. In this connection, several examples of

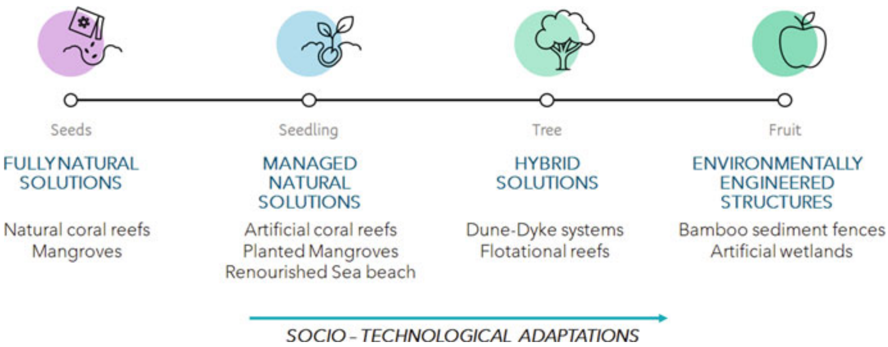


Fig. 15.1 Types of nature-based solutions (NbS) available and adopted for coastal and marine habitat management and development. The NbS can provide green alternatives for total habitat management (seed) or supportive (seedling). Ensemble solutions (tree) and naturally conceived products (fruit) can also be effective NbS options as illustrated

coastal and marine NbS options can be provided in the global as well as Indian context.

15.3.1 Global Case Studies

Global case studies provide a glimpse of the NbS efforts that may of three important interventional types as described in Eggermont et al. (2015):

1. No or minimal interventions in ecosystems: examples include mangrove conservation and/or preservation as core/buffer area protective solutions.
2. Partial interventions: implementation of innovative management approaches towards development of landscapes in order to improve the delivery of selected NbS options compared to conventional interventions. Examples for the coastal zone operations include evolutionary-oriented fisheries management which has a beneficial effect on restoration of native fishery stocks and thereby contribute to coastal resiliencies.
3. Management of the ecosystems on an intrusive level or creation of new ecosystems themselves. Examples include creation of artificial wetlands, reefs, seaweed farms, etc.

The entire scales of the operations described above from the perspectives of benefits and trade-offs are described here taking specific case studies as examples. To reduce the effect of coastal erosion and hurricane-induced strong wave in Puerto Morelos, Mexico, on the Mayan Riviera, artificial coral reefs were planted as a part of NbS (Acclimatise News 2019). It had been noticed after 5 years of completion in 2015 that artificial reefs helped to recover the beach along with the fish attraction in the reefs. In case of Mayakoba beach, also artificial coral reefs were planted to reduce the sand dune losses, which negatively impacted the nearby mangroves, turtles, birds, etc. owing to the effect of hurricane (Acclimatise News 2019). The establishment of Sand Motor, Netherlands, under an NbS was useful to set up natural sand dunes against beach erosion on the coast. The expansion of sea beach attracted tourist and has transitioned into good places for community recreation (Luijendijk and Oudenhoven 2019). The port city of Dar es Salaam in Tanzanian was suffering from deforestation, soil erosion and sedimentation owing to the rapid urbanization which resulted in the loss of fertile agricultural land as well as loss of lives and livelihoods due to the successive floods (Gajjar 2020). In such scenario, Tanzania Urban Resilience Programme has been prepared a draft under NbS through reforestation, dredging of the river, plantation of mangroves and solid waste management by 2030. Gajjar (2020) also studied that the Municipal Climate Protection Programme developed key components of community-based ecosystem, green economy and disaster management system under NbS programme to reduce several climate change-oriented impacts such as sea level rise, storm surges, water scarcity, etc. in Thekwini, South Africa. It was also useful in terms of co-beneficial effects of employment generation, community ownership, etc. for societal benefits. In connection, the 'Ecosystem-based Adaptation to Climate Change in Seychelles project (2014–2020)' has been adopted in Mahé and Praslin, Seychelles, to minimize the risk generated by cyclone and associated storm surges, sea level rise, etc. through the restoration of ecosystem functionality where local civil societies were deeply involved (Gajjar 2020). Moreover, Mueller and Bresch (2014) mentioned that annual damages worth USD20 can be avoided due to hurricanes through the protection of Folkestone Marine National Park, located in Barbados.

Duarte et al. (2017) studied the global NbS services of seaweed farms highlighting their significant carbon sequestration properties and roles as carbon dioxide (CO_2) sinks, contributing to total or partial biofuel production. Further, they highlighted the huge potentials of the seaweed farms as CO_2 mitigators to the tune of about 1500 tons CO_2 per km^2 per year of avoided emissions from: (1) fossil fuels and (2) facilitating further reduction of the emissions from agriculture, as well as, (3) lowering methane emissions attributed to cattle when included in cattle feed. Other ecosystem services of the seaweed aquaculture such as damping the wave energy in the sea, mechanical consolidation of shorelines, enhancing the pH and supplying dissolved oxygen to the surface waters by their presence contribute twofold to NbS: (1) mitigation and adaptation to climate change as biomass and (2) alleviating the effects of ocean acidification and anoxia as a constituent of the coastal and marine food web.

Kelly et al. (2012) described the use of human-nature partnerships as NbS methodologies to secure the conservation and preservation of marine resources, including living resources such as the dolphins, illustrating the uses and apparent trade-offs through three case studies from the Shannon Dolphin and Wildlife Foundation (SDWF, Ireland), the Dolphin Space Programme (DSP, Scotland) and the Pembrokeshire Marine Code Group (PMCG, Wales). The study highlighted the use of heuristic analyses of the indicators of sustainability of the NbS partnerships as well as the development of policy interventions supportive of the NbS measures adopted. Recently, Narayan et al. (2016) researched the multimodal ecosystem services of NbS in coastal and marine environments; these advancements in the knowledge of the use of NbS for coastal studies are illustrated in Fig. 15.2. The study highlighted the efficiency of two types of NbS hitherto mentioned (see Fig. 15.1) to support different anthropogenic uses, for example, the shoreline protection.

15.3.2 Indian Scenario

In case of India along with other South Asian countries, i.e. Indonesia, Sri Lanka, Thailand and Malaysia, community-based coastal habitat restoration has been initiated by Wetlands International, IUCN, under NbS approaches of ecological restoration. The government of India had notified Island Protection Zone (IPZ) in 2011 through the conservation of mangroves and renourishment of beaches and sand dunes with the objectives of promoting development in a sustainable manner along with supporting the livelihoods of the local community (University of Oxford 2021). India is also on the way to implement the Integrated Coastal Zone Management

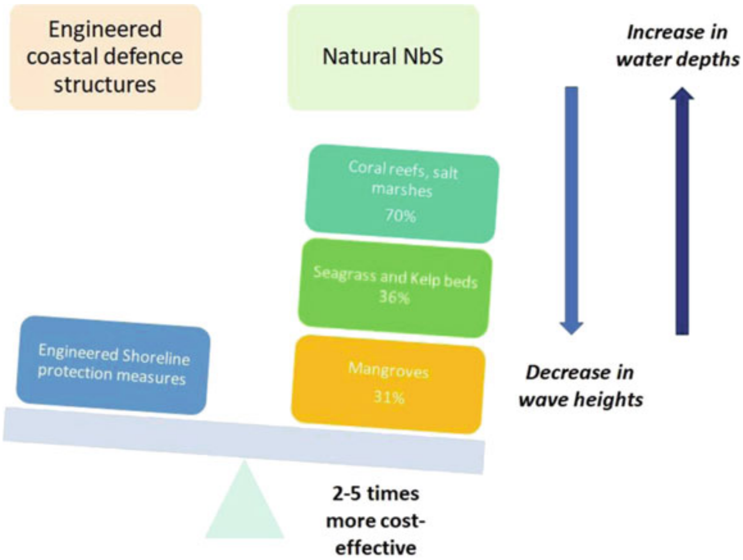


Fig. 15.2 Example of implementation of coastal NbS for shoreline defence and protection described in Narayan et al. (2016) illustrating the benefits of the use of natural NbS ecosystems for the coastal defence

(ICZM) to conserve and protect the critical coastal and marine habitats as well as coastal and marine geomorphology in association with 'Mangroves for the Future (MFF)' coordinated by IUCN with an initiative of coastal livelihood support. Under the latest 'BG infrastructural policy scheme', Atal Mission for Rejuvenation and Urban Transformation (AMRUT) is aiming to improve the governance and sustainability of Indian cities under NbS approaches, having eight components: water supply, sewerage, septage, storm water drainage, urban transport, green spaces and parks, administrative reforms and capacity-building (Gajjar 2020). Such studies are quite important to address challenges to coastal cities in India; for example, the coastal city of Panaji is impacted by coastal erosion, land degradation and loss of biodiversity owing to the sea level rises, urbanization and habitat alternation, respectively, where mainstreaming of NbS can offer both short-term and long-term benefits by technological interventions. Another example of the planning for NbS-based coastal protective measures is presented at the 6 km long St Inez Creek, connecting Mandovi River and the Arabian Sea, which is significant from the environmental as well as socio-cultural perspectives; however, its functionality has been reduced due to both anthropogenic activities and natural degradation. To restore the functionality of the creek, a floating bioremediation system was created as NbS in 2017 with the help of experts and local youths with varied effects. Apart from this, a mixed approach, i.e. water quality monitoring, natural remediation, solid waste filtering, sewage treatment and green space coverages along the creek, has been proposed under NbS approach for the restoration of the functionality of the creek (Gajjar 2020).

In 2007, IUCN and MSSRF jointly developed the Integrated Mangrove Fishery Farming System (IMFFS) in Tamil Nadu to sustain the livelihoods of the local fishing community and also to stop the unsustainable aquaculture practices that resulted in the collapse of shrimp farming since the 1990s (IUCN 2016). Further NbS at vulnerable locations along the coastal Bay of Bengal has been reported to benefit the lives and livelihoods of the fishing community at several marine fish landing centres by artificial coral reefs formation, dredging of the sedimented rivers, beach nourishment, etc.

15.4 NbS for Achieving Targets of the Sustainable Development Goals (SDG) for India

The Sustainable Development Goal (SDG) 14 ('Life below water') deals with the dependence of human beings on the ocean, especially with respect to the coastal and marine fisheries. About 40% of the total world population lives within 100 km of the coast and fully depend on the ocean for their livelihoods. Further, more than 15% of the total protein consumed by 4.3 billion people across the globe comes from seafood (Pisupati 2016). Apart from these, the offshore ocean provides 30% of the total global petroleum and natural gas production, while ocean currents, tides, waves and winds are used to generate non-conventional energy worldwide which is environment-friendly due to low CO_2 emissions (Cicin-Sain 2015). However, the conservation and sustainable usages of marine resources under SDG 14, imposed by the United Nations, are still limited (Pisupati 2016). The SDG 14 consisting of seven targets, i.e. 14.1, 14.2, etc., emphasize on three thematic areas: marine pollution, marine climate as well as marine resources.

With more than 25 marine protected areas consisting of 10,000 sq. km located in 106 peninsular islands, the marine biodiversity of India is a great asset, providing numerous ecosystem services; however, suitable and proper plans and approaches need to be implemented for achieving the target related to the SDG 14. In India, NITI Aayog has been empowered to oversee the overall progress associated with the SDGs and the capacity-building to achieve the same. Such efforts from the central government have been crucial to promote the use of NbS in the sustainable management practices across the country.

For example, it has been reported that 112 km^2 of mangrove forest had been increased in the coastal regions of India compared to the previous assessment while more than 15,000 ha were planted in the coastal Gujarat region. The Government of India has also been launched *National Fisheries Policy 2020* to provide momentum in *Blue Revolution* (NFDB 2020). Presently, various national- and state-level legislations are collaborating for the management as well as protection of the marine environment through the community participation under the scheme of Integrated Coastal Zone Management Project (Government of India 2017). Despite a long history of its marine resource management, however, India suffers from reliable datasets associated with the depth information on the marine resources, its status and trends at national as well as state level (Pisupati 2016). Under the circumstances, it is clear that NbS options if facilitated for the country through policy-driven changes can provide effective means to plan and execute the sustainable management practices. Further, the following are the major considerations that need to be addressed for dealing with the management of the coastal and marine resources:

1. The availability of knowledge to pursue NbS.
2. The policy-driven gaps in addressing the need for NbS-based planning for coastal and marine conservation.
3. The gap between the availability and use of technology to provide the impetus for capacity-building and training of all levels of stakeholders for coastal and marine governance under the perspective of NbS.
4. The complexity of the data and the need for multi-criteria decision analyses make a case for the need for coordinated computational efforts and technology-based approaches to realistically achieve the targets of the SDG 14.

Presently, it is very urgent to collate various information and data regarding different agreed targets and indicators of SDG 14 for achieving sustainable marine resource management. In this connection, the Ministry of Statistics and Programme Implementation, Government of India, has prepared National Indicator Framework (as shown in Table 15.3) related to the SDGs for identifying data and information gaps; probable indicators align with the global indicators and also create a strong network in between ministries, institutions and civil societies (Government of India 2020). The present investigation provides a unique compilation of the indicator-wise assessment of the NbS needs for India which are summarized in Table 15.3.

15.5 Scope for the Use of Technology for Adapting to NbS Frameworks as NbS Assisting Technologies (NAT)

A significant amount of research and development efforts in the area of marine resources monitoring in India is focussed on the generation of marine fishery advisories including potential fishing zone (PFZ) and ocean state forecast (OSF), introduced in the earlier subsection. ESSO-INCOIS-derived Marine Fishery Advisories, i.e. PFZ advisory, a reliable and short-term forecast of the fish aggregation zone in the open sea, using remotely sensed data would be helpful for the sustainable marine resource management in the Indian context (ESSO-INCOIS, 2020). PFZ not only contributes to an increase in the capture of fishes with shortening the time period but also is environment-friendly as it is helpful in declining the CO_2 emissions in the marine environment as a result of less fuel consumption due to minimization of search time (NCAER 2010, 2015). According to the study conducted by NCAER (2015), it has been revealed that saving one litre of diesel can reduce 2.63 kg of CO_2 which is equal to INR 36,200 crores per annum in a 25 years life. From a management perspective, the use of PFZ and OSF

Table 15.3 Present status of India in achieving Sustainable Development Goal 14 (SDG 14), associated indicators for each target under SDG 14 as well as selection of NbS methods for achieving the targets (source: Government of India 2020; modelling frameworks from Culhane et al. 2020)

Target	Descriptions of target	Indicators	Appropriate NbS models or systems
14.1	Prevention and reduction of marine pollution particularly from land-based activities by 2025. This includes marine debris and nutrient pollution	14.1.1 Coastal Water Quality Index	Flotational wetlands for sequestration of excess nutrients
		14.1.3 Percentage of use of nitrogenous fertilizer to total fertilizer (NPK)	
14.2	Sustainable management and protection of marine and coastal ecosystems, strengthening their resilience and restoration by 2020	14.2.1 Percentage change in area under mangroves (similar to 14.5.2)	Mangrove plantation
		14.2.3 Percentage change in marine protected areas (MPA)	Beach nourishment
14.3	Minimize and address the impacts of ocean acidification scientifically	14.3.1 Average marine acidity (pH) measured at the agreed site of representative sampling stations	Use of seaweed farms, etc.
14.4	Regulation of harvesting and end overfishing, illegal, unreported and unregulated fishing and destructive fishing practices by 2020, protect/conserve fish stocks	14.4.1 Maximum sustainable yield (MSY) in fishing, (in million metric ton (mt)/year	Artificial coral reef formation, riverine channel preservation through shore-based plantation management to allow fish stock diversification, etc.
14.5	Conservation of at least 10% of coastal and marine areas by 2020	14.5.1 Coverage of protected areas in relation to marine areas	Plantation of mangroves, seaweeds, seagrass, preservation of local eco-cultural ecosystem services preservation etc.
		14.5.2 Percentage change in area under mangroves (similar to 14.2.1)	Mangrove plantation
14.6	Prohibition of fisheries subsidies which contribute to overcapacity and overfishing planning by 2020	National indicator is still under development	Technology-aided scenario modelling, policies to encourage foot fishing in shallow seas and coastal lagoons to preserve fish stocks and prevent habitat fragmentation of economically important species
14.7	Achieving an increase in economic benefits to small island developing states	National indicator is still under development	NbS habitats attractive to native fish species

(continued)

Table 15.3 (continued)

Target	Descriptions of target	Indicators	Appropriate NbS models or systems
	and least developed countries through sustainable use of marine resources by 2030		
14.a	Scientific management of marine technology, as per the Intergovernmental Oceanographic Commission Criteria and Guidelines on the Transfer of Marine Technology	14.a.1 Budgeting resources (budget estimates)	Use of marine fishery advisories such as Potential Fishing Zones, including species-specific advisories, Ocean State Forecasts, coral bleaching alert, multi-hazard vulnerability mapping, oil spill advisory for effective budgeting of resources managment protocols
14.b	Access for small-scale artisanal fishers to marine resources and markets	14.b.1 Assistance to the traditional/artisanal fishers	Integrated Mangrove Fishery Farming System, river channel widening by adopting on-shore NbS practices, improving markets for locally procured marine products through their promotion as food which is sustainably-procured, encouraging foot-fishing and non-motorised fishing in shallow water environments with provisions for direct, on-site markets for eco-tourists, etc.
14.c	Conservation and sustainable use of oceans and their resources by implementing international law as reflected in the United Nations Convention on the Law of the Sea, as per the legal framework for the conservation and sustainable use of oceans	14.c.1 Compliance of international laws	NbS scenario-based computational models

advisories can contribute towards planning a technology-based NbS framework for sustainable fishing.

PFZ forecasts in India were initiated in 1989–1990 for the first time using NOAA AVHRR-derived sea surface temperature (SST; Mane and Mishra 2017) until the successful launching of the IRS-P4 satellite (Giri et al. 2016). However, SST-derived PFZ advisory was found to be not adequate in tropical and equatorial waters during summer owing to strong stratification which prevented the arrival of cool nutrient-rich waters to the sea surface from the deeper layer; surface wind might also affect the frontal structure (Wilson et al. 2008). Post the launch of the IRS-P4 (Oceansat) on May 26, 1999, Solanki et al. (2001) developed an integrated approach using OCM-derived chlorophyll-a (Chl-a) and AVHRR-derived SST to constrain PFZ in the Indian water. Hence, the PFZ algorithm matches the presence of Chl-a along with favourable SST which are very productive, to predict the highly favourable zones in the coastal sea for the fish aggregation (Giri et al. 2016).

At present, marine fishing in India has been concentrated within the narrow belt of 50 m depth in inshore water (Nammalwar et al. 2013), providing maximum contributions to the fishery-based economy. Remote sensing data can also provide better information regarding the planning and managing of the fishing-related activities nearer to the coastal region (Miguel and Santos 2000; Sreedhar 2002). The oceanographic conditions, such as SST, Chl-a and Ocean Fronts, influence the fish stocks (Klemas 2012, 2013), and satellite-derived SST and Chl-a have been found to be satisfactory in providing high receptivity and large spatial coverage for monitoring the same (Pillai and Nair 2010). The advisories provided by INCOIS for OSF services were initiated in 2009; include wave heights, wave direction, wind speed, wind direction, tides, currents, etc.; are also helpful to ensure the safety of the fishermen by making their appropriate decision for venturing into the deep ocean (e.g. Kundu and Santhanam 2021a); and are also helpful for the coastal community (Nayak et al. 2007; Nair and Pillai 2012; ESSO-INCOIS 2020). In the formulation of the PFZ advisory, the ocean colour (concentration of chlorophyll) indicates the area of high biological production 'fish accumulation zones' where the fishes accumulate for their feeding and spawning (Chandran et al. 2004; Solanki et al. 2005) in relation to ocean state factors: SST, front, topographic structure, upwelling, eddies, etc. The SST are indicative of the thermal environment for enhancing biological productivity (Solanki et al. 2003), and since the cooler waters contain the highest nutrient materials, SST inversely correlate with PFZ areas (Solanki et al. 2003, 2005). The temperature gradient in the ocean also attracts fishes; the ocean colour features coincide with the thermal fronts, related to the high primary productivity (Solanki et al. 2001; Kripa et al. 2014). An additional example is the restricting of a traditional model of PFZ, wherein the PFZ advisory systems consider real-time parameters and predict most favourable spots using multi-criteria analysis between the parameters (Kundu et al. 2020).

Studies conducted by the National Council of Applied Economic Research (NCAER) the net economic benefits from successful identification of PFZ can be of the order of INR 500 billion per annum. Such improved capabilities of the advisories can add to eco-sustainability by saving fuel consumption of motorized boats to reach the PFZ (NCAER 2010). Thus, while the PFZ advisories help the fishing community to locate large fish shoals by reducing the search time, thereby saving diesel consumption, the OSF advisories provide fishers and their family accurate and critical information on the status of the ocean-related weather conditions and hence provide a greater sense of security, avoiding the loss of lives and property (MSSRF 2014a, b; Kundu and Santhanam 2021b). Presently, marine fisheries add to the earnings by foreign exchange from the export of fishery products corresponding to 10% of overall export, while it accounts only for 0.91% of total GDP (NFDB 2020). From the above perspective, the effective use of geospatial technology in the form of national marine fishery advisories is proposed here as unique 'NbS Assisting Technologies' (NAT) since they are excellent tools for promoting and minimizing the sea-based anthropogenic effects on the ecosystem.

15.6 Conclusions

The present study highlights the fact that the use of NbS measures if inculcated into the marine and coastal resources planning can invariably lead to infrastructural and developmental benefits by meeting the SDG targets 14 for India. Strategies incorporating NbS would be helpful in preserving coastal and marine ecosystem properties and, at the same time, promoting sustainable fisheries as well as promoting equity among the fishers and capacity-building in fishery-based occupations. These directly correspond to the achievement of societal goals for development in India promoted by prestigious programmes of national interests such as SAMAVESH of NITI Aayog. Hence it becomes important to support the capacity-building in terms of technological advancements in improving the NbS for sustainable fishery practices.

NbS Assisting Technologies (NAT), such as the potential fishing zone (PFZ) and the ocean state forecast (OSF) advisories provided on a regular basis to maritime states in India, can help to achieve the maximum benefits of the installations that support NbS on the coast and at sea by three ways: (1) as scientific planning tools to optimize the activities of motorized and mechanized fishing boats made, (2) as tools to derive policy-based decisions on permissible fishing ranges of the motorized versus non-motorized boats operating in the Indian seas based on the carrying capacity of the sea and (3) to optimize the marine trophic status with the maximum sustainable yields by the conjunctive use of technology with coastal NbS strategies. Thus, the use of NAT can be crucial to advance the infrastructural benefits of the use of NbS for coastal and marine ecosystems.

Further, such NAT approaches can support causality-linkage frameworks, by linking geospatial modelling tools with a combination of stakeholder-driven decisions support systems which provide the outputs for management of the ecosystems. Further, simulation and virtual testing of the green solutions in the place of conventional solutions in computational environments such as deep learning environments can save considerable time and effort to test the applicability in real time. Thus, the use of inference-based approaches in ecosystem assessments can be beneficial to achieve the targets of SDG 14 by automating the monitoring efforts and the use of evolutionary learning approaches of NAT for active and dynamic management of India's coastal and marine resources. The above-mentioned points require consideration from a policy perspective and need to be formalized to achieve

NbS goals and a green solutions-backed economy to improve socio-ecological relationships between the humans and the seas.

Acknowledgements The authors wish to thank Prof. Shailesh Nayak, Director, NIAS Bengaluru, and Prof. S. Ayyappan, Chancellor, Central Agricultural University, Imphal, and Chairman, Karnataka Science and Technology Academy, Bengaluru, for inspiration to study the current gaps in policy-based research for coastal and marine environments in India. The authors are grateful to Prof. R. Srikanth, NIAS Bangalore, for his encouragement to do socially relevant research. The authors are also grateful to two anonymous reviewers for reviewing the manuscript and for providing suggestions to improve the same. SKK acknowledges the PhD Fellowship provided by the Ministry of Earth Sciences (MoES), Government of India, vide Grant No. MoES/16/15/11-RDEAS (NIAS) awarded to the National Institute of Advanced Studies, Bengaluru, Karnataka. HS acknowledges the use of Turnitin Software provided by NIAS Bangalore for similarity checking for the present paper.

Conflict of Interest Statement The authors report no conflict of interest for this publication.

References

Boumans R, RomanJ AI, Kaufman L (2015) The Multiscale Integrated Model of Ecosystem Services (MIMES): simulating the interactions of coupled human and natural systems. Ecosyst Serv 12:30–41. https://doi.org/10.1016/j.ecoser.2015.01.004

Bradley D, Merrifield M, Miller KM, Lomonico S, Wilson JR, Gleason MG (2019) Opportunities to improve fisheries management through innovative technology and advanced data systems. Fish Fish 20(3):564–583. https://doi.org/10.1111/faf.12361

Chandran RV, Solanki HU, Dwivedi RM, Nayak S, Jeyaram A, Adiga S (2004) Studies on the drift of ocean colour features using satellite-derived sea surface wind for updating potential fishing zone. Indian J Mar Sci 33(2):122–128

Cicin-Sain B (2015) Goal 14—conserve and sustainably use oceans, seas and marine resources for sustainable development. UN Chronicle LI(4) Retrieved from https://www.un.org/en/chronicle/article/goal-14-conserve-and-sustainably-use-oceans-seas-and-marine-resources-sustainable-development

Cohen-Shacham E, Walters G, Janzen C (eds) (2016) Nature-based Solutions to address global societal challenges. IUCN, Switzerland. https://doi.org/10.2305/IUCN.CH.2016.13.en

Culhane FE, Robinson LA, Lillebø AI (2020) Approaches for estimating the supply of ecosystem services: Concepts for ecosystem-based management in coastal and marine environments. In: Ecosystem-based management, ecosystem services and aquatic biodiversity. Springer, Cham. https://doi.org/10.1007/978-3-030-45843-0_6

Duarte CM, Wu J, Xiao X, Bruhn A, Krause-Jensen D (2017) Can Seaweed Farming Play a Role in Climate Change Mitigation and Adaptation? Frontier Marine Science 4:100. https://doi.org/10.3389/fmars.2017.00100

Eggermont H, Balian E, Azevedo JM, Beumer V, Brodin T, Claudet J, Fady B, Grube M, Keune H, Lamarque P, Reuter K (2015) Nature-based solutions: new influence for environmental management and research in Europe. GAIA-Ecol Perspect Sci Soc 24(4):243–248. https://doi.org/10.14512/gaia.24.4.9

ESSO-INCOIS (2020) Potential Fishing Zone (PFZ) advisory. Earth System Science Organization—Indian National Centre for Ocean Information Services. Retrieved from https://incois.gov.in/MarineFisheries/PfzAdvisory

FAO (2018) Exploring SDG 14.b and its proposed indicator 14.b.1. In: Franz N (ed) FAO Fisheries and aquaculture proceedings, vol 59, pp 1–39. Retrieved from http://www.fao.org/3/ca0140en/CA0140EN.pdf

Gajjar S (2020) Nature-based solutions to climate change in coastal cities. Afr Perspect Global Insights 308:1–17. Retrieved from https://media.africaportal.org/documents/Occasional-Paper-308-gajjar.pdf

Giri S, Manna S, Chanda A, Chowdhury A, Mukhopadhyay A, Chakraborty S, Hazra S (2016) Implementing a spatial model to derive potential fishing zones in the Northern Bay of Bengal lying adjacent to West Bengal Coast, India. J Indian Soc Remote Sensing 44(1):59–66. https://doi.org/10.1007/s12524-015-0472-2

Government of India (2017) Voluntary national review report on implementation of sustainable development goals. Retrieved from https://sustainabledevelopment.un.org/content/documents/15836India.pdf

Government of India (2020) Sustainable development goals—national indicator framework (Version 2.1). Retrieved from https://www.mospi.gov.in/documents/213904/0/Annex-III.pdf/d4679e60-071e-0652-b147-582dd520b3f9?t=1596972547966

Hinds L (1992) World marine fisheries: Management and development problems. Mar Policy 16(5):394–403. https://doi.org/10.1016/0308-597X(92)90007-C

ICAR-CMFRI (2020) Marine fish landings in India 2019. Retrieved from http://eprints.cmfri.org.in/14325/1/MarineFishLandingsinIndia_2020_CMFRI.pdf

IUCN (2016, October 1) Farmed fishing: a nature based solution to increased resilience. Retrieved April 07, 2021, from International Union for Conservation of Nature: https://www.iucn.org/news/india/201610/farmed-fishing-nature-based-solution-increased-resilience

IUCN (2021) Commission on ecosystem management. Retrieved from Nature-based Solutions: https://www.iucn.org/commissions/commission-ecosystem-management/our-work/nature-based-solutions

Kapos V, Wicander S, Salvaterra T, Dawkins K, Hicks C (2019) The role of the natural environment in adaptation. Background Paper for the Global Commission on Adaptation, Rotterdam and Washington DC. Retrieved fromhttps://www.ecoshape.org/app/uploads/sites/2/2017/08/3324-19_WP_GCA_Paper_WEB-002.pdf

Kelly C, Essex S, Glegg G (2012) Reflective practice for marine planning: a case study of marine nature-based tourism partnerships. Marine Policy 36(3):769–781. https://doi.org/10.1016/j.marpol.2011.10.023

Klemas V (2012) Remote sensing of environmental indicators of potential fish aggregation: an overview. Baltica 25(2):99–112. https://doi.org/10.5200/baltica.2012.25.10

Klemas V (2013) Fisheries applications of remote sensing: an overview. Fish Res 148:124–136. https://doi.org/10.1016/j.fishres.2012.02.027

Kripa V, Mohamed KS, Prema D, Mohan A, Abhilash KS (2014) On the persistent occurrence of potential fishing zones in the southeastern Arabian Sea. Indian J Geo-Mar Sci 43(5):737–745

Kundu SK, Santhanam H (2021a) All pain and no gain: factors impacting local and regional sustainability due to COVID-19 pandemic with respect to the Indian marine fisheries. Curr Res Environ Sustain 3. https://doi.org/10.1016/j.crsust.2021.100086

Kundu SK, Santhanam H (2021b) A report on the impacts of cyclone Yaas over a fish landing centre vulnerable to cyclonic storms and natural hazards – Talsari, Northern Odisha. Local Environ 26(9):1043–1050. https://doi.org/10.1080/13549839.2021.1964457

Kundu SK, Santhanam H, Srikanth R (2020) A technical assessment of the use of current geospatial technologies to derive marine fishery advisories in India and the Way Forward, Asian Conference on Remote Sensing 2020 Full paper available at: https://a-a-r-s.org/proceeding/ACRS2020/ifomqo.p

Link JS, Browman HI (2014) Integrating what? Levels of marine ecosystem-based assessment and management. ICES J Mar Sci 71(5):1170–1173

Link JS, BrodziakJ K, Edwards SF, Overholtz WJ, Mountain D, Jossi JW, Fogarty MJ (2002) Marine ecosystem assessment in a fisheries management context. Can J Fish Aquat Sci 59(9):1429–1440

Luijendijk A, Oudenhoven VA (2019) The sand motor: a nature-based response to climate change: findings and reflections of the interdisciplinary research program nature coast. Delft University

Publishers, Retrieved from. http://pure.tudelft.nl/ws/portalfiles/portal/53666598/2019_Luijendijk_van_OUdenhoven_eds_The_Sand_Motor_A_Nature_Based_Response_to_Climate_Change_NATURECOAST.pdf

Mane SU, Mishra AD (2017) Application of remote sensing with R tool in validation of PFZ along Coast of Ratnagiri: a survey. IOSR J Electron Commun Eng (IOSR-JECE) 12(3):104–109. https://doi.org/10.9790/2834-120302104109

Matthew A (2015) Small-Scale Fisheries (SSF) in India. Retrieved from https://www.un.org/Depts/los/nippon/unnff_programme_home/unnff_programme_sg_report/AnsyMatthew_Small-scale_fisheries.pdf

Miguel A, Santos P (2000) Fisheries oceanography using satellite and airborne remote sensing methods: a review. Fish Res 49(1):1–20. https://doi.org/10.1016/S0165-7836(00)00201-0

MSSRF (2014a) Impact of INCOIS scientific forecast services towards improving the lives and livelihoods of fishing communities across Tamil Nadu and Puducherry. Retrieved from https://incois.gov.in/documents/scientificForecastServices.pdf

MSSRF (2014b) Potential fishing zone advisories and conversion from partnership in Gilakaladindi Village in Krishna District, Andhra Pradesh-a preliminary study. Retrieved from https://incois.gov.in/documents/Gilakaladindi_Study.pdf

Mueller L, Bresch D (2014) Economics of climate adaptation in Barbados – facts for decision making. In: Murti R, Buyck C (eds) Safe Havens: protected areas for disaster risk reduction and climate change adaptation. IUCN, Switzerland. Retrieved from https://portals.iucn.org/library/sites/library/files/documents/2014-038.pdf

Nair PG, Pillai VN (2012) Satellite based potential fishing zone (PFZ) advisories – acceptance levels and benefits derived by the user community along the Kerala coast. Indian J Fish 59(2):69–74

Nammalwar P, Satheesh S, Ramesh R (2013) Applications of remote sensing in the validations of Potential Fishing Zones (PFZ) along the coast of North Tamil Nadu, India. Indian J Mar Sci 42(3):283–292

Narayan S, Beck MW, Reguero BG, Losada IJ, Van Wesenbeeck B, Pontee N, Sanchirico JN, Ingram JC, Lange GM, Burks-Copes KA (2016) The effectiveness, costs and coastal protection benefits of natural and nature-based defences. PLoS One 11(5):e0154735

Nayak S (2017) Coastal zone management in India - present status and future needs. Geo-Spatial Inform Sci 20(2):174–183. https://doi.org/10.1080/10095020.2017.1333715

Nayak S (2020) Remote sensing for national development: the Legacy of Dr. Vikram Sarabhai. J Indian Soc Remote Sensing 48(8):P1101–P1120. https://doi.org/10.1007/s12524-020-01156-x

Nayak S, Srinivaskumar T, Nagarajakumar M (2007) Satellite-based fishery service in India. In: GEO Secretariat (ed) The full picture. Tudor Rose, Geneva, Switzerland, pp 256–257

NCAER (2010)impact assessment and economic benefits of weather and marine services. https://moes.gov.in/writereaddata/files/ImpactAssessment-MOES.pdf

NCAER (2015) Economic benefits of dynamic weather and ocean information and advisory services in India and cost and pricing of customized products and services of ESSO NCMRWF & ESSO-INCOIS. https://incois.gov.in/documents/ImpactAssessment-NCAER2015.pdf

Acclimatise News (2019) Life's a beach: nature-based solutions for coastal protection. Nottinghamshire: climate change impact, defence Retrieved from https://www.acclimatise.uk.com/2019/06/06/lifes-a-beach-nature-based-solutions-for-coastal-protection/

NFDB Report, National Fisheries Policy, National Fisheries Development Board (2020). Retrieved from: http://nfdb.gov.in/PDF/National_Fisheries_Policy_2020.pdf

Pillai VN, Nair PG (2010) Potential fishing zone (PFZ) advisories-are they beneficial to the coastal fisherfolk? A case study along Kerala coast, South India. Biol Forum – Int J 2(2):46–55

Pisupati B (2016) Marine resources and the challenges to sustainability. In India and sustainable development goals: the way forward. pp. 173–179. Retrieved from http://ris.org.in/pdf/SDGs_Report_Chapter_14.pdf

Pontee N, Narayan S, Beck WM, Hosking A (2016) Nature-based solutions: lessons from around the world. Maritime Eng 69(1):29–36. https://doi.org/10.1680/jmaen.15.00027

Posner S, VerutesG KI, Denu D, Ricketts T (2016) Global use of ecosystem service models. Ecosyst Serv 17:131–141. https://doi.org/10.1016/j.ecoser.2015.12.003

Pramod G (2010) Illegal, unreported and unregulated marine fish catches in the Indian exclusive economic zone. https://www.researchgate.net/publication/238790315

Seppelt R, Dormann CF, Eppink FV, Lautenbach S, Schmidt S (2011) A quantitative review of ecosystem service studies: approaches, shortcomings and the road ahead. J Appl Ecol 48(3):630–636

Solanki HU, Dwivedi RM, Nayak SR (2001) Synergistic analysis of SeaWifs chlorophyll concentration and NOAA-AVHRR SST features for exploring marine living resources. Int J Remote Sensing 22(18):3877–3882. https://doi.org/10.1080/01431160110069845

Solanki HU, Dwivedi RM, Nayak S, Gulati DK, John ME, Somvanshi VS (2003) Potential Fishing Zones (PFZ) forecast using satellite data derived biological and physical processes. J Indian Soc Remote Sensing 31(2):67–69. https://doi.org/10.1007/BF03030773

Solanki HU, Mankodi PC, Nayak SR, Somvanshi VS (2005) Evaluation of remote-sensing based potential fishing zones (PFZs) forecast methodology. Continent Shelf Res 25(18):2163–2173. https://doi.org/10.1016/j.csr.2005.08.025

Sreedhar U (2002) Remote sensing and fisheries. In: Handbook of fishing technology. Retrieved from http://210.212.228.207/bitstream/handle/123456789/1332/Remote%20sensing%20and%20fisheries.pdf?sequence=1

Townsend M, Davies K, Hanley N, Hewitt JE, Lundquist CJ, Lohrer AM (2018) The challenge of implementing the marine ecosystem service concept. Front Mar Sci 5:359

UN Economic and Social Council (2019) UN Special edition: progress towards the Sustainable Development Goals. https://www.un.org/ga/search/view_doc.asp?symbol=E/2019/68

University of Oxford (2021, April 7). Nature-based solutions policy platform. Retrieved from Your Nation: https://www.nbspolicyplatform.org/your-nation/?country=116

Wilson C, Morales J, Nayak S, Asanuma I, Feldman G (2008) Ocean-colour radiometry and fisheries. In: Platt T, Hoepffner N, Stuart V, Brown N (eds) Why ocean colour? The societal benefits of ocean-colour technology. Reports of the International Ocean-Colour Coordinating Group, No. 7. IOCCG, Dartmouth, Canada, pp 47–58

Harini Santhanam is an environmental scientist working as an Assistant Professor with the School of Natural Sciences and Engineering at the National Institute of Advanced Studies (NIAS), Bengaluru, India.

Sudip Kumar Kundu is a doctoral student with the National Institute of Advanced Studies (NIAS), Bengaluru, India.

Physical Vulnerability Assessment to Flooding of Residential Houses Along the Coastal Areas in Santa Rosa City, Laguna, Philippines

16

John Maverick S. de Leon and Damasa B. Magcale-Macandog

Abstract

The Philippines sits along the edge of the Pacific Ring of Fire, exposed to natural geologic hazards including earthquakes and volcanic eruptions. Climate change–related hazards are highly pronounced in the Philippines, namely, typhoons, floods, landslides, and wind gusts. Twenty-two typhoons hit the country in 2020 causing more than a million worth of damages in properties and resources and many deaths and displacing more than a hundred thousand people. This study focused on developing a vulnerability analysis in three barangays identified as flood-prone areas in the City of Santa Rosa in Laguna in the Philippines. The most vulnerable of the structural types is the one with 100% of the structural type destroyed because of its structurally inferior floors (ground) and walls (bamboo). The analysis of physical vulnerability yielded barangay Sinalhan as most vulnerable to floods because it is most vulnerable based on structural type, height of ground floor, and distance from the Laguna Lake. The analysis of socio-economic vulnerability also yielded barangay Sinalhan as most vulnerable to floods. Attention must be paid to land-use policies and urban greening to diminish the impacts of flooding. A combined top-down and bottom-up approach is recommended in order to manage flood risk and build community resilience against future flooding in a manner that is sustainable for urban environments and benefits their populations.

J. M. S. de Leon
International Training and Development Center, Thai Nguyen University of Agriculture and Forestry, Thai Nguyen, Vietnam

D. B. Magcale-Macandog (✉)
Institute of Biological Sciences, College of Arts and Sciences, University of the Philippines Los Baños, Laguna, Philippines
e-mail: dmmacandog@up.edu.ph

S. Dhyani et al. (eds.), *Blue-Green Infrastructure Across Asian Countries*,
https://doi.org/10.1007/978-981-16-7128-9_16

Keywords

Physical vulnerability · Floods · Building materials · Disaster risk reduction · Philippines

16.1 Introduction

The United Nations Framework Convention on Climate Change (UNFCCC 1992) defines climate change as "a change of climate that is attributed directly or indirectly to human activities that alters the composition of the global atmosphere in addition to natural climate variability observed over comparable time periods." The Intergovernmental Panel on Climate Change (IPCC) reported evidences with high confidence that global warming up to 1.5 °C as compared to pre-industrial levels in several regions (Hoegh-Guldberg et al. 2018) with increases in intensity, duration, and amount of rainfall has occurred in some regions while other regions experience increase in droughts. In 2010, the National Research Council had reported that global climate is changing and the 1 °C increase in temperature has resulted to sea level rise, severe typhoons, and heavy rainfall. It is the main reason why climate is displaced and some hazards such as floods, earthquakes, hurricanes, and typhoons occur more or fewer in some areas in the Earth (NRC 2010). Higher sea surface and subsurface temperatures contribute largely to the strength of typhoons (Holden and Marshall 2018). It is widely speculated that anthropogenic activities are a great contributor to climate change.

16.1.1 Climate Change in the Philippines

Long-term climatic records by the Philippine Atmospheric, Geophysical and Astronomical Services Administration (PAGASA) have shown an increase of 0.62 °C in the annual average mean temperature since the 1960s. The number of warm days has increased, while consequently the number of cold nights had decreased in various parts of the country (SNC 2015). Analyzing historical tropical cyclone tracks, Salvacion et al. (2014) noted that spatiotemporal risks to tropical depression and typhoon in the country have changed over the past decades. Evidences of climate change can be seen in the Philippines through the changing patterns of the southwest monsoon (SW). The intensity of the SW passing through the Philippines is stronger than normal which brings in longer rainy season and more typhoons (Cinco et al. 2014). The heavy rains with increased intensity and amount of rainfall are largely attributed to climate change. Warren (2016) has noted that more destructive cyclonic storms occur in the southwestern Pacific than before and this is attributed to global warming.

The Philippines is one of the top five highly vulnerable countries in the world and susceptible to natural disasters (Guha-Sapir et al. 2013). The archipelago sits along the edge of the Pacific Ring of Fire, thereby exposed to natural geologic hazards including earthquakes and volcanic eruptions. Further it is located in Southeast Asia along the Pacific typhoon belt bound by the Pacific Ocean in the eastern side and by the Philippine West Sea in the western side. Attributed to the country's geographical location along the typhoon belt of the Pacific Ocean, the Philippine archipelago, composed of 7100 islands, is vulnerable to climate change (Warren 2016). More than 20 typhoons and tropical depression pass through the Philippine islands every year. The eastern side of the country is hit more often by typhoons coming from the Pacific Ocean during the rainy season months of May to December (SNC 2015).

Intersecting southwest monsoon rains and tropical cyclones results to copious rainfall that may spawn landslides and flooding causing hazards and disasters (Cheong et al. 2011; Heistermann et al. 2013). The most destructive typhoons packed with strong winds and heavy rains occur during an El Niño year (Cinco et al. 2014). Typhoons and floods are the main natural hazards in the Philippines primarily due to its location across the Pacific typhoon belt (Warren 2016; Acosta et al. 2013).

Flooding is defined as too much water in a new area, or it is when water has overflown into a place that is normally dry (Alberta Water Portal 2013). When high-intensity rains or more typhoons strike an area which has no proper drainage systems or when canals, dams, and other waterways are clogged with garbage, the large volumes of runoff water will cause flooding. Extreme weather conditions also create an excess of runoff that is above the capacity of the drainage systems in an area (Adetunji and Oyeleye 2013) and exceeds the absorptive capacity of the ground or when the rivers and tributaries overflow. Prolonged high-intensity rainfall will transform the soil to become saturated until the soil will no longer be able to absorb or store large volume of water leading to increased surface runoff. Further, the excess water will enter the rivers, lakes, or other bodies of water until it overflows leading to higher levels of flood (Jackson 2017). Flashfloods may occur in a subwatershed with steep or undulating terrain gradients, denuded surface, less vegetation, less permeable soil surface, human settlements, and a short response time of the basin (Doswell III 2015).

Nasiri et al. (2016) stated that the many urban areas worldwide are likely to experience the serious effects of floods. They further indicated that regular flooding will occur because of global climate change, rapid urbanization, and land conversion into residential or built-up areas and infrastructure transforming its permeable soil to an impermeable surface causing the decline recharge of groundwater and poor watershed management (Nasiri et al. 2016; Konrad 2016).

Flooding is an extremely dangerous natural event, and it has the potential to wipe away an entire city and the coastline areas which causes extensive damage to life and property (eSchooltoday 2010). The socio-economic status or well-being of a community is primarily affected by flooding (bbc.co 2017). Not only will it cause deaths and injuries to people, it can also cause damage to property, destruction of crops, loss of livestock, and deterioration of health conditions (Acosta et al. 2016). As communication links and infrastructure such as power plants, roads, and bridges are damaged, people are forced to leave their homes and normal life is disrupted (Chief Scientist 2011). Similarly, loss of livelihood, damage to infrastructure, reduction in purchasing power, and loss of land value can leave communities economically vulnerable and can cause long-term impacts (Hamburg University of Technology 2010). Floods can also be a traumatic experience and can cause deep impacts for the victims and their families especially on children. Displacement from one's home, loss of property, and disruption to business and social affairs can cause continuing stress. For some people, the psychological impacts can be long-lasting (Chief Scientist 2011). Flooding can also increase the risk of waterborne diseases such as typhoid fever, cholera, leptospirosis, and hepatitis A and diseases from vectors such as mosquitoes causing dengue fever and malaria.

16.1.2 Impacts of Climate Change–Related Hazards in the Philippines

Currently, more than half of the Filipino population are living in urban areas of Luzon (Sanchez 2020). It is projected that 70% of the population will reside in urban areas, and this will increase further to 84% by 2050. Population migration to urban areas is primarily due to the livelihood opportunities offered by industrialization and urbanization. It is duly recognized by the Philippine government that increasing population is accompanied by problems related to congestion, overcrowding, infrastructure demands, pollution, health, and resource management (UN Habitat 2015).

Environmental degradation due to rapid urbanization, land-use change, and high population growth rate further enhance the negative impacts of climate change in the Philippines (Abucay et al. 2014; Eugenio et al. 2014, 2016; Holden and Marshall 2018). These destructive typhoons wreak havoc in the natural ecosystems, communities, and livelihood hampering economic growth. Twenty-two typhoons hit the country in 2020 causing more than a million worth of damages in properties and resources and many deaths and displacing more than a hundred thousand people. In November 2020, the country was hit by destructive typhoons "Rolly" (international name: "Goni") and "Ulysses" (international name: "Vamco") successively causing massive floods and destruction in Luzon island, specifically CALABARZON, MIMAROPA, Bicol Region, Cordilleras, Cagayan Valley, Central Luzon, and Metro Manila (NDRRMC 2020; Reuters 2020; PAGASA 2020).

Typhoons accompanied by high-intensity rains, gusty winds, floods, and tidal waves greatly affect the densely populated Luzon and Visayas islands (Warren 2016; Lucero-Prisno et al. 2020). Particularly, communities residing in urban areas located in hazardous areas near riverbanks, coasts, catch basins, and low-lying areas are severely affected by these typhoons (UNICEF and UN Habitat 2015).

16.1.3 Community-Based Vulnerability Assessment to Flooding

Managing flood hazards with the aim of safety and well-being of the people and saving their environment are few of the main responsibilities of the authorities or local governments in the flood-prone areas by reducing vulnerability levels and increasing resilience of the people in flood-stricken locales (Nasiri et al. 2016). One of the procedures and the first in this process is assessing the vulnerability level of the area and its people to identify vulnerability issues to ultimately adopt effective and appropriate adaptive and coping measures (Takemoto 2011).

Basically, vulnerability assessment is an assessment to assess the exposure, sensitivity, impacts, and adaptive and coping capacities of an area and its people to natural calamities such as typhoons, landslides, earthquakes, and floods. Vulnerability assessment or vulnerability analysis is a risk management process to quantify, identify, and rank possible vulnerabilities to threats in an area (Techopedia 2017). Such studies identify and determine the spatial location of people during disasters and the extent of the effects of these natural threats to the people (Okayo et al. 2015; Mendel 2006). It is a location-specific study because the vulnerability level of an area differs with the type of hazard and the physical and geologic characteristics of an area and socio-economic features of its people.

With numerous studies on assessing vulnerability, it has no universal definition (Birkmann 2007), and since it is interdisciplinary, the definition of vulnerability varies with context (Füssel 2010). That is why the concept of vulnerability is approached from different professional fields and disciplines by disaster management agencies, the academe, and the climate change community (De Leon 2006). According to Intergovernmental Panel on Climate Change (IPCC), vulnerability is the degree of susceptibility and the inability to manage climate variability and extremes by a system (IPCC 2014). It refers to the state of receptiveness to the harmful effects from exposure to different climate hazards and the ability to cope with and recover from such calamities.

Vulnerability to natural hazards can be classified into four (Kingma and van Westen 2009 as cited by Fernandez et al. 2016). These are physical, social, economic, and environmental vulnerabilities. Physical vulnerability includes factors that control flood effects on the physical infrastructure of people in a certain area. In his physical vulnerability analysis of Kelurahan Sewu in Indonesia, Zein, in 2010, considered building structure, height of ground floor, number of floors, building age, and building contents as factors affecting the physical vulnerability of an area. Guarin et al. (2004) in their flood risk assessment of the town of San Sebastian in Guatemala considered building, building contents, and road networks as physical factors affecting vulnerability. In addition to this, a study on the physical vulnerability of residents in Jabonga, Agusan del Sur, in the Philippines, near Lake Mainit, also considered distance from the lake as one of the factors affecting physical vulnerability (Crisologo et al. 2016). Socio-economic vulnerability tackles effect of floods on economic assets, source of livelihood and amount of income, and event groups (Westen and Kingma 2009). It also includes coping mechanisms and adaptive capacities of people based on age and gender distribution, livelihood and income, educational level, period of stay, housing status, and household size (Zein 2010). The combination of these two types of vulnerability is a function of hazards and their physical impacts, exposure of the elements affected by these hazards, and sensitivity or lack of capacity of a population to prepare, absorb, and recover from natural calamities (Gotangco and Perez 2010). Physical and socio-economic vulnerabilities are the only concerns in this study.

In order to reduce the impacts residents in an area experience before, during, and after a natural hazard such as floods, a community-based vulnerability assessment is a must. These impacts are commonly measured in terms of costs to businesses, property, and infrastructure. Compared to damages to buildings, however, the total effects of flood hazards are much greater especially to people who have fewer access to resources and less capacity for recovery. Due to various socio-economic and physical factors, there are residents within an area that are more vulnerable to the effects of flood hazards than the others. It is essential to do the community-based vulnerability assessment as early as possible for the community to formulate mitigation and adaptation strategies for flood hazards which can happen anytime. With mitigation and adaptation strategies in place, the vulnerability to flooding of people in an area will decrease, and their resilience to flood hazards will increase. To strengthen and raise awareness of disaster-prone areas, community participation in disaster mitigation policy-making and implementation is important so as the community's involvement in flood assessment through their experiences to reduce impacts to flood hazards (Zein 2010). Furthermore, in developing countries such as the Philippines, community-based approaches are more cost-effective and not technology demanding when gathering, consolidating, and recreating experiences of victims in flood-prone regions (Guarin et al. 2004).

16.1.4 Physical Characteristics

The formulation of mitigation strategies and its subsequent implementation relies on a thorough vulnerability analysis of the physical factors at risk. Ultimately, the data from these assessments can be used in planning mechanisms to evaluate damages and minimize economic losses (Mazzorana et al. 2014).

A physical vulnerability assessment of two areas in Saint Lucia by Uwakwe in 2015 used building description and contents; building occupancy and function; building materials; number of floors; building maintenance; building style; and building age, size, elevation, and ownership. In the study, physical vulnerability was assessed using the depth-damage method to assess vulnerability of building structures and the Spatial Multi-Criteria Evaluation (SMCE) to assess the vulnerability of all buildings in the two areas. From the first method, results show that the most vulnerable building structure from the eight identified structural types is the building built with wood floors, wood walls, and GI sheet roofs. On the other hand, results from SMCE indicate that in the areas of study, Castries old CBD and Dennery Village, the percentage of building that is highly susceptible to floods is 14% and 36%, respectively. In another study in two eastern England coastal towns, Kelman (2002) identified failures in building structures using number of building stories; relative height of buildings; elevation; height of walls; floor and exterior perimeter area; building design; building age; and types and number of walls, doors, windows, and other openings to two-dimensional vulnerability matrices. These matrices were then used to create possible disaster management systems.

In the Philippines, a vulnerability assessment to landslides and flooding along the Santa Rosa-Silang Riverine System using LiDAR and GIS-based hydrological modeling technologies was conducted by Magcale-Macandog et al. in 2015. Their results indicate that communities located in coastal areas and along the riverbanks in the downstream areas of the Santa Rosa-Silang Riverine System are more vulnerable to floods than communities far from the bodies of water. This observation is reflected in the generated flood hazard maps by local government units within the Santa Rosa-Silang Riverine System.

Other vulnerability assessment studies in the Philippines are those conducted by Pati (2011) in the towns of Mabitac and Santa Maria in Laguna and Dagoc (2012) in Cagayan de Oro City. A vulnerability analysis from the data gathered by Pati through a survey in the towns of Mabitac and Santa Maria was developed. The data from the survey was used to create necessary maps for the vulnerability analysis. The social vulnerability analysis performed in the research sites indicated that barangays Jose Rizal, Masinao, Adia, and Coralan in Santa Maria and barangays San Antonio, Nanguma, Lambac, and Pag-asa in Mabitac are very vulnerable to floods. In Cagayan de Oro, Dagoc adopted a GIS-aided flood risk assessment in three low-lying barangays of Iponan River Watershed. Basic socio-economics and household structure information were gathered from 145 respondents. This together with household coordinates determined using GPS was used to create different vulnerability maps.

These studies have greatly contributed in the increased understanding of the impacts of flood hazards and its mitigation. These investigative works also stress the value and importance of conducting vulnerability assessments to floods in an area or community. The results of which will help people in the Philippines and all over the world prepare for, adapt to, cope with, and mitigate the impacts of flood hazards.

16.2 Research Methodology

16.2.1 Flooding in Santa Rosa City, Laguna, Philippines

In Laguna Province in Region IV-A (CALABARZON) in the Philippines, Santa Rosa City is one of the areas which experiences severe flooding when long rainy seasons and rampant typhoons strike. It has a total area of 54.84 km^2 (21.17 square miles) covering its 18 barangays with an average elevation of 20.3 m. It has a total population of 414,812 having a population density of 7564 per km^2 (PSA 2021). Santa Rosa City lies at 14°17'03''N and 121°05'20''E (earthexplorer.com). Santa Rosa City's Flash Flood Areas and Submerged Barangays Map indicates that barangays Sinalhan, Aplaya, and Caingin are among the most affected communities during flooding in the city.

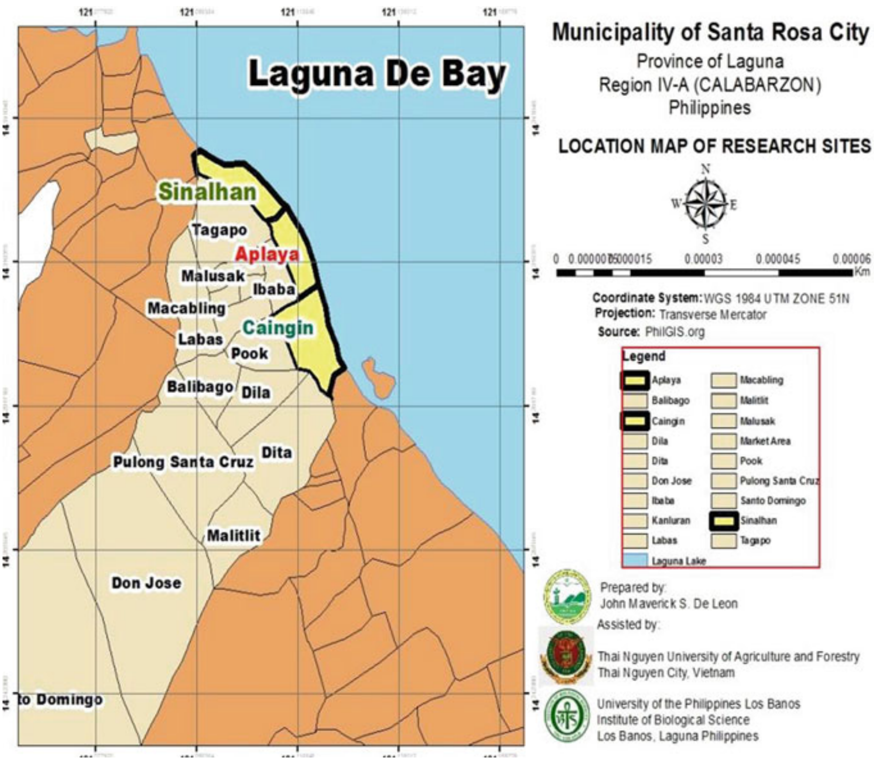


Fig. 16.1 The geographical location map of the three barangay research sites (barangays Sinalhan, Aplaya, and Caingin) in the City of Santa Rosa in Laguna, Philippines

The communities in Santa Rosa City located along the shores of the vast Laguna de Bay are proven to be prone or more vulnerable to flooding when long rainy seasons and prevalent typhoons strike. In recent years, super typhoons such as Milenyo in 2006, Ondoy in 2009, and Glenda in 2014 greatly affected low-lying or coastal communities of Santa Rosa City. The research sites of the study are communities located along the lake shores of Santa Rosa City, namely, Barangay Sinalhan, Barangay Aplaya, and Barangay Caingin which are mostly residential areas due to large population of residents. The total number of households and residents in the three barangay research sites is 3449 households with 15,858 residents in Barangay Aplaya; 4799 households with 24,481 residents in Barangay Caingin; and 4844 households with 26,274 residents in Barangay Sinalhan (PSA 2021). Barangay Aplaya lies at 14°19'11''N and 121°07'12''E, Barangay Caingin lies at 14°18'09''N and 121°07'37''E, and Barangay Sinalhan lies at 14°19'51''N and 121°06'31''E (earthexplorer.com). The geographical location of the three research sites is shown in Fig. 16.1.

16.2.2 Physical Vulnerability Analysis

The physical vulnerability analysis discussed in this section focuses only on building structure/material, building height, proximity to Laguna Lake, building age, and number of floors. The sensitivity to flooding of the surveyed respondents was included in this section. This study focused on developing a vulnerability analysis in three barangays identified as flood-prone areas in the City of Santa Rosa in Laguna in the Philippines. Because of the lack of community-based vulnerability assessments in the flood-prone areas in the City of Santa Rosa that focuses on the experiences of people, it is imperative that a community-based physical and socio-economic vulnerability assessment to flooding should be done to formulate mitigation, coping, and adaptation strategies by both the residents and the local government to lessen the fatalities and decrease physical destruction to properties and other effects of flooding in the flood-prone areas of the city.

16.3 Results

16.3.1 Building Material Analysis

Of the possible 210 structural types and based on the gathered data from the 50 respondents in each barangay, 15 structural types in Barangay Caingin, 20 structural types in Barangay Aplaya, and 23 structural types in Barangay Sinalhan were present and considered for the building material aspect of the physical vulnerability analysis.

The graphs in Fig. 16.2 show the extent of damage to buildings with respect to structural type in Barangay Caingin. Figure 16.2a shows the extent of damage based on the number of structural types, and Fig. 16.2b shows extent of damage as a percentage of the structural type. Results indicate (Fig. 16.2a) that the main structural types in Barangay Caingin are CON-GI-CON (26 households), CER-TEG-CON (four households), CON-TEG-CON (four households), and CON-GI-WD (three households). Of these major structural types (Fig. 16.2b), CON-GI-WD is most vulnerable with 100% of households having some form of damage from floods, and CER-TEG-CON and CON-GI-CON are least vulnerable with 50% and 65% of households having some form of damage from floods, respectively. Although the structural type CON-GI-WD has concrete floors and GI roofs, its walls are made of wood which is structurally inferior relative to concrete and bricks. It is apparent that CER-TEG-CON and CON-GI-CON are least vulnerable because their floors, roofs, and walls are relatively made up of structurally superior materials. Overall, however, considering all structural types, the most vulnerable are OTH-GI-WD and GR-NP-WD with 100% total destruction during floods. ANOVA shows significant differences in the data of both the number of structural types ($F = 5.2 > FC = 2.1$) and the extent of damage ($F = 3.7 > FC = 3.3$) at $P = 0.05$.

In Fig. 16.3, the graphs show the extent of building damage with respect to the number and percentage of the structural types of the surveyed households in

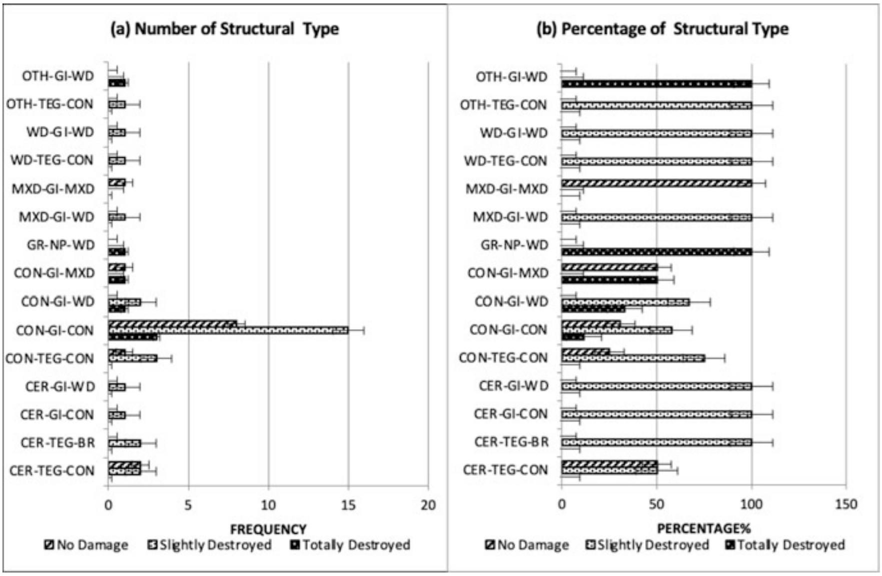


Fig. 16.2 Extent of damage of each structural type in Barangay Caingin: (**a**) number of structural type and (**b**) percentage of structural type. **CON* concrete, *CER* ceramic, *BR* brick, *WD* wood, *BAM* bamboo, *GR* ground, *NP* nipa, *GI* galvanized iron, *TEG* tegula, *LS* long span, *MXD* mixed materials, *OTH* others. **The ordering of structural parts: floor-roof-wall

Barangay Aplaya. From Fig. 16.3a, the major structural types present in Barangay Aplaya are CON-GI-CON (26 households), CON-TEG-BR (four households), and GR-GI-BAM (two households). From Fig. 16.3b, the most vulnerable of these structural types is GR-GI-BAM with 100% of the structural type totally destroyed because of its structurally inferior floors (ground) and walls (bamboo). From the same graph, the least vulnerable is CON-GI-CON with only 65% of the structural type having any form of damage. This is because the materials used in the major structural parts, concrete floors, GI roofs, and concrete walls, relatively, are structurally superior. Overall, however, seven structural types are vulnerable to floods with 100% of each structural type totally destroyed: OTH-TEG-BAM, WD-TEG-BAM, MXD-TEG-BR, GR-GI-MXD, GR-GI-BAM, and CER-TEG-CON. Except for the last structural type, all types have either floors, walls, or both relatively made of inferior materials such as wood, bamboo, mixed materials, and ground (soil). ANOVA shows significant differences in the data for the number of structural types ($F = 7.3 > FC = 1.9$) but not on the extent of damage ($F = 1.8 < FC = 3.2$) at $P = 0.05$.

The extent of damage to buildings with respect to the number and percentage of each structural type in the surveyed households in Barangay Sinalhan is shown in Fig. 16.4. The main structural types present (Fig. 16.4a) are CON-GI-CON (22 households), CER-GI-CON (four households), GR-NP-BAM (two households), and CON-GI-WD (one household). The most vulnerable to flooding is GR-NP-BAM and CON-GI-WD both with 100% either totally or slightly destroyed

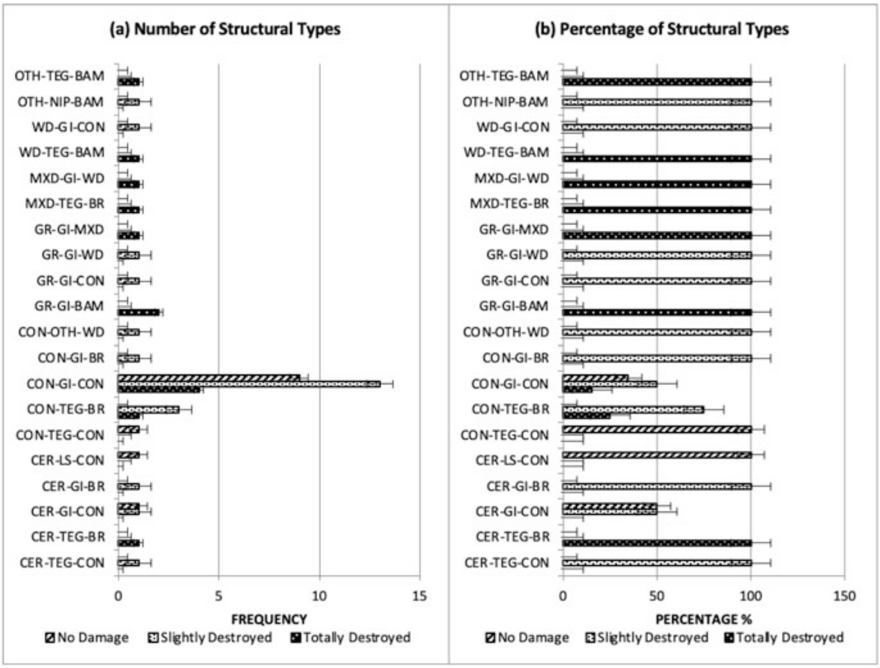


Fig. 16.3 Extent of damage of each structural type in Barangay Aplaya: (**a**) number of structural type and (**b**) percentage of structural type. **CON* concrete, *CER* ceramic, *BR* brick, *WD* wood, *BAM* bamboo, *GR* ground, *NP* nipa, *GI* galvanized iron, *TEG* tegula, *LS* long span, *MXD* mixed materials,*OTH* others. **The ordering of structural parts: floor-roof-wall

(Fig. 16.4b). Again, this is due to the inferior material of construction of the floors, walls, or both used in these structural types. The least vulnerable of the major structural types is CER-GI-CON and CON-GI-CON with 75% and 87% of the structural types totally or slightly destroyed, respectively. This is due to the relatively higher structural superiority of concrete, GI sheets, and ceramics to other materials of construction. It should be noted, however, that of the three barangays, Barangay Sinalhan has the highest percentages of totally and slightly destroyed structural types deemed structurally superior. Overall there are six structural types that are most vulnerable to floods with a 100% total destruction: OTH-GI-BR, MXD-GI-MXD, CER-LS-MXD, GR-GI-WD, GR-NIP-MXD, and CER-GI-WD. All structural types have either floors, walls, or both made up of inferior materials such as wood, mixed materials, ground (soil), and other materials such as plastic and roofs made up of nipa, the least superior of all roof types. ANOVA shows no significant differences in the data for the number of structural types ($F = 1.6 < FC = 1.7$) and on the extent of damage ($F = 2.3 < FC = 3.2$) at $P = 0.05$.

Generally, the major structural type in all barangays is CON-GI-CON which is considered having a low vulnerability to flood because concrete walls and floors and GI roofs are structurally superior to other alternatives. FEMA (2008) also classifies

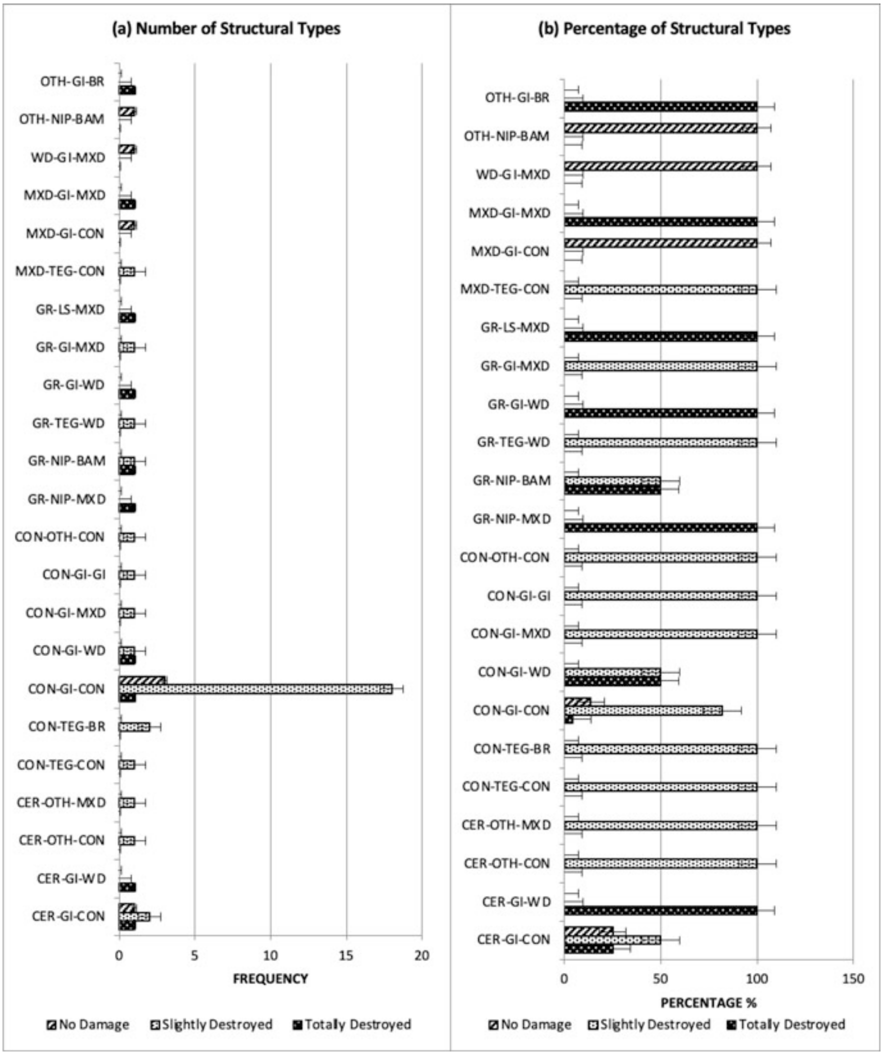


Fig. 16.4 Extent of damage of each structural type in Barangay Sinalhan: (**a**) number of structural type and (**b**) percentage of structural type. **CON* concrete, *CER* ceramic, *BR* brick, *WD* wood, *BAM* bamboo, *GR* ground, *NP* nipa, *GI* galvanized iron, *TEG* tegula, *LS* long span, *MXD* mixed materials, *OTH* others. **The ordering of structural parts: floor-roof-wall

the use of concrete, ceramic materials, and treated wood as acceptable and untreated wood as unacceptable for flooring and the use of concrete, bricks, and treated wood acceptable and untreated wood and bamboo unacceptable for wall construction. In general, masonry (brick, building stone such as marble, granite, travertine and limestone, cast stone, concrete block, glass block, and cob) and concrete are unlikely to be severely damaged by contact with floodwater. On the other hand, timber and other wooden materials swell and may distort on wetting causing damage in other parts of the structure, and also wood that become wet and cannot dry may be at risk of decay and unwanted growth of fungi in the long term (Scottish Government 2015). In other words, structural types with floors, walls, or both made of wood, bamboo, mixed materials, and other materials such as plastics have high vulnerabilities to flood due to their relative structural inferiority.

Unlike walls and floors which are directly affected or destroyed by floods, the material of construction of roofs is more related to the structure's role in the coping mechanisms of people exposed to flood hazards. People in flood-prone areas use their roofs as a preliminary and emergency evacuation facility. This will minimize the destruction to lives and property (including the building contents) during a flood incident while waiting help from the local government or for the flood waters to subside. In that case, the use of galvanized iron and other superior materials for the roof material of houses is important.

Comparing the three barangays, results indicate that with respect to building materials, Barangay Sinalhan has the highest vulnerability to flood because of two reasons. First, it has six structural types that are most vulnerable to floods. Second, the percentage of households with damages to the major structural type CON-GI-CON is highest in Barangay Sinalhan (87%) compared to those of barangays Caingin (70%) and Aplaya (65%). Although Barangay Aplaya has seven structural types that are most vulnerable to floods, it has the lowest percentage damage on the major structural type CON-GI-CON (65%).

16.3.2 Effect of Height of Ground Floor and Distance from Lake

Figure 16.5 shows the effect of ground floor height on the extent of damage, in percent, of the houses of the respondents in the three barangays. The percentage of damaged houses in Barangay Caingin with ground floor heights equal to or less than 3 m is 40% and with ground floor heights greater than 3 m is 34% (Fig. 16.5a). In Barangay Aplaya, the percentage of damaged houses with heights of 3 m or less is 52% and with heights greater than 3 m is 24% (Fig. 16.5b). For Barangay Sinalhan, the percentage of damaged houses with heights of 3 m or less is 44% and with heights greater than 3 m is 42% (Fig. 16.5c).

Building houses with higher than the ground level is one of many coping mechanisms of residents in flood-prone areas (Zein 2010). The building of houses with higher ground floors in flood-prone areas should decrease their vulnerability to floods (Uwakwe 2015). ANOVA shows that the differences in the data for extent of damage for barangays Caingin ($F = 22.5 > FC = 19$) and Sinalhan ($F = 22.5 > FC = 19$) are statistically significant at $P = 0.05$. This means that the amount of damage is not affected by the height of the ground floor. The differences in the data for Barangay Aplaya on the other hand, however, is not statistically significant at $P = 0.05$ meaning the extent of damage on the residences is not a function of the height of the ground floor. This makes barangays Sinalhan and Caingin more vulnerable to floods based on height of the ground floors of houses.

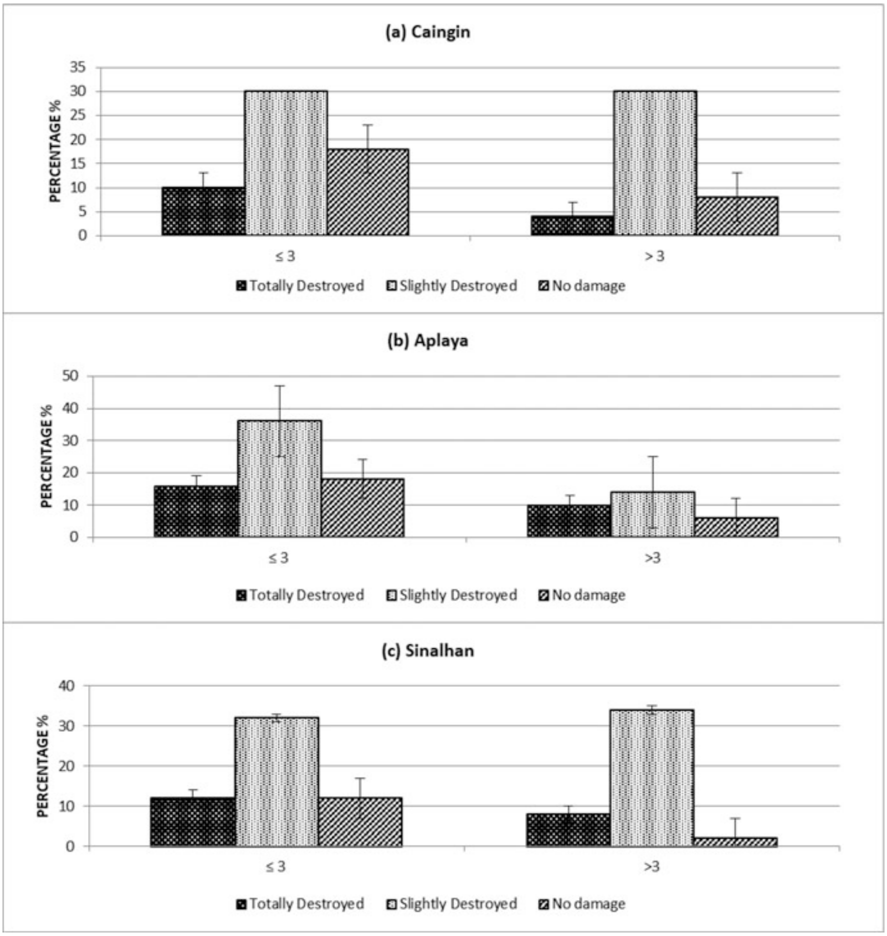


Fig. 16.5 Effect of ground floor height on the extent of damage (%) to houses in barangays (**a**) Caingin, (**b**) Aplaya, and (**c**) Sinalhan from floods

Figure 16.6 shows the effect of the proximity of the houses of the respondents from the lake on the extent of damage houses incur during floods. The Laguna Lake acting as a catch basin for Metro Manila, Laguna, and Rizal during heavy rainfall makes the residences near the lake vulnerable to flooding (LLDA 2015). ANOVA of the data shows that there is a significant difference at $P = 0.05$ in both distance from the lake and the extent of damage for both barangays Caingin ($F = 87.3 > FC = 6.9$; $F = 106.8 > FC = 6.9$) and Sinalhan ($F = 9.6 > FC = 6.9$; $F = 10.5 > FC = 6.9$). This means that the extent of damage is significant at any distance. On the other hand, for Barangay Aplaya, the extent of damage is insignificant at any distance ($F = 1.4 < FC = 6.9$ at $P = 0.05$). This makes barangays Caingin and Sinalhan more vulnerable to floods than Barangay Aplaya based on the distance from the lake.

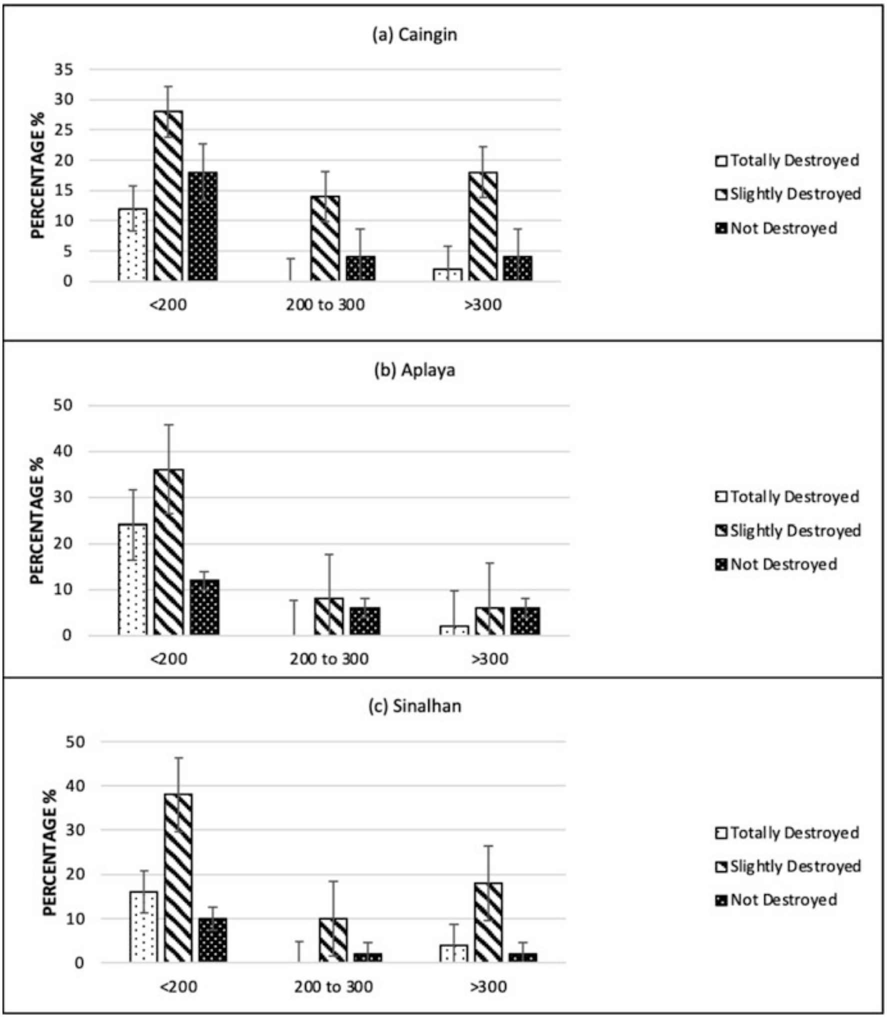


Fig. 16.6 Effect of distance from the lake on the extent of damage (%) to houses in barangays (**a**) Caingin, (**b**) Aplaya, and (**c**) Sinalhan from floods

16.3.3 Effect of Building Age and Number of Floors

The effect of building age to the extent of damage caused by flooding on houses of the respondents in the three barangays in percentage household is shown in Fig. 16.7. The vulnerability of houses to floods increases with building age. Generally, the older the building, the more it is vulnerable to the impacts of floods (Uwakwe 2015). ANOVA shows that there are no significant differences in the data for all barangays. This means that the extent of damage at any building age is not significant at $P = 0.05$.

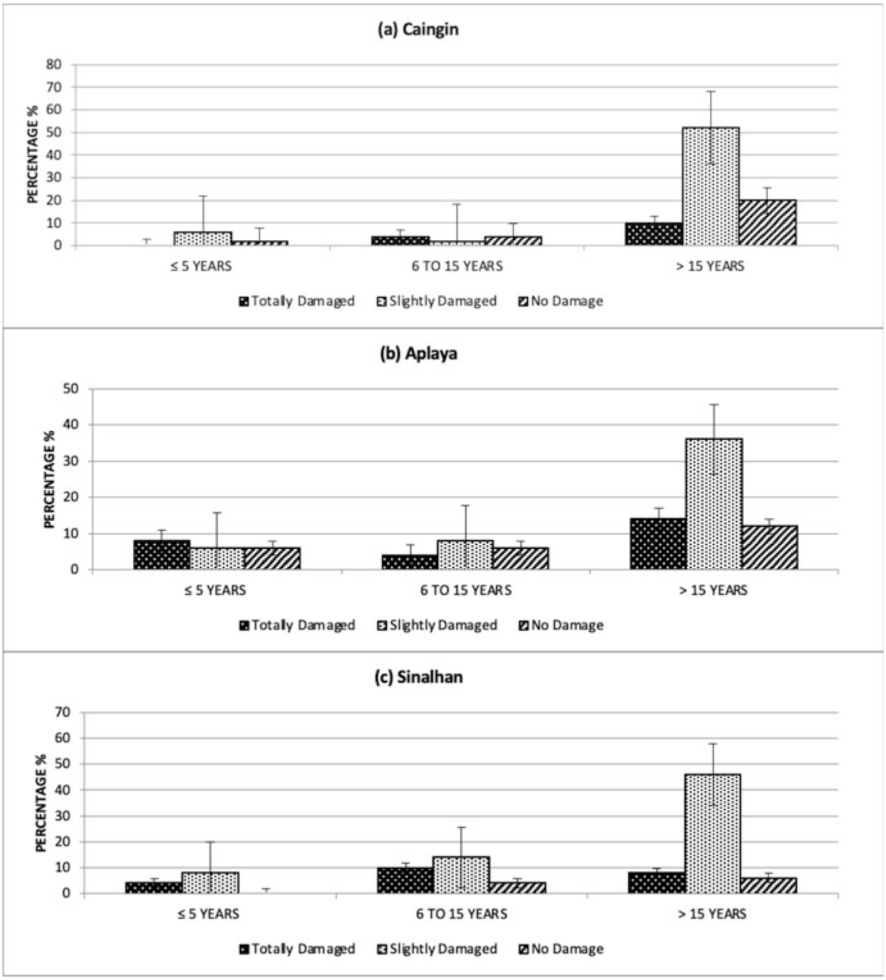


Fig. 16.7 Effect of building age on the extent of damage (%) to houses in barangays (**a**) Caingin, (**b**) Aplaya, and (**c**) Sinalhan from floods

The effect of the number of floors on the extent of damage of floods on residences of the surveyed households is shown in Fig. 16.8. Two-story buildings are more flood resilient than their one-story counterparts (Uwakwe 2015). ANOVA of the data for barangays Caingin and Sinalhan revealed no significant difference. Meaning for any number of floors the extent of damage is not significant. On the other hand, ANOVA for the data for Barangay Aplaya shows a significant difference for both number of floors ($F = 69.1 > FC = 18.5$) and extent of damage ($F = 22.4 > FC = 19$) at $P = 0.05$. This means the extent of damage for any number of floors is significant. This makes Barangay Aplaya more vulnerable to floods than the other barangays.

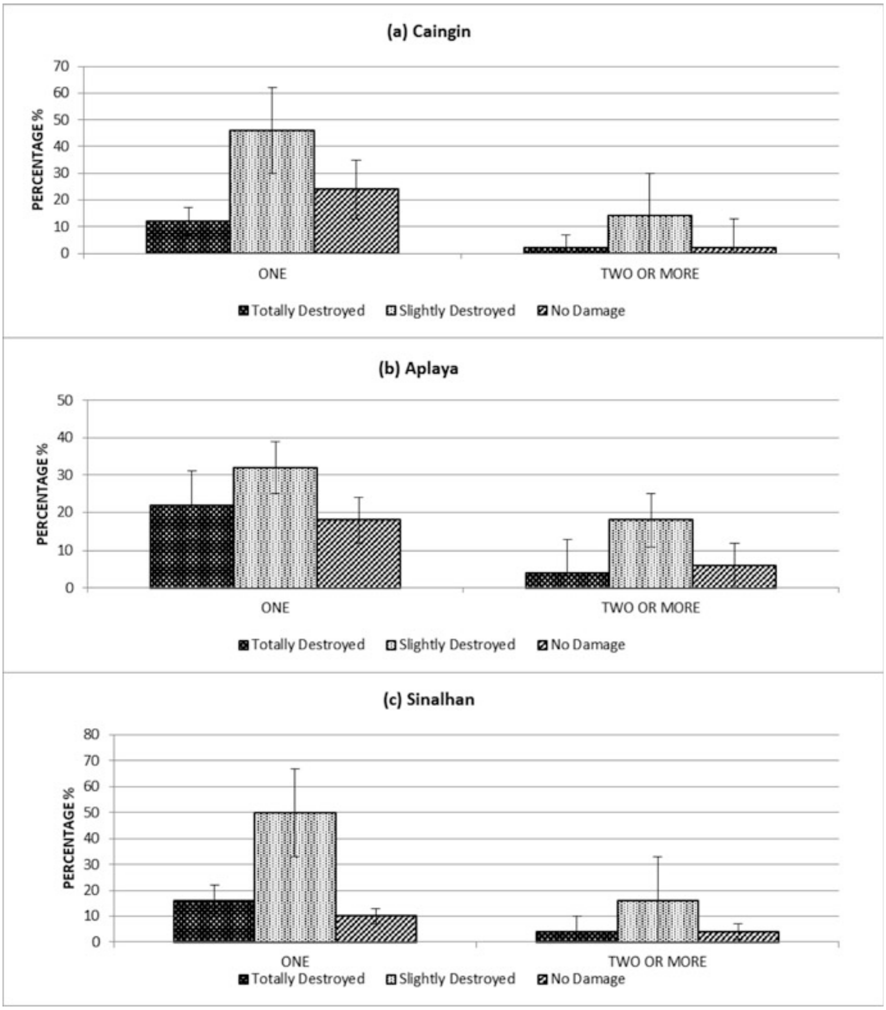


Fig. 16.8 Effect of number of floors on the extent of damage (%) to houses in barangays (**a**) Caingin, (**b**) Aplaya, and (**c**) Sinalhan from floods

An analysis of building materials or structural type (floor-roof-wall) revealed that Barangay Sinalhan is the most vulnerable to floods. Considering both height of ground floor and proximity to the lake, barangays Sinalhan and Caingin are the most vulnerable to flood hazards. Based on both building age, all barangays are equally vulnerable. And based on the number of floors, Barangay Aplaya is highly vulnerable. This makes Barangay Sinalhan the most vulnerable to floods based on the physical vulnerability analysis.

16.4 Discussion and Conclusion

Physical analyses were performed to assess the vulnerability to floods of barangays Caingin, Aplaya, and Sinalhan. In the physical vulnerability assessment, the extent of damage to the household buildings was analyzed based on structural type, building height, proximity to the Laguna Lake, building age, and number of floors. The analysis of physical vulnerability yielded Barangay Sinalhan as most vulnerable to floods because it is most vulnerable based on structural type, height of ground floor, and distance from the Laguna Lake. Barangay Sinalhan was most vulnerable to floods with a vulnerability score of 0.78 which is in the range of high vulnerability and Barangay Aplaya as the least vulnerable to floods with a vulnerability score of 0.49 which is in the range of low vulnerability.

After identifying, analyzing, and assessing the different physical and socio-economic elements at risk during floods, impacts of floods, adaptive capacity and coping mechanisms with respect to floods, and the perception of respondents on government intervention and assistance, recommendations on Disaster Risk Reduction and Managament (DRRM) were suggested to the city government and barangay officials.

16.5 Disaster Reduction and Management Recommendations

- Implement and integrate DRRM and Climate Change Adaptation (CCA) principles to laws on land use in flood-prone areas, building code, the National Greening Program, and existing ordinances on DRRM.
- Conduct inventory of critical infrastructure to floods by barangay, and enhance the existing mechanisms in increasing the disaster resilience of flood-reducing infrastructure and natural water systems or the blue infrastructure by the city government in coordination with the barangays such as:
  - Improving and cleaning sewerage systems.
  - Cleaning of rivers and lake.
  - Building additional catch basins in spillways.
  - Building of dikes or levees near rivers and lake.
- Regular vulnerability assessments and hazards mapping every 3 years as recommended by the National Disaster Risk Reduction and Management Plan (NDRRMP) by the city government in coordination with the barangays.
- Develop mechanism for risk financing and insurance schemes at the barangay level to mitigate the financial effects of floods.
- Developing and setting up localized or community-based early warning system (EWS) to enhance monitoring, forecasting, and warning of flood hazards. This should include procurement of necessary equipment, building or needed infrastructure, and training of city and government officials who will eventually implement it.

Conflict of Interest Statement The authors report no conflict of interest for this publication.

References

Abucay ER, Acosta LA, Magcale-Macandog DB, Espaldon MVO, Monsalud FC, Jacildo AJ, Talubo JPP, Lalican NM, Malenab MCT, Pabico JP, Nelson GLM (2014) Systems-based landslide susceptibility model as a tool in disaster risk management of the impacts of typhoons in Eastern Luzon in 2004. Regional Environmental Change. Special Issue

Acosta LA, Klein RJ, Reidsma P, Metzger MJ, Rounsevell MD, Leemans R, Schröter D (2013) A Spatially Explicit Scenario-Driven Model of Adaptive Capacity to Global Change in Europe. Glob Environ Chang 23:1211–1224. https://doi.org/10.1016/j.gloenvcha.2013.03.008

Acosta LA, Eugenio EA, Macandog PBM, Magcale-Macandog DB, Lin EK, Abucay ER, Cura AL, Primavera MG (2016) Loss and damage from typhoon-induced floods and landslides in the Philippines: community perceptions on climate impacts and adaptation options. Int J Global Warming 9(1):33–65. https://doi.org/10.1504/IJGW.2016.074307

Adetunji M, Oyeleye O (2013) Evaluation of the causes and effects of flood in Apete, Ido Local Government Area, Oyo State, Nigeria. Evaluation 3(7)

Alberta Water Portal (2013) Learn: what is flooding? Retrieved March 25 2017, from http://albertawater.com/what-is-flooding#ftnt1

Birkmann J (2007) Risk and vulnerability indicators at different scales: Applicability, usefulness and policy implications. Environ Hazards 7:20–31. https://doi.org/10.1016/j.envhaz.2007.04.002

Cheong HB, Kwon IH, Kang HG, Park JR, Han HJ, Kim JJ (2011) Tropical cyclone track and intensity prediction with a structure adjustable balanced vortex. Asia-Pac J Atmos Sci 47(3): 293–303. https://doi.org/10.1007/s13143-011-0018-7

Chief Scientist (Office of the Queensland Chief Scientist) (2011) What are the consequences of floods? Retrieved March 15, 2017, from http://www.chiefscientist.qld.gov.au/publications/understanding-floods/flood-consequences

Cinco TA, de Guzman RG, Hilario FD, Wilson DM (2014) Long-term trends and extremes in observed daily precipitation and near surface air temperature in the Philippines for the period 1951–2010. Atmos Res 45:12–26. https://doi.org/10.1016/j.atmosres.2014.03.025

Crisologo ES, Relox RE, Trinidad RB, Vedra SA (2016) Assessment of flood risk and adaptation efforts of the communities of Jabonga, Agusan del Norte, Philippines. School of Graduate Studies, Mindanao State University at Naawan, 9023 Naawan, Misamis Oriental, Philippines; 2 College of Arts and Sciences, Mindanao University of Science and Technology, Lapasan, 9000 Cagayan de Oro City, Philippines. Advances in Environmental Sciences Bioflux. 8(3): 283–289. http://www.aes.bioflux.com.ro/docs/2016.283-289.pdf. Retrieved July 15, 2017

Dagoc FL (2012) GIS-aided flood risk assessment of the low-lying areas of Iponan River Watershed in Cagayan De Oro City, Philippines. pp. 1–169. SESAMTH-5690

De Leon JCV (2006) Vulnerability: a conceptual and methodological review. United Nations University, Institute for Environment and Human Security, Bonn, p 84p

Doswell CA III (2015) Flashfloods. In: North, Pyle, Xhang (eds) Encyclopedia of atmospheric sciences, 2nd edn. Academic Press, London

eSchooltoday (2010) Your cool facts and tips on flooding: Introduction to flooding. Retrieved March 15, 2017, from http://eschooltoday.com/natural-disasters/floods/what-is-a-flood.html

Eugenio EA, Acosta LA, Abucay ER, Macandog PBM, Magcale-Macandog DB, Eugenio JMA, Lin EKH (2014) Livelihood adaptation to impacts of extreme events in the Philippines: A decade after the typhoon-induced disasters in Infanta, Quezon. Paper presented at the National Conference on Integrated Natural Resources and Environment Management (NC-INREM 2014). SEARCA, Los Baños, Laguna on October 16–17, 2014

Eugenio EA, Acosta LA, Magcale-Macandog DB, Macandog PBM, Lin EK, Eugenio JMA, Manuta J (2016) Adaptive capacity of Philippine communities vulnerable to flashfloods and landslides: Assessing loss and damage from typhoon Bopha in Eastern Mindanao. Int J Sustain Dev 19(3):279–314. https://doi.org/10.1504/IJSD.2016.078290

FEMA (Federal Emergency management Agency) (2008) Technical Bulletin 2–08, Flood-Resistant Materials Requirements for Buildings Located in Special Flood Hazard Areas in accordance with the National Flood Insurance Program. Department of Homeland Security FEMA Federal Insurance and Mitigation Administration, Washington, DC, p 20472

Fernandez P, Mourato S, Moreira M (2016) Social vulnerability assessment of flood risk using GIS-based multicriteria decision analysis. A case study of Vila Nova de Gaia (Portugal). Instituto de CienciasAgrarias e AmbientaisMediterranicas (ICAAM), Universidade de Evora, P olo da Mitra, Ap. 94, 7002-554, Evora, Portugal e Instituto Polit ecnico de Castelo Branco Escola Superior Agraria, Portugal. http://www.tandfonline.com/doi/abs/10.1080/19475705.2015.1052021. Retrieved July 21, 2017

Füssel HM (2010) Review and quantitative analysis of indices of climate change exposure, adaptive capacity, sensitivity, and impacts, vol 2010. LACER-LACEA, Bogotá, p 34. https://openknowledge.worldbank.org/handle/10986/9193. Retrieved June 20, 2017

Gotangco K, Perez R (2010) Understanding vulnerability and risk: the CCA-DRM nexus. Klima, Climate Change Center, Manila, pp 1–27. https://www.scribd.com/document/194004227/VULNERABILITY-AND-RISK. Retrieved June 22, 2017

Guarin PG, Van Westen CJ, Montoya L (2004) In: Guarín GP (ed) Community-based flood risk assessment using GIS for the town of San Sebastián, Guatemala. International Institute for Geo-information Science and Earth Observation (ITC), Enschede, pp 29–49. https://research.utwente.nl/en/publications/community-based-flood-risk-assessment-using-gis-for-the-town-of-s. Retrieved June 20, 2017

Guha-Sapir D, Hoyois P, Below R (2013) Annual disaster statistical review 2012: the numbers and trends. CRED, Brussels. http://www.cred.be/sites/default/files/ADSR_2012.pdf

Hamburg University of Technology (2010) Negative socio-economic impacts of floods. Retrieved March 15, 2017, from http://daad.wb.tuharburg.de/tutorial/integrated-flood-management-ifm-policy-andplanning-aspects/social-aspects-and-stakeholderinvolvement/social-aspects/negative-socio-economic-impacts-of-floods/

Heistermann M, Crisology I, Abon CC, Racoma BA, Jacobi S, Servando NT, David CPC, Bronstert A (2013) Brief communication "Using the new Philippines radar network to reconstruct the Habagat of August 2012 monsoon event around Metropolitan Manila". Nat Hazards Earth Syst Sci 13(3):653–657. https://doi.org/10.5194/nhess-13-653-2013

Hoegh-Guldberg O, Jacob D, Bindi M, Brown S, Camilloni I, Diedhiou A, Djalante R, Ebi K, Engelbrecht F, Guiot J, Hijioka Y(2018) Impacts of 1.5 C global warming on natural and human systems. Global warming of 1.5 C. An IPCC Special Report

Holden WN, Marshall SJ (2018) Chapter 24. Climate change and typhoons in the Philippines: extreme weather events in the anthropocene. Integrating Disaster Science and Management. https://doi.org/10.1016/B978-0-12-812056-9.00024-5

Intergovernmental Panel on Climate Change (IPCC) (2014) Summary for policy makers. 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. Intergovernmental Panel on Climate Change: Geneva. Cambridge University Press, Cambridge/New York, NY, pp 1–32. https://www.ipcc.ch/pdf/assessment-report/ar5/wg2/ar5_wgII_spm_en.pdf. Retrieved June 20, 2017

Jackson A (2017) "Flooding". Geography AS notes. Retrieved July 24, 2017, from https://geographyas.info

Kelman I (2002) Physical flood vulnerability of residential properties in Coastal, Eastern England. Doctoral Thesis. Dissertation submitted for the degree of Doctor of Philosophy, University of Cambridge, U.K. pp. 1–324. http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.615.7515&rep=rep1&type=pdf. Retrieved June 20, 2017

Konrad CP (2016) Effects of urban development on floods. U.S. Geological Survey. Fact Sheet 076–03. https://pubs.usgs.gov. Retrieved July 24, 2017

Laguna Lake Development Authority (LLDA) (2015) Laguna de Bay Basin Master Plan: 2016 and beyond. Laguna LakeDevelopment Authority. Quezon City, Philippines,. 23 pp. https://llda.gov.ph/wp-content/uploads/dox/ldbMP2016.pdf

Lucero-Prisno DE, Bernardino GD, Camua AA, Lin X, Adebisi YA (2020) Philippines braces for the typhoon season amidst COVID-19. Lancet Reg Health West Pac 1:1. https://doi.org/10.1016/j.lanwpc.2020.100003

Magcale-Macandog DB, Endo I, Kojima S, Johnson BA, Bragais MA, Macandog PBM, Onishi A, Scheyvens H (2015) Evaluation of the resiliency of the Silang-Santa Rosa subwatershed, Laguna, Philippines. Paper presented on October 11–13, 2015 at LoCARNet 4th Annual Meeting International Conference of Low Carbon Asia Positive Action from Asia – Towards COP21 and Beyond at Double Tree Hotel, Johor Bahru, Malaysia. Research Result

Mazzorana B, Simoni S, Scherer C, Gems B, Fuchs S, Keiler M (2014) A physical approach on flood risk vulnerability of buildings. Hydrol Earth Syst Sci 18(9):3817–3836

Mendel G (2006) Climate change, urban flooding and the right of urban poor in African: key findings from six African cities. Action Aid International, London/Johannesburg, pp 1–8. RetrievedJune 20, 2017from https://www.actionaid.org.uk/sites/default/files/doc_lib/urban_flooding_africa_report.pdf

Nasiri H, Yusof MJ, Ali TA (2016) An overview to flood vulnerability assessment methods. Sustain Water Resour Manag 2(3):331–336. https://doi.org/10.1007/s40899-016-0051-x

National Research Council (2010) Adapting to the impacts of climate change. America's Climate Choices: Panel on Adapting to the Impacts of Climate Change. The National academies Press, Washington, DC, p 293

NDRRMC (2020) Situational Report re Preparedness Measures and Effects for Severe Tropical Storm "ULYSSES" (I.N. VAMCO). Retrieved November 13, 2020, from http://ndrrmc.gov.ph/

Okayo J, Odera P, Omuterema S (2015) Socio-economic characteristics of the community that determine ability to uptake precautionary measures to mitigate flood disaster in Kano Plains, Kisumu County, Kenya. Geoenvironmental Disasters 2(1):1–22. https://doi.org/10.1186/s40677-015-0034-5

PAGASA (2020) Annual tropical cyclone tracks. Retrieved Nov. 14, 2020 from http://bagong.pagasa.dost.gov.ph/information/about-tropical-cyclone

Pati RC (2011) Flood vulnerability analysis for the towns of Mabitac and Santa Maria, Laguna, Philippines. College, Laguna: Graduate School, University of the Philippines Los Baños. pp.1–144. SESAMDIS-5683. LG 996 2011 E8 P38

Philippine Statistics Authority (PSA) (2021) Retrieved July 13, 2021, from https://psa.gov.ph/population-and-housing/node/164786

Reuters S (2020, November 01) Strongest typhoon of 2020 slams the Philippines, killing at least 10. Retrieved November 13, 2020, from https://edition.cnn.com/2020/11/01/asia/philippines-super-typhoon-goni-landfall-intl-hnk/index.html

Salvacion AR, Acosta LA, Asaad AB, Espladon MVO, Lapitan ML (2014) Mapping tropical cyclone risk in the philippines using historical track record. Regional Environmental Change, Special Issue

Sanchez M (2020) Philippines: Urban Population 2005–2019 Statista. Statista Retrieved 15 November 2020 from https://www.statista.com/statistics/603662/philippines-urban-population/#statisticContainer

Scottish Government. Planning Advice Note PAN 69 (2015, updated). Planning and building standards advice on flooding. Retrieved July 15, 2017, from http://www.gov.scot/Publications/2004/08/19805/41597

SNC (2015) Second National Communication (SNC) to the United Nations Framework Convention on Climate Change. Philippines. pp. 110.

Takemoto S (2011) Moving towards climate smarts flood management in Bangkok and Tokyo. Master thesis Massachusetts Institute of Technology, pp. 1–87 http://hdl.handle.net/1721.1/67243. Retrieved June 28, 2017

Techopedia (2017) Vulnerability assessment. https://www.techopedia.com/definition/16525/vulnerability-assessment. Retrieved June 14, 2017

UN Habitat (2015) Achieving sustainable urban development (ASUD) project brief. https://unhabitat.org/sites/default/files/download-manager-files/Brochure%20-%20ASUD%20-%20Project%20Brief%20-%20For%20Online%20Publishing.pdf. Retrieved 19 July 2021

United Nations Framework Convention on Climate Change (1992) United Nations

Uwakwe AC (2015) Assessment of physical vulnerability to flood in Saint Lucia. Case studies: Castries old Central Business District and Dennery Village. Thesis submitted to the Faculty of Geo-Information Science and Earth Observation of the University of Twente in partial fulfilment of the requirements for the degree of Master of Science in Geo-information Science and Earth Observation. Specialization: Natural Hazards and Disaster Risk Management Enschede, The Netherlands. pp. 1–100. http://www.charim.net/sites/default/files/handbook/otherpages/MSC/Anne%20Chinyere%20Uwakwe-s6012345.pdf. Retrieved June 20, 2017

Warren J (2016) Typhoons in the Philippines: a historical review. Retrieved Nov. 14, 2020, from https://www.arcgis.com/apps/MapJournal/index.html?appid=586f9150ae87491a8c7f1b86db7952a9

Westen CV, Kingma N (2009) Session 5: vulnerability assessment. In: Multi-hazard risk assessment Guide book. United Nations University, ITC School on Disaster Geoinformation Management. Session 5, Vulnerability assessment, pp 5183. Retrieved March 15, 2017, from ftp://ftp.itc.nl/pub/westen/Multi_hazard_risk_course/Guidebook/Guidebook%20MHRA.pdf

World Health Organization (2006) Humanitarian Health Action (WHO). Flooding and communicable diseases fact sheet. www.who.int. Retrieved June 15, 2017

Zein M (2010) A Community Based Approach to Flood Hazard Assessment in Flood Prone Areas: A case study in Kelurahan Sewu, Surakarta City-Indonesia. Masteral Thesis. Gadjah Mada University and International Institute for Geo-Information Science and Earth Observation Enschede, The Netherlands. pp. 73. https://www.itc.nl/library/papers_2010/msc/aes/zein.pdf. Retrieved June 14, 2017

John Maverick S. de Leon is a Graduate of Bachelor of Science in Environmental Science and Management at Thai Nguyen University of Agriculture and Forestry in Thai Nguyen, Vietnam.

Damasa B. Magcale-Macandog is a Professor of Plant Ecology at the Institute of Biological Sciences, College of Arts and Sciences, University of the Philippines Los Baños, Laguna, Philippines.

17 The Significance of Ancient Water Systems and the Sacred Groves in the Landscape of Badami, Karnataka: A Geospatial Study

Kuili Suganya, Mythrayi Harshavardhan, and M. B. Rajani

Abstract

Modifying and exploiting the environment to cater to people's needs have been a continuous process throughout history. A multidisciplinary analysis of settlements and their environs gives valuable insights into the infrastructure systems (water systems) that existed in the past. It is possible to study the strengths and weaknesses of these systems, along with the positive and negative impacts on the environment and the changes that have taken place over the centuries. This chapter discusses the modifications carried out in the landscape of Badami in Karnataka to harvest water for the settlement since its establishment as an Early Chalukyan capital in the seventh century. The chapter also highlights the significance of sacred groves in the historic landscape of Badami. The remnants of fortified walls, temples, water features, and sacred grooves testify to the ingenious engineering systems that existed in the past. Some of these historical infrastructure facilities are functional even today. They support the present settlement of Badami, exhibiting resilience and sustainability as these modifications are sensitive to terrain conditions. The chapter concludes by stressing the importance of studying the past infrastructure systems sustained through ages.

K. Suganya (✉)
National Institute of Advanced Studies, IISc Campus, Bengaluru, India

Manipal Academy for Higher Education, Manipal, Karnataka, India
e-mail: kuilisuganya@nias.res.in

M. Harshavardhan · M. B. Rajani
National Institute of Advanced Studies, IISc Campus, Bengaluru, India

S. Dhyani et al. (eds.), *Blue-Green Infrastructure Across Asian Countries*,
https://doi.org/10.1007/978-981-16-7128-9_17

Keywords

Ancient water systems · Badami · Hydrology · Sacred groves · Sustainability

17.1 Background

Natural conditions such as climate, resource availability (material and water), and terrain conditions played a vital role in shaping the spatial organization of settlements in the past. Various strategies to modify the terrain were adopted to make the place livable. These adaptations and modifications seemed to be conducive to the local environmental conditions. While the modifications had a sustainable approach and helped maintain the environment, they also enhanced the livability of the settlement as it adopted a less-density peri-urban approach (Scarborough and Isendahl 2020). Modifying, maintaining, and managing the environment by human beings have been a continuous process, taking place regularly since time immemorial (Scarborough 2003). The environment collapses, revives, rejuvenates, and deteriorates over a period, and this process is cyclical (Dhavalikar 2000). There is no such environment that is pristine and unexplored globally (Shepard 1999) or in the Indian context (Morrison 2013). People of the past have judiciously used natural resources as they also made mistakes and exploited the environment. One way to comprehend the built environment and spatial organizations of past settlements is from their material remains. These reveal the various aspects of spatial planning and design principles implemented. The material remains reveal the strengths of the planning and design principles implemented and their impacts on the environment over time.

The research findings discussed in this chapter focus broadly on urban geography, urban planning history, and archaeology. Urban historical geography focuses on the "social, cultural, economic, political, and environmental processes that have shaped" an urban center (Lombardo and Lewis 2013). Urban planning history looks into the collective actions as spatial relationships, built forms, functional and aesthetic principles shaped the city (Smith 2007). Archaeology helps to understand the past landscapes and man's interactions with the environment. It also helps to analyze the many methods used to modify the landscape and the efficient use of natural resources for sustenance, especially in connection with water features (Shaw and Sutcliffe 2003; Morrison 2010).

This chapter draws knowledge from the disciplines of historical geography, planning history, and archaeology to analyze the built forms in an ancient settlement shaped/influenced by the environmental factors while mainly focusing on the region's topography. This approach has helped galvanize concepts to study the landscape around the ancient fortified city of Badami, in Karnataka, India, from the context of water systems and the verdant spaces that have helped with its sustenance.

17.2 Badami: An introduction

An urban area with a high density of population and closely built spaces with a maximum concentration of power and culture is characterized as a town or a city (Mumford 1938, p. 3). The rise of a city comes with a spatial organization, an amalgamation of various functions within a limited area confined by a wall, which often housed temples, markets, hall of justice, and water systems (like springs) (Mumford 1938, p. 31; Norwich 2016, p. 10). The Indian ancient literary sources describe urban cities as having distinct characteristics based on their nature and function, such as capital, temple, trade, and fort city. However, it is not easy to distinguish these characteristics (Ghosh 1973, p. 45). Badami houses the remnants of a capital city (its fortifications), and the town continues to exist today as a small sub-district headquarters with the characteristics of a heritage settlement.

Badami is in the semi-arid Deccan region of peninsular India and is a part of the geological basin of the “Kaladgi” formation. This settlement is to the west of a sandstone hill range surrounded by the stream—Saraswathi Halla (west and south), Kendur Halla (north), and the river Malaprabha (east). The sandstone hill range covers about 34 km^2 with a perimeter of 29 km within which the temples, forts, and settlements of Badami are located (henceforth, Badami range). Badami and the surrounding region are known for water sources trapped closer to the surface resulting in perennial water sources such as springs and waterfalls (Michell 2014, p. 250).

A mid-sixth-century CE cliff inscription (Padigar 2012, p. 11) belonging to the Early Chalukyan period (mid-sixth to mid-eighth centuries CE) describes Badami as a capital city strengthened by fortified walls. The other fortified settlement near Badami that existed from Early Chalukyan times is Aihole, a trading city on the river Malaprabha located to the northeast of Badami. By the eighth century CE, as Badami was a capital city, the other settlements of the region Aihole was a trading center (Abraham 1988, p. 42), and Pattadakal was a religious capital (Filliozart and Filliozat 2015, p. 17). Toward the end of the twelfth century, the fortified cities of Torgal and Vikramapura (Arasibidi) existed as secondary capitals to the Later Chalukyan kingdom (eleventh to twelfth centuries CE), whose primary capital was by then Basavakalyan. A region that began with one capital at Badami by the end of the twelfth century CE had multiple secondary capitals, thereby having a multicentered administration. Even though Badami was no longer a capital city by the twelfth century CE, it continued to be important. Badami’s importance is evident from the continuous patronage during the Vijayanagar period (fourteenth to sixteenth centuries CE). In the later years, there was a continuous struggle to take control of the city by the Bahmani Sultanate (fourteenth to seventeenth centuries CE), the Marathas (eighteenth century CE), Tippu Sultan (late eighteenth century), and the British (early nineteenth century) (Padigar 2012, p. 12). The heritage structures from the early Chalukyan era to the fortification remains from Tippu Sultan’s period are a testimony to the same. This chapter looks into how the city of Badami survived through the ravages of time and sustained itself in the context of water harvesting and verdant spaces.

17.3 Verdant Spaces: The Sacred Groves

Badami range is in a hot and dry arid climate with dry deciduous thorny forest. Although it is thinly vegetated, it has a rich floristic diversity of about 558 flowering plant species, a source for food, fuel, fodder, gum, dye, and medicinal value that have the potential to support the socio-economy of the region (Dalavi et al. 2019). It is crucial to discuss the prevalent vegetation and its importance in an otherwise dry, sparsely vegetated landscape. The natural vegetation of the Badami range is a mix of *Albizia amara* and acacia shrubs in combination with grassland ecosystems. The sandstone range is home to *Commelina badamica*, a flowering plant variety, probably endemic to this range and the nearby Gajendragad (Nandikar and Gurav 2018).

Among this dry landscape covered by shrubs and rarely occurring trees is a hill stream, forming a V-shaped narrow valley flanked with high sandstone hills covered with silt (local name *Kolla*). The *Kolla*, characterized by natural springs with broad canopied trees (banyan, peepal, neem, mango, tamarind, and jamun) (Gaussen 1965; Jeelani 2006, p. 34),[1] enables an oasis-like microclimate. These are locations, which house temples creating an ambience of a sacred grove. One twelfth-century literature from the later Chalukyan king's court describes that such verdant spaces were for royal use (Ali 2011). Three such verdant Kolla are to the east of Badami range: Mahakuta, Chikka Mahakuta, and Naganathana Kolla. The Mahakuta and Chikka Mahakuta have springs confined by a reservoir (locally known as *Honda*); Naganathana Kolla has a deep ditch filled with water from a stream nearby. The excess water of the Tirtha gets channelled for irrigation in many springs. Apart from these three well-known sacred *Kolla*, many others exist in this region, one of which is the *Arali Tirtha* east of Badami with a spring on a cliff face inside a cavern.

Studies on other sacred groves of India highlight their significant role in the upkeep of the region's ecosystem by conserving biodiversity, recharging the aquifers, and aiding in soil conservation (Malhotra et al. 2001; Khan et al. 2008). Verdant sacred groves exist amidst a heterogeneous land use of forests, agricultural land, grazing pastures, and settlements, enhancing the landscape's diversity (Ray et al. 2014).

17.4 Water Systems of Badami

This section explores the environs of Badami both geospatially (using satellite remote sensing data) and informed knowledge (on the construction systems of heritage structures of the region). The study enabled us to identify the traces and appreciate the ancient water systems of the semi-arid settlement of Badami, functioning even today.

The settlement of Badami is located west of a reservoir, Agastya Tirtha, covering eighth hectares. The settlement and the reservoir are at the foothill of a horseshoe-

[1] As observed on field.

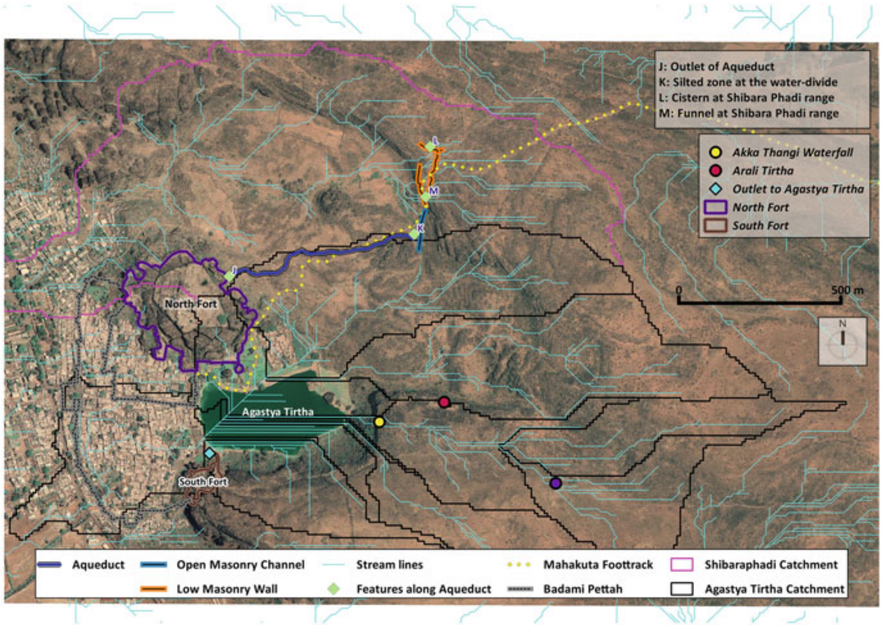


Fig. 17.1 Google Earth imagery overlaid with streamline and catchment map generated from Cartosat 10 m DEM along with the water features that aid in supplying water to the reservoir at Badami

shaped sandstone range dotted with historic fortifications, caves, and temples. This reservoir was the primary source of water supply to the settlement in the past (Campbell 1884, p. 500). It has an embankment in dressed stone masonry constructed to store water gathered from the *Akka Thangi* waterfalls (about 40 m high) to the reservoir's east. The twelfth-century CE Yellamma Temple (Padigar 2012, p. 12) at the west embankment indicates the reservoir's existence since then. The sanctum of the main temple of the East Bhutanatha group, dated to the eighth century CE (Padigar 2012, p. 48), faces the Tirtha, which asserts the possibility of the reservoir's existence even further back in time. The reservoir's outlet is through a small channel built within a long gateway, probably of the later Chalukyan phase (Fig. 17.1). The gateway also acts as a spillway during a heavy influx of water during rains. In the past, excess water fed the moat of the settlement (Padigar 2012, p. 15).

Among the reservoirs constructed within a 20 km radius of Badami, and located on sandstone geological formations, the reservoir at Badami is the largest. The other higher-capacity reservoirs are at Kendur and Nandikeswara, having a catchment of 5700 and 420 hectares,[2] respectively. The lesser-capacity reservoirs of Nandikeswara-Kenchamma, Nagarhal-Shankaralinga, and Kabbalageri have a

[2]Calculation of the catchment area of the reservoirs is by processing the SRTM 30 m resolution DEM, in GIS software using hydrology tools.

higher catchment than Badami reservoir (140 hectares of catchment) (Table 17.1). Unlike the other reservoirs of the region, the large Badami reservoir having a relatively lesser catchment triggered our curiosity for exploring and understanding the formation of this large reservoir. Was the source to Badami's reservoir perennial and requiring a larger capacity, or was water diverted from other catchments? This question propelled us to conduct our research on the extensive water systems embedded in the landscape of Badami. A literature review on the archival records, scholarly works and scrutiny of old maps of the region highlighted the following.

The literature about the region's ancient art, architecture, and history does not discuss of water being harvested from the river Malaprabha—unlike in the neighboring river Tungabhadra (Dikshit et al. 1993, p. 27). Also, there is no mention of access to water from an external catchment as in the Deccan Sultanate's capital Bijapur (Cousens 1889, p. 9).

Until the implementation of minor irrigation project scheme (Sathyan 1966, p. 172) under the third 5-year plan (mid-1960s), this semi-arid region depended on wells, rivers, perennial streams, and springs, with a few tanks (e.g., Kendur) for its water needs (Campbell 1884, pp. 560–561). The 1884 gazetteer describes four cisterns and a masonry conduit that supplied the north fort of Badami (Campbell 1884, p. 561). The other source, which authenticates the presence of the masonry conduit, is a map titled *Sketch of the Fort and Pettah of Badaumy* drafted by a British military engineer, John Jeffery O'Donnoghue, in 1818,[3] marking a few tanks and an aqueduct. These multiple sources referring to an aqueduct and a masonry conduit led to a geospatial exploration of the environs of Badami, followed by field surveys. The exploration resulted in identifying a 600 m-long aqueduct from the Vijayanagara period in various stages of collapse (Harshavardhan and Suganya 2020). The Archaeological Survey of India protects a part of this structure as a fort wall.[4]

We made some distinct observations during the field surveys, such as the absence of semicircular or a rectilinear bastion, the straight cross section of the wall, the low height of the masonry wall, and lime concrete used as the waterproofing layer. These observations are used to characterize the masonry as a water-supplying conduit and not a fortification wall (Davison-Jenkins 1997; Deloche 2001, pp. 77, 84, 95, 134; Brubaker 2004, pp. X, 86, 101, 369–370; Deloche 2007, p. 49).[5] The crucial observation of the structure is identifying the two verticals of the aqueduct with traces of lime concrete in ruinous condition covered with thick vegetation, authenticated the masonry positively as an aqueduct based on Davison-Jenkins's (1997) recording at Hampi Vijayanagara. A probable construction period of this structure is deduced based on the unique Vijayanagara period rectilinear quarry

[3] https://g.co/arts/c9CSmkJ1BgPpz3hQ9 (accessed on 14 May 2021).

[4] www.bhuvan-app1.nrsc.gov.in/culture_monuments/; http://www.asidharwadcircle.in/

[5] According to Brubaker (2004), the royal enclosure at Hampi has one bastion for approximately every 500 m, and bastions are absent at fort walls only when the terrain is impassable.

Table 17.1 The reservoirs around the Badami range found in sandstone geological formation

No.	Reservoir name	Area (hectare), volume (cum), and dimensions (m)					
		Catchment area	Reservoir area	Embankment height	Average depth	Reservoir capacity	Catchment area per 10 cum
1	Kendur	5700	200	6	3	60,000	0.95
2	Muttalgeri	725	2	3	3	600	12.08
3	Nandikeswara-Kenchamma	420	10	3	3	3000	1.40
4	Nagarhal-Shankaralinga	260	5	3	3	1500	1.73
5	Kabbalageri	190	5	2	3	1350	1.41
6	Badami	140	8	5	3	2400	0.58
7	Vakkandurga	140	4	4	3	1200	1.17
8	Mallapur	120	3	2	3	750	1.60
9	Kelur-Panchalingeshwara	100	2	2	3	600	1.67
10	Halakurki	44	6	4	3	1800	0.24

marks (Kuppa and Menon 2018)[6] found on the sandstone blocks of the aqueduct (Fig. 17.2). Accelerator mass spectrometry (AMS) dating on the material samples from the site can further explore this dating in future.

The geospatial data, such as the Digital Elevation Model (DEM), are used for generating three-dimensional views and hydrology maps (both stream and catchment maps) to visualize and verify the terrain's conduciveness to transport water. Field observations led to interesting observations on the subtle modification made to the terrain to harvest water from the neighboring catchment area. On characterizing the aqueduct based on the construction systems, a ground profile gradient map of the 600 m-long aqueduct was plotted using the elevation values from the Cartosat10 m DEM. The gradient of 1:30 where the end "A" (near the north fort) is lower than "B" proves the conduciveness of the terrain to transport water to the north fort (Fig. 17.3) as mentioned in the archival records. Superimposing the aqueduct layer, DEM, and hydrology maps highlighted the location of the aqueduct along the water divide of the catchments of Badami reservoir and its northern Shibaraphadi hill. Any physical structure spanning valleys and hills is intrusions in the terrain (e.g., a road or a canal) that alters the topographic characteristics, terrain conditions, soil structure, and hydrological path (Board and Council 2005). An aqueduct is a water-conducting structure spanning valleys and hills, thereby holding all the properties for causing changes to the terrain and its properties. The Badami aqueduct might have potentially altered the landscape if it was not along the water divide; hence, as per our deductions, it was built causing minimal disruption to the terrain. In addition, the use of the local sandstone in the construction of the aqueduct camouflages the massive structure with the terrain morphology.

Fieldwork upstream of the open masonry channel at "B" enabled us to record a few subtle modifications to the terrain from various historical periods. They are (a) the Mahakuta foot track doubling as a water channel (Fig. 17.2c), (b) a channel cut into the cliff probably from the eighth century (based on the inscription and the Naga sculptures which represent water body), (c) a funnel profile to guide the water of the mesa plateau of the Shibaraphadi hill onto the cliff channel (Fig. 17.2d), (d) low masonry wall along the Mahakuta foot track and the edge of the mesa plateau guiding the runoff water from the upstream catchment of Shibaraphadi into the funnel, and (e) the small cistern cut into the rock surface[7] from where the water of the north sub-catchment of the Shibaraphadi is collected and guided along the low masonry wall (Fig. 17.2e). Thus, the entire water of the 35 hectares of the upstream portion of the Shibaraphadi catchment drains into the Badami reservoir via the open masonry channel into the stream formed along the hill slopes of the Tattukote catchment (Fig. 17.2f). Another catchment to the south of the Tattukote catchment

[6]The chisel marks formed during quarrying of stone blocks as seen on few of the stone blocks used in construction of the masonry are the quarry marks. A curvilinear mark indicates Chalukyan period, and rectilinear belongs to Vijayanagara period.

[7]Dateable to Vijayanagara period based on the quarry marks.

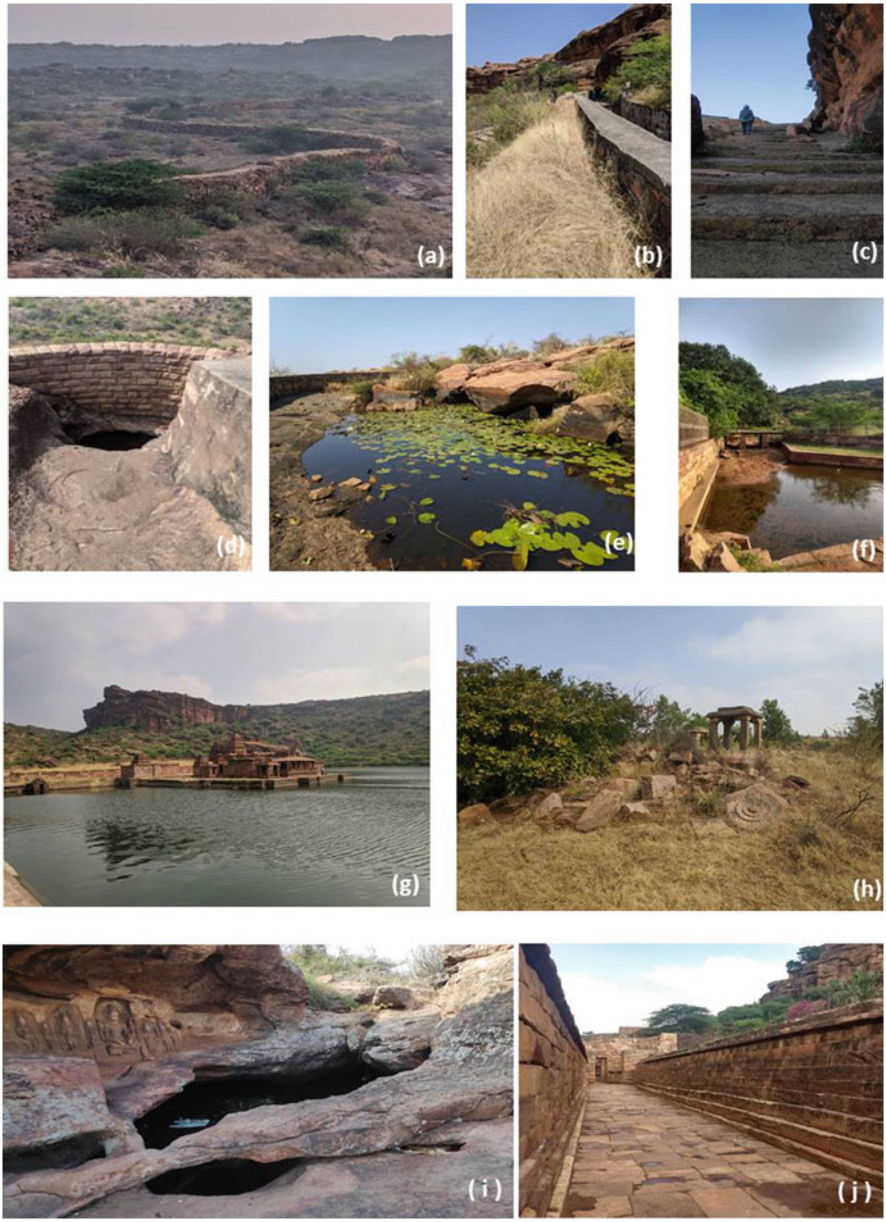


Fig. 17.2 Field photographs: (**a**) view of the aqueduct, (**b**) open masonry channel, (**c**) cliff channel, (**d**) funnel at cliff channel M, (**e**) cistern L, (**f**) inlet channel to the reservoir, (**g**) Akka Thangi waterfalls (in January), (**h**) upper Arali Tirtha, (**i**) Arali Tirtha, and (**j**) outlet channel to Agastya Tirtha

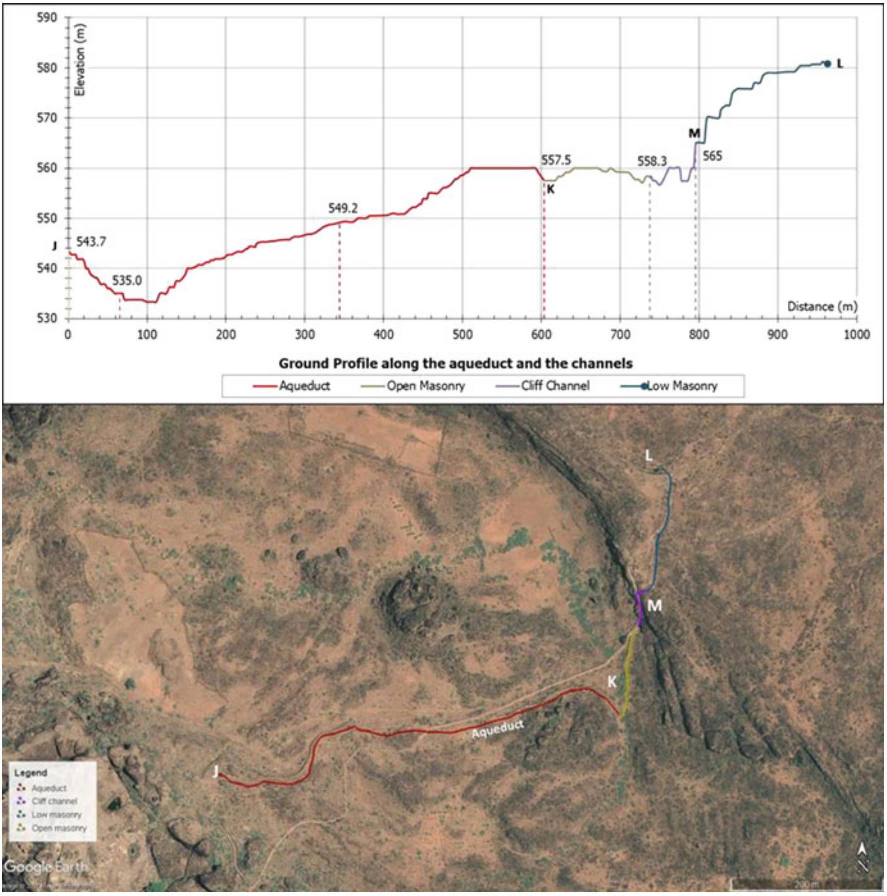


Fig. 17.3 (Top) Ground profile graph to verify the conduciveness of the terrain. The graph was prepared by extracting elevation values of the ground from Cartosat 10 m DEM. (Bottom) Google Earth Image of 2009 marked with the location of the aqueduct, open masonry channel, cliff channel, funnel, and cistern

gathers both the runoff water and spring water from a cavern locally called Arali Tirtha (Fig. 17.2i).

Quarry marks identified by Menon indicate the modifications on the cliff to channel water into creating the twin fall in the Akka Thangi catchment (Menon 2017). Upstream of Akka Thangi stream is a reservoir next to a temple complex (upper Arali Tirtha or Malayappana Gudi in ruins) (Fig. 17.2h). Five natural cisterns and two square cisterns inside the treasury of Tippu Sultan are at the summit of the north fort (Fig. 17.3). The present ruinous condition of the aqueduct might have been due to disuse, probably followed by the abandoning of the north fort. The entire water systems interconnected in a network (apart from the collapsed aqueduct) have sustained the Badami reservoir for over a thousand years.

17.5 Current Scenario and the Way Forward

Badami has been on the World Heritage status tentative list[8] and the National Heritage City Development and Augmentation Yojana (HRIDAY)[9] since 2015 and has all the potentials of attracting tourism-related infrastructure developments and related planning strategies. KUIDFC (2009) proposed an infrastructure project for Badami which aimed at enhancing the quality of the urban environment, owing to the inadequate infrastructure facilities, like water supply and sanitation. It states that the river Malaprabha is the primary source of water supply to the settlement and it is also where sewage and surface runoff water drains. Subsequently, a water-quality assessment in 2014 records a higher presence of the bacteria *E. coli* (10^4/100 ml) in the waters of the river Malaprabha and a slightly lesser presence of the bacteria in Agastya Tirtha (10^1/100 ml), deeming both the waters unsuitable for consumption and other domestic purposes without the necessary monitoring and treatment (Kakaraddia et al. 2014). A 2017 report (Yadav 2017, pp. 8, 9) on the aquifers of the Badami sub-district records groundwater resources that are being overexploited. It proposes methods for recharging the groundwater by providing check dams and percolation tanks. However, the growth of Badami has exacerbated environmental problems that can be linked to pollution, improper waste management, and poor sanitation.

There is an increased need for urban regeneration underpinned by multifaceted nature-based solutions to address the challenges and ensure sustainable and resilient settlements. Badami requires an adaptive and resilient strategy that integrates not only newer designs and processes for infrastructure development but also recommendations, which considers the existing system that has been in place for thousands of years (as the water systems of Badami discussed in this paper). This study asserts that recognizing the existence of a historical infrastructure would pave the way for a sustainable "Blue-Green" approach that creates a network of natural, seminatural, and designed landscape elements (Lamond and Everett 2019) while reducing stress on "gray" infrastructure like subsurface piped systems (O'Donnell et al. 2017). Although the nature-based solutions can offer a terrain-sensitive approach to the development of the landscape, there is also a need to acknowledge the historical, social, cultural, economic, and ecological aspects and include multiple actors for efficient planning and reshaping practices. A holistic framework of ideas that combines theoretical concepts with empirical knowledge (recognizing the living water systems at Badami) is imperative.

[8] https://whc.unesco.org/en/tentativelists/5972/ (accessed on 14 May2021).

[9] http://mohua.gov.in/cms/hariday.php (accessed on 14 May 2021).

17.6 Conclusion

Human settlements throughout history have been in proximity to water, and the settlement of Badami is no different. Badami and its surrounding region exhibit a carefully engineered water supply network that supports the reservoir and many sacred groves within the hill range that enhance the microclimate in this dry semi-arid region. The sacred structures located in the landscape add value to it and play a vital role in the sustenance of the landscape. This study enabled us to identify features that have sustained for over a thousand years due to their continuous requisite to the local landscape and supported the livelihood of the local people. Though the water systems of this capital city resulted from simple modifications, their performance involves a certain complexity. The system captured water of the neighboring catchment, leading to reduced water reaching downstream of the Shibaraphadi catchment-, thereby altering the ecosystem in this catchment. Looking at it on a larger scale, this alteration coupled with preserving the verdant spaces balances the ecosystem and delivers water-related ecosystem services.

Scrutinizing the hydrology maps of the landscape, coupled with field exploration, has enabled us to appreciate a carefully modified terrain with minimal interventions such as low walls, incision of the ground, and cliff faces to channel water along the terrain. These constructions and small interventions may not look monumental, but they effectively harvest water for various needs to an otherwise semi-arid locale through an elaborate low-key water supply network from both the catchments. Even minor damage to the low walls (which look like a boundary wall) is sufficient to prevent the water of the Shibaraphadi catchment from feeding the Agastya Tirtha reservoir. A lack of awareness about these water-channelling features among the local people, governing authorities, and experts designing developmental works may overlook these subtle features and may eventually disappear from the landscape.

The age-old practice of this semi-arid region, which utilizes one infrastructure for dual purposes, i.e a foot track also used as a water channel, is a sustainable approach adopted by not altering the hydrology of the terrain. Badami range has survived for over a thousand years with its water systems and sacred grooves, reflecting remarkable skill and a noteworthy feat of engineering while adopting simple nature-based solutions with minimal intrusion. The reservoir's upstream catchments form an integral part of a more extensive water supply network system. The sacred grooves have helped enhance the microclimate and, more importantly, maintain a balance in the ecosystem. By studying the landscape closely, we can acquire a knowledge base for planning sustainable and robust infrastructure. Hence, planning and policy interventions influenced by the local geography and cultural dynamics can have an environmental and socio-economic impact (Monteiro et al. 2020). If planned well, the heritage settlement of Badami can present as an example of engineering heritage.

Acknowledgments This study is part of the project titled "Historical Water Systems in the extended landscape of Malaprabha River Valley," funded by the Indian Heritage in Digital Space (IHDS) of the Department of Science and Technology (DST), Government of India. The study reported here forms a chapter in the first author's doctoral thesis enrolled for PhD at the Manipal Academy of Higher Education (MAHE), Manipal, Karnataka. We thank the valuable comments provided by the reviewers, Dr. Rajashree Ray, Centre for Studies in Ethnobiology, Biodiversity and Sustainability (CEiBa), Kolkata, and Mr. Xavier Benedict, Art & Architecture Research, Development and Education (AARDE) Foundation, Chennai, to refine the manuscript. We thank Prof. Srikumar Menon at NIAS for his valuable inputs about the history and architecture of Badami.

Conflict of Interest Statement The authors report no conflict of interest for this publication.

References

Abraham M (1988) Two medieval merchant guilds of South India. Manohar Publications, New Delhi

Ali D (2011) Botanical technology and garden culture in Somesvara's Manasollasa. In: Ali D, Flatt E (eds) Garden and landscape practices in precolonial India: histories from the Deccan. Routledge, Delhi, pp 39–53

Brubaker R (2004) Cornerstones of control: the infrastructure of imperial security at Vijayanagara, South India. University of Michigan, Michigan

Campbell JM (1884) Gazetteer of the Bombay Presidency, Bijapur, vol XXIII. Government Central Press, Bombay

Cousens H (1889) Bijapur: the old capital of the Adil Shahi Kings: a guide to its ruins with a historical outline. Thacker and Co., Bombay

Dalavi J, Kambale S, Jadhav V et al (2019) Forest flora of Badami Hills of Bagalkot district, Karnataka, India. Phytotaxa 393(3):204–250

Davison-Jenkins DJ (1997) The irrigation and water supply systems of Vijayanagara. American Institute of Indian Studies, New Delhi

Deloche J (2001) Études Sur Les Fortifications De L'Inde: III. La fortification hindoue Dans Le Sud De L'Inde (VI e). Bulletin De L'École Française D'Extrême-Orient 88:77–134

Deloche J (2007) Studies on fortification in India. Nouvelle édition [enligne]. Institut Français de Pondichéry, Pondicherry

Dhavalikar MK (2000) Ladders and snakes: cyclical shifts in culture process. In: Settar S, Kaimal PKV (eds) We lived together. Pragati Publications and Indian Council of Historical Research, Delhi, pp 1–13

Dikshit GS, Kuppuswamy GR, Moha SK (1993) Tank irrigation in Karnataka: a historical survey. Gandhi Sahitya Sangha, Bangalore

Filliozart V, Filliozat P (2015) Saiva monuments at Pattadakal. Archaeological Survey of India, New Delhi. www.asi.nic.in/wp-content/uploads/2015/12/Pattadakal_16_0516.pdf. Accessed 29 Jan 2021

Gaussen H (1965) Mysore: international map of the vegetation and the environmental conditions, scale 1:1,000,000, sheet no: ND43. Indian Council of Agricultural Research and French Institute of Pondicherry, Pondicherry

Ghosh A (1973) The city in early historical India. Indian Institute of Advanced Studies, Simla

Harshavardhan M, Suganya K (2020) Water harvesting systems of the past – a case study of Badami, India. In: Proceedings of national seminar on recent advances in geospatial technology & applications. IIRS, Dehradun, pp 170–175

Jeelani S (2006) Gazetteer of India, Karnataka state Gazetteer, Bijapur district (Bagalkot District included). Government of Karnataka, Bangalore

Kakaraddia KH, Kugali NM, Yadawe MS (2014) Determination of physicochemical properties and Escherichia coli in water. Online Int Interdiscip Res J 4(1):156–162. http://www.oiirj.org/oiirj/jan-feb2014/18.pdf. Accessed 14 Jul 2021

Khan ML, Khumbongmayum AD, Tripathi RS (2008) The sacred groves and their significance in conserving biodiversity: an overview. Int J Ecol Environ Sci 34(3):277–291

KUIDFC (2009) North Karnataka Urban Sector Investment Program (Tranche 2) - Badami TMC Initial Environmental Examination (IEE). Karnataka Urban Infrastructure Development Finance Corporation, Government of Karnataka, Belgaum

Kuppa M, Menon SM (2018) Stories from silent stones: on the shape of wedge marks as a diagnostic of stone-craft of different periods. Heritage 6:438–486

Lamond J, Everett G (2019) Sustainable Blue-Green Infrastructure: a social practice approach to understanding community preferences and stewardship. Landsc Urban Plan 191:103639. https://doi.org/10.1016/j.landurbplan.2019.103639

Lombardo N, Lewis R (2013) Urban planning and geography. Oxford bibliographies in geography. https://doi.org/10.1093/OBO/9780199874002-0080

Malhotra KC, Gokhale Y, Chatterjee S (2001) Cultural and ecological dimensions of sacred groves in India. Indian National Science Academy, New Delhi

Menon SM (2017) Beyond the tourist's Badami. Deccan Herald. https://www.deccanherald.com/content/591789/beyond-tourists-badami.html. Accessed 9 Oct 2020

Michell G (2014) Temple architecture and art of the early Chalukyan: Badami, Mahakuta, Aihole, Pattadakal. Niyogi Books, New Delhi

Monteiro R, Ferreira JC, Antunes P (2020) Green infrastructure planning principles: an integrated literature review. Land 9:525

Morrison K (2010) Dharmic projects, imperial reservoirs, and new temples of India: an historical perspective on dams in India. Conserv Soc 8(3):182–195

Morrison K (2013) The human face of the land: why the past matters for 'India's environmental future, NMML Occassional Paper History and Society New Series 27. Nehru Memorial Museum and Library, New Delhi

Mumford L (1938) The culture of cities. Harcourt, Brace and Company, New York

Mumford L (1961) The city in history: its origins, its transformations, and its prospects. Harcourt Brace Jovanovich Inc, New York

Nandikar MD, Gurav RV (2018) A new species of Commelina (Commelinaceae) from India. Webbia 73(2):233–237. https://doi.org/10.1080/00837792.2018.1540743

Norwich JJ (2016) From Mesopotamia to Megalopolis. In: Norwich JJ (ed) The great cities in history. Thames and Hudson, London

O'Donnell EC, Lamond JE, Thorne CR (2017) Recognising barriers to implementation of Blue-Green Infrastructure: a Newcastle case study. Urban Water J 14(9):964–971. https://doi.org/10.1080/1573062X.2017.1279190

Padigar SV (2012) Heritage series: Badami. Department of Archaeology, Museums and Heritage, Bangalore

Ray R, Chandran MDS, Ramachandra TV (2014) Biodiversity and ecological assessments of Indian sacred groves. J For Res 25:21–28. https://doi.org/10.1007/s11676-014-0429-2

Sathyan BN (1966) Mysore State Gazetteer Bijapur District. Government Press of Printing Stationery and Publications, Bangalore

Scarborough VL (2003) How to interpret an ancient landscape. Proc Natl Acad Sci U S A 100(8):4366–4368. https://doi.org/10.1073/pnas.0831134100

Scarborough VL, Isendahl C (2020) Distributed urban network systems in the tropical archaeological record: toward a model for urban sustainability in the era of climate change. Anthropocene Rev 7(3):208–230

Shaw J, Sutcliffe J (2003) Ancient dams, settlement archaeology and Buddhist propagation in central India: the hydrological background. Hydrol Sci J 48(2):277–291. https://doi.org/10.1623/hysj.48.2.277.44695

Shepard K (1999) The ecological Indian: myth and history. W.W. Norton and Company, London
Smith ME (2007) Form and meaning in the earliest cities: a new approach to ancient urban planning. J Plan Hist 6(1):3–47. https://doi.org/10.1177/1538513206293713
TRB, NRC (2005) Assessing and managing the ecological impacts of paved roads. Transportation Research Board; National Research Council, Washington, DC. https://doi.org/10.17226/11535
Yadav S (2017) Badami Taluk aquifer maps and management plans, Bagalkot District, Karnataka State. Central Ground Water Board, Bangalore

Kuili Suganya is currently pursuing a doctoral programme at the National Institute of Advanced Studies (NIAS), Bengaluru, India.

Mythrayi Harshvardhan is a Project Fellow currently working at the National Institute of Advanced Studies (NIAS), Bengaluru, India.

M. B. Rajani is an Associate Professor at the National Institute of Advanced Studies (NIAS), Bengaluru, India.

Part V

BGI for Environmental Risk Management

Urban Sustainability and Resilience Building: Blue-Green Infrastructure for Air Pollution Abatement and Realizing Multiple Co-benefits

18

Rakesh Kadaverugu, Shalini Dhyani, Rajarshi Dasgupta, Pankaj Kumar, and Chandrasekhar Matli

Abstract

Sustainable Development Goal 11 (sustainable cities and communities) is important to be localized and achieved due to increasing urbanization across the world. Air quality management has emerged as a major urban challenge because of increasing pollution load and people getting exposed to polluted environment due to the rapid urbanization. Local climate modifications by urban landscape such as building morphology, vegetation, and water bodies define the transport of pollutants. Diminishing water bodies, dwindling green spaces, and ever-increasing built-up area have further pushed the urban centers toward the tipping point. Passive air pollution abatement and microclimate modification by mainstreaming integrating nature-based solutions (NbS) (especially nature-based infrastructure (NbI) and green infrastructure (GI)) in urban planning can help. Mainstreaming NbS in urban planning has found its relevance in the developed countries and needs recognition in urban plans of developing and underdeveloped countries. In the present chapter, we provide evidence to support mainstreaming of NbS in urban air quality management and heat mitigation in the urban canopy layer that has the potential to bring multiple co-benefits with it. Urban resilience and sustainability in the Anthropocene will equip future cities for improving air quality and also cushion the harmful effects from extreme weather events (urban heat island effect, heatwaves, flash floods, groundwater depletion, etc.) which are accelerated due to climate variability. This chapter

R. Kadaverugu (✉) · S. Dhyani
CSIR-National Environmental Engineering Research Institute, Nagpur, Maharashtra, India

R. Dasgupta · P. Kumar
Institute for Global Environmental Strategies, Kanagawa, Japan

C. Matli
National Institute of Technology, Warangal, Telangana, India

S. Dhyani et al. (eds.), *Blue-Green Infrastructure Across Asian Countries*,
https://doi.org/10.1007/978-981-16-7128-9_18

explores opportunities and challenges of integrating blue-green infrastructure in improving urban resilience and sustainability and especially to localize SDG 11 and other interlinked SDGs.

Keywords

Nature-based solution · Blue-green infrastructure · Urban air quality · Climate change · Sustainability · Resilience

18.1 Introduction

Anthropocene has a significant impact on natural ecosystems that further alter and affect the global climatic rhythm. Rampant urbanization has resulted in high population densities and massive infrastructure buildup (Andersson et al. 2017). Shrinking blue and green spaces and rampant concretization have resulted and affected local microclimate by enhanced heat islands and air pollution (Lahoti et al. 2019; Dhyani et al. 2018, 2020a, b). Air pollution is one of the major causes of premature mortality across the globe. More than half of the world's population resides in fast-growing urban centers, and the same is projected to increase to 68% by 2060 (UNDESA 2018). Unlike regional background air quality, the air in urban centers is getting continuously ingested with the anthropogenic emissions from vehicles, domestic and commercial utilities, construction activities, resuspended dust, etc. Studies show that nearly 80% of urban dwellers are exposed to polluted air (WHO 2018), which is reducing the average life expectancy by 1.6–1.9 years in India and 0.06–0.3 years in China (Balakrishnan et al. 2019; Wu et al. 2020). Similarly, Pascal et al. (2013) estimated that 22 months of life expectancy can be increased by complying to WHO $PM_{2.5}$ air quality standards according to a study conducted in 25 European countries. A few studies have quantified that health-care costs are expected to increase from $21 billion in 2015 to $176 billion by 2060, and the economic loss due to loss of working days is projected at $3.7 billion. This overall economic burden due to outdoor air pollution will be costing 1% of global gross domestic product (GDP) by 2060 (OECD 2016). Hence, there is growing need to manage urban airsheds to create better living spaces and ensure human well-being. Global conventions have been underpinning the need for the design of sustainable urban habitats for human well-being (SDG 11). Climate Adaptation Summit (CAS 2021) has recently pledged for converting 1000 cities across the world sustainable and resilient. Sustainable Development Goal (SDG) 11 on sustainable cities and communities underlines the action necessary for making urban centers sustainable and resilient by implementing localized practices in line with the global commitments as it indirectly supports and helps in localizing other pertinent SDGs like 3 (good health and well-being), 12 (responsible consumption and production), 13 (climate action), and 15 (life on land). Convention on Biological Diversity (CBD) and Sendai Framework for Disaster Risk Reduction (2015) also stress on

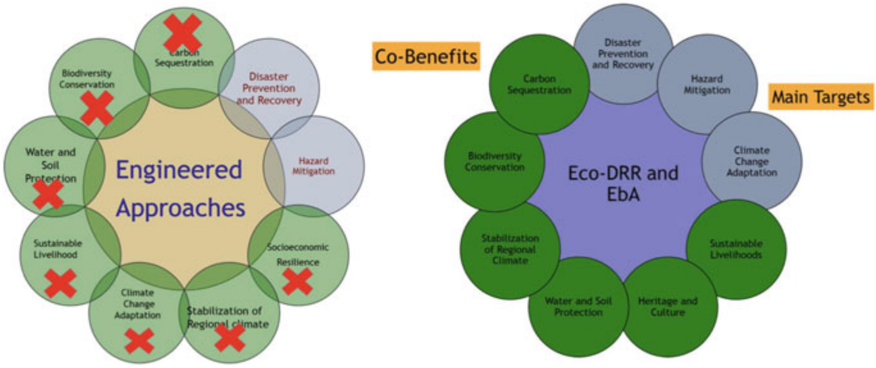


Fig. 18.1 Comparing conventional engineering approaches with nature-based solutions (NbS) with multiple co-benefits along with targeting hazard mitigation and climate change adaptation. (Adapted from Dhyani et al. 2020a, b)

mainstreaming sustainable and ecosystem-based approaches for disaster risk reduction.

Urban resilience and ecosystem-based approaches based on sound ecological principles are supported and promoted for being incorporated in climate actions and urban planning (Suárez et al. 2018). To address challenges of fast-growing urban areas especially climate change, human health, and safety, urban policy planning concerns and dialogues are to nature-based solutions (NbS) (Raymond et al. 2017). Urban areas are new disaster hotspots, and the world is witnessing growing acceptance of NbS due to increasing climate and disaster vulnerability in urban areas (Dhyani et al. 2018, 2020a, b). NbS and resilience are endorsed as a balancing approach in urban planning to counter the problem of global warming (Suárez et al. 2018). NbS with zero or negative carbon footprint helps in achieving climate mitigation and adaptation strategies for natural as well as built-up ecosystems. Although engineered solutions (gray infrastructure/concrete structures) offer instant mitigation benefits, they are costlier and short-term solutions and many times energy intensive with massive carbon footprints, whereas NbS offer multiple co-benefits to nature and human systems (Fig. 18.1).

Urban NbS approaches (viz., urban green and natural infrastructure that includes urban forests, campus green spaces, parks, playgrounds, ecological engineering, urban agriculture) are acknowledged in multiple instances as approaches that have the potential to address urban climate adaptation, mitigation, and DRR issues (Armson et al. 2013; Dhyani and Thummarukuddy 2016; Raymond et al. 2017; Dhyani et al. 2018, 2020a, b). Efficient NbS models and approaches provide evidence of improving air quality (Calfapietra et al. 2015; Kadaverugu et al. 2019), urban biodiversity, ecosystems and ecosystem services (Connop et al. 2016; Tan and Jim 2017; de Oliveira and Mell 2019; Cameron et al. 2020; Chausson et al. 2020), heat islands (Makido et al. 2019; Kadaverugu et al. 2021b), and urban flash flood reduction (Majidi et al. 2019; Kadaverugu et al. 2021a) and addressing

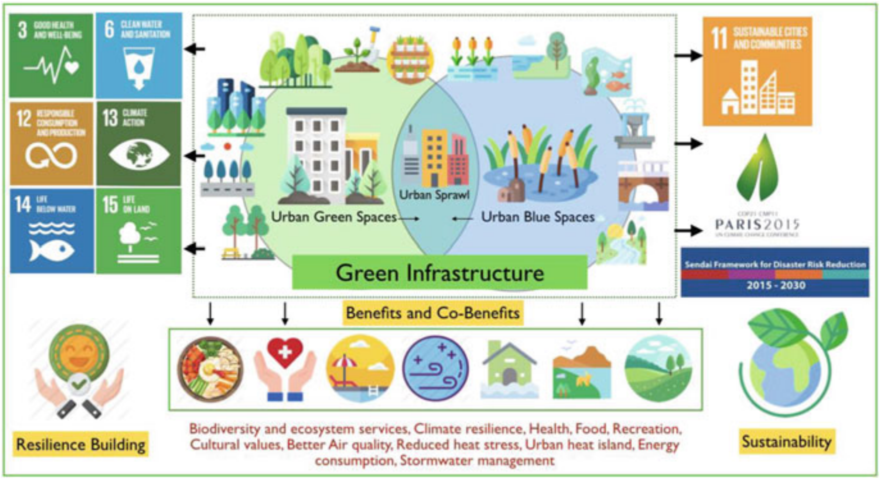


Fig. 18.2 Urban blue-green infrastructure and their multiple co-benefits for realizing global sustainable development, disaster risk reduction, and climate goals

other crosscutting challenges like urban sustainability (Perez and Perini 2018), public health, and well-being (Bennett et al. 2015).

Conversion of a part of urban land use into dedicated blue and green spaces and implementing certain green infrastructure–based passive technologies help air purification and a multitude of other ecosystem services (co-benefits), such as stormwater retention, reducing urban heat island effect, reducing noise pollution, and promoting biodiversity; all these enhance the social, cultural, economical, psychological, and spiritual benefits to people (Figs. 18.1 and 18.2). International assessment reports by the Intergovernmental Panel on Climate Change (IPCC), Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES)), Paris Convention on Climate Change (2015), Sendai Framework for Disaster Risk Reduction (2015), Convention on Biodiversity, and UN Sustainable Development Goals (2015) have been urging and encouraging nations to recognize the role of NbS as a climate adaptation and biodiversity conservation strategy. The UN Decade on Restoration (2021–2030) is further going to strengthen this global effort by promoting restoration of landscapes and degraded areas outside natural ecosystems in human-modified urban areas. Urban green spaces (UGS) and blue spaces in general lower the ambient temperature and increase the absolute humidity levels in the surface layer that affect positively the dispersion and deposition of the pollutants. Apart from these, the vegetation and water bodies influence the wind speed and direction and the bulk movement of the pollutants. At urban scale, the green and blue spaces modify the land surface interaction with the surface layer in terms of latent and sensible heat exchanges, which in turn drives the development of mixing height and hence affects the dispersion of pollutants.

The widespread implementation of NbS at the urban level enhances the natural elements and addresses diverse societal challenges (Seddon et al. 2019). NbS also enhances urban resilience toward extreme weather events which are being accelerated by global warming and climate change. Even if global warming is limited to <1.5 °C, there will be some impacts due to climate inertia and feedbacks that are carried forward by the present rate of climate change. In any scenario of global emission capping, there will be ramifications due to ongoing climate feedbacks, which are going to be reflected in a rise in the sea-level and modified weather systems. The frequency and intensity of extreme weather events especially heatwaves and floods are projected to increase in the warming world (Ward et al. 2016; Jiang et al. 2019). Adaptation to the impacts of climate change is therefore a necessary strategy and specifically through NbS so that further damage to nature can be reduced. At present there are very few syntheses on NbS for air quality mitigation covering an outlook on future climate change and scenarios. Particularly the advantage of NbS for air quality should be available for policymakers, urban planners, researchers, and other important stakeholder groups for effective policy planning so that broadly designed nationally determined contributions (NDC) for combating climate change can be effectively implemented at local scales. The present study focusses on the role of green and blue infrastructure (as NbS) in mitigating urban air pollution and discusses aspects of sustainable urban design, role of local meteorology, and adaptation and mitigation strategies in the warming world due to climate change, followed by the conclusions and way forward.

18.2 Urban Blue-Green Infrastructure

In this chapter, the term blue infrastructure refers to water spaces like wetlands, rivers, rivulets, lakes, ponds, canals, ports, fountains, and streams, whereas green space refers to urban forests, campus forests, parks, gardens, green walls, green roofs, avenue plantations, protected forests, and grasslands. Whereas the term green infrastructure (GI) refers to any nature-based infrastructure enveloping both the blue and green spaces that provide multitude of benefits to the urban systems like stormwater runoff reduction, air purification, thermal insulation, contributing to potable water, increasing aesthetic value, reduction in urban heat island effect, etc. that support human health and well-being. The thinking in green infrastructure should amalgamate the individual roles of (blue) water and (green) vegetation part, as well as their synergistic nexus. This inseparable dependence of blue and green ecosystems is a holistic phenomenon when green infrastructure (GI) is referred to (Rozos et al. 2013). Hence, the terms GI and blue-green infrastructure are used interchangeably in this chapter, which refers to the NbS for improving urban systems and supporting human well-being.

18.3 Urban Canopy Layer

The bottom most atmospheric layer of thickness 1–4 km is exposed to the diurnal variations of land surface processes driven by solar radiation. The upward movement of latent and sensible heat fluxes from the land surface features creates enough turbulence to ensure sufficient mixing up of the lower atmosphere layer—known as the planetary boundary layer (PBL). The combination of mixing height and wind speed defines the rate at which the air is being ventilated or flushed away, known as ventilation coefficient (VC). The ventilation of urban air is subjected to temperature gradients between the downtown and the fringes, resulting in urban heat island (UHI) effect. The release of anthropogenic heat into the urban canopy further exasperates the intensity of UHI and accelerates the buildup of air pollution. Both indoor and outdoor air quality are getting polluted due to several anthropogenic actions/sources. Factors affecting the dispersion and deposition of air pollutants at the urban scale should be understood for better managing the urban air systems and environment. Further, the dispersion and deposition of air pollutants are governed by the wind profile, which is significantly affected by the building and vegetation configurations. Temperature and relative humidity are two important meteorological parameters that affect the transport of pollutants. Maintaining air quality under compliance is essential for human well-being especially human health and reduction in damage to vegetation and property. Both active and passive measures of air pollution control are essential for attaining compliance to the pollution standards. Hence the role of building geometry, vegetation characteristics, and microclimatic conditions plays a crucial role in dispersion and deposition of air pollutants in urban settings.

18.4 Urban Heat Island Reduction

As already stated, in the urban setting, the urban air is subjected to temperature gradients between the downtown and the surrounding fringes, resulting in the urban heat island effect. Green infrastructure or UGS provides cooling effect at an urban scale due to shade, evapotranspiration, and changing the reflectance properties of urban surfaces. Green infrastructure is a broad term that refers to the soil, vegetation, water bodies, and bioengineered systems which have the potential to regulate microclimate and provide a multitude of ecosystem services like air quality improvement, stormwater management, and cultural benefits (Keeley 2011) including social, economical, and psychological benefits to human beings. Lined parks and city waterways improved thermal well-being and helped in developing community resilience in Cyprus by reducing heat islands (Giannakis et al. 2016).

Absence of high-resolution urban infrastructure data is a significant limitation that poses challenge in accurately studying the propagation of the cooling effect by UGS. Also, lack of high-resolution satellite temperature products impedes the spatial analysis over urban centers. Mathematical models that account for energy balance by considering the vegetation interactions with the local temperature are highly preferred for building-scale temperature simulations, for which anthropogenic heat from the buildings, vehicles, and other activities is essential to improve the accuracy. A multitude of deterministic models, empirical models, and remote sensing applications are available that are handy in the quantification of the cooling effect of UGS on the urban environment. Due to the advancement in computational power and availability of urban-scale meteorological models such as ENVI-Met, ADMS-Urban, weather research and forecasting (WRF) model, computational fluid dynamics (CFD) models, and statistical regression models, several researchers have reported the change in UHI due to the various scenarios of changes in green cover (Tiwari et al. 2020). Few studies on UHI reported a perturbation in urban temperature from 0.2 to 3.0 °C due to land-use changes such as conversion from grasslands to a frosted area, concretization, dwindling blue spaces, and haphazard urbanization, and one can find these examples in their cities. There are clear observations of urban locals preferring green and blue spaces over concretized public parks and playgrounds because of their cooling effects. Studies on UHI reduction stressed the need for green infrastructure in urban conglomerations (Dhyani et al. 2018, 2020a, b). The shape and size of the UGS also influence heat mitigation, and there exists an asymmetric relation between UGS size and heat mitigation or temperature reduction (Kadaverugu et al. 2021a, b). Factors like distance to the UGS, local land use, meteorological variables, and water bodies influence the spread of the cooling effect around the UGS.

Localized warming up of atmosphere over the downtown of urban centers due to the anthropogenic heat is known as urban heat island (UHI) effect. This results in a temperature gradient between the core urban centers and peri-urban areas. The warming of urban areas is now a common phenomenon across the world. The temperature difference is about 0–7 °C which depends on several local factors like vegetation cover, built-up density, local meteorology, and anthropogenic heat emissions. UHI effect is a well-known phenomenon and is widely studied and reported (Yu et al. 2020). To summarize, UHI is mainly produced by four factors: dense building materials and dark pavements; 3D geometry of buildings which absorb solar radiation and restrict the air circulation; decline in previously abundant vegetation cover, which reduces shade and limits evapotranspiration; and waste heat (anthropogenic heat) addition into the cities (Larsen 2015). The UGS ameliorate the UHI intensity by cooling the local air through the evapotranspiration process and shade. Also, the UGS modifies the albedo of the surface that also contributes in heat mitigation. NbS interventions through green rooftops and green walls are proven to reduce the UHI. A study by Gill et al. (2007) has projected that maximum surface temperature over Greater Manchester will drop by 1.7–3.7 °C by incorporating 10% green cover in a highly impervious built-up area. Associating these UHI and heat stress studies with heat-related mortality, the increase in the risk has been estimated. Stone et al. (2014) projected that due to a rise in average temperature by 1.2 and 2.2 °C in Atlanta and Phoenix by the year 2050, the heat-related mortalities will rise by 77% and 55%, respectively. The diminishing UGS and vegetation cover of the cities due to rapid development is one of the leading drivers of UHI intensification. To offset the heat, people depend on the space cooling by the energy-intensive air conditioners, which further emit the exhaust heat and exacerbates the UHI. The vicious cycle of heating up of the urban centers is a serious health risk. In Anthropocene, there is huge dependency on fossil fuels for transportation and space cooling; the emitted carbon dioxide is the biggest contributor to global warming. At this crossroads, relying on UGS in heat mitigation is a win-win alternative that not only cools the urban airsheds but also improves the overall quality of air.

Summarization of historical climate data over a city can provide valuable insights on the changes in indices such as cooling degree days (CDD), heating degree days (HDD), extreme heat events (EHE), and precipitation indices. Studies correlating the historical land-use changes in terms of vegetation cover with the climate indices provide insights into the role of UGS in mitigating the climate-induced weather extremes (Kadaverugu et al. 2011).

18.5 Urban Air Quality and Role of Green Spaces

A multitude of factors not limited to urban geometry, vegetation landscapes, and local meteorological conditions such as wind speed (WS), wind direction (WD), temperature (T), and relative humidity (RH) play an important role in defining the dispersion and deposition of pollutants. For instance, deposition of particulate matter (PM) is strongly affected by RH, T affects dispersion and decomposition of reactive pollutants, solar radiation triggers the photochemical transformations, and rainfall washes away the air pollutants. For instance, the formation of tropospheric ozone is lowered at lower ambient air temperatures. WS and WD define the bulk movement of the pollutants in an urban canopy. Moreover, a two-way feedback mechanism exists between pollutants and meteorological variables, which are highly dynamic and nonlinear. Studies show that the atmospheric fine particulate or secondary aerosol formation is dependent on gaseous pollutant concentrations and air temperature, which further affects the atmospheric capacity to absorb solar radiation and hence affects the air temperature. Urban geometry also plays a significant role in modifying the local microclimate through building shade, channeling wind profile, and creating recirculation zones and cavity formation, which leads to entrapment of pollutants. Especially, UGS modify the local temperature in the vicinity (see Sect. 18.4).

The characteristics of GI or UGS (including bushes, hedges, green walls, green roofs, and vegetation) that influence the pollution removal are density of the vegetation or porosity of canopy; physical dimensions of the vegetation such as length, heights, thickness, and spacing; and tree species-specific characteristics such as leaf geometry, leaf thickness, hairs or wax on leaves, biogenic emissions, and pollution tolerance index (Abhijith et al. 2017). Vegetation interacts with the gaseous atmospheric pollutants through dynamic gaseous exchanges between the vegetation (leaf stomata) and atmosphere (Kadaverugu 2015) which is dependent on factors such as ambient air temperature, CO_2 concentration, soil moisture pressure, and solar radiation. Experiments by Nowak et al. (2006, 2013b) on the removal of gaseous pollutants (O_3, NO_2, CO, and SO_2) and particulate matter (PM) by vegetation showed that the removal is dependent on the tree cover, pollution concentration, and meteorological factors that affect the transpiration and deposition velocities of the pollutants. The pollution removal ability of vegetation varies due to the variations in these characteristics across the urban areas, due to a multitude of factors affecting the wind profile and local meteorology. PM deposited on leaf surfaces can be resuspended back to the atmosphere due to high winds and washed-off by the rainfall or mixes with the soil beneath due to leaf fall. CFD studies revealed that tree canopies alter the wind movement between the canopy and the surrounding atmosphere. Sometimes canopies break the eddies and act as turbulence diffusers especially in calm conditions, but sometimes they may act as a source of turbulence and facilitate turbulent diffusion of air pollutants. Experimental studies have also observed the thermal stratification around the canopies having significant effect on pollution dispersion and diffusion. It is critical to interpret the benefits of tree canopies in air pollution which are highly dependent on the local factors (built environment) and vegetation characteristics which are city specific. It is true that the pollution removal is maximum due to the presence of hedges in the street canyons and thick vegetation along the roads (open highways) (review summary by Abhijith et al. 2017).

Street canyon configurations (height to width ratio), wind direction (lateral to the canyon, perpendicular to the canyon, or oblique to the canyon), and wind speed are important parameters that define the entrapment of the pollutants generated within the canyon. Several studies based on the mathematical models using CFD have tested the multiple parameter configurations and their effect on the pedestrian-level pollution exposure (Abhijith et al. 2017). The majority of studies have shown that there is an increase of 20–96% in concentrations of various pollutants in street canyons due to the presence of trees. But, the presence of trees has shown a reduced pollution concentration under the different spatial arrangements of trees, wind direction, and wind speed. It is reported that the wind, blowing in an oblique direction to the canyon, creates relatively harmful conditions for pedestrian pollution exposure. The arrangement of tree row plantation either in the middle (along the divider) or at the kerb (curb) side, tree spacing, and tree canopy characteristics significantly affect the pedestrian exposure concentration. CFD modeling studies show that from the air pollution point of view, GI has both positive and negative impacts on pedestrian air quality depending on the urban building and GI characteristics. Salmond et al. (2013) have observed that NO_2 concentration in the street canyon in Auckland has increased by 213% (compared with ambient concentration) during leaf-on period and 190% during the leaf-off season. They also observed an increased NO concentration by 471% and 373% during leaf-on and off seasons, respectively. Previous studies have reported that the presence of trees in the street canyons increases the ground-level pollutant concentrations, due to the cold start of the vehicles. In the absence of trees in a street canyon, spiral- and helical-type flow will develop especially when the wind is blowing within 60° perpendicular to the canyon, which leads to 2–3 times higher concentrations in the leeward side than the windward side (Salmond et al. 2013). The presence of thick leaves on the trees in the canyon will limit the upward movement of the fresh vehicle emissions, which increase the accumulation of pollutants within the canopy. Other evidence suggests that vegetation with spacings and gaps (high porosity in the canopy) leads to lower air pollution concentrations in street canyons, whereas high-porosity vegetation increases the concentration in open-road conditions (Abhijith et al. 2017). Tong et al. (2015) have reported that trees considerably reduce the Turbulent Kinetic Energy (TKE) in the wake zone and promote recirculation zones in which the buildup of particulate matter is evident. The alteration of local aerodynamics around the tree canopy significantly affects the dispersions and deposition rates of the pollutants of varying sizes. In their study, Tong et al. (2015) observed higher downwind particulate concentration in the transects having trees, than without trees. Distance between trees and road, wind direction, and vegetation characteristics are vital in defining the pollution reduction benefits from the vegetation barriers along the roads. Some of the vegetation-related parameters used in the urban air quality research are canopy density (CD), crown volume fraction (CVF), spacing, height, width and length, leaf area index (LAI), leaf area density (LAD), and porosity. Type of vegetation such as evergreen, deciduous, coniferous, and mixed forest types is also considered along with the leaf-on and leaf-off seasonal effects.

Studies have found a significant evidence of pollutant removal by urban green walls and roofs despite their inferior appearance compared with trees at local and city scale (Speak et al. 2012; Jeanjean et al. 2015). Baik et al. (2012) showed that green roofs (roofs with greenery on them) have contributed to a reduction of 32% air pollution concentration by facilitating a 2 °C cooling intensity at breathing levels in a canyon. The cooling gradient has enhanced the canyon vortices and has created higher dispersion ability arising from the downward sinking cool air in the canyon. Contrastingly Pugh et al. (2012) have observed a marginal reduction in pollutant concentration with almost no recognition of cooling gradient. The proximity of green roofs to the vehicular emissions/traffic corridors has shown a significant pollutant reduction (around 24% reduction) (Tan and Sia 2005; Speak et al. 2012). Data collected from a pilot project on a green rooftop in Singapore suggests a significant reduction of SO_2 by 37%, whereas nitrogen dioxide showed varying results (Tan and Sia 2005). Resuspension of dust from the uncovered green rooftops and gravel material could be an interfering agent while measuring the effectiveness of removal of particulate matter.

The functioning and benefits of trees in reducing air pollution are highly dependent on the interactions between the vegetation type and the surrounding urban environment (canyon characteristics, green walls, green roofs, etc.) and local meteorology. Generalization of the air purification benefits due to the presence of trees in street canyons should be carefully considered only after validation with the local studies. In general, the presence of green spaces will improve the overall air quality status at the urban scale, but such generalization is not possible at building scale in street canyons. The review of studies on the beneficial role of urban green spaces on air pollution reduction suggested that it should be measured with caution, as the pollution reduction behavior of trees is highly localized that depends on several factors and those cannot be generalized for every urban landscape design. Local experimental and CFD studies are necessary for optimal urban landscape design if air quality improvement is one of the major objectives.

18.6 Role of Blue Spaces in Air Quality Improvement

Urban blue spaces including ponds, lakes, canals, rivers, and ports, along with fountains, are proven to have positive effects on local microclimate, especially in reducing the ambient temperature by 2–6 °C, due to evaporative cooling. Blue spaces also promote the nearby vegetation and facilitate transpiration through the greenery which in turn help in ambient cooling. The studies on air purification benefits offered by the cooling effect due to urban water bodies are not widely reported. Water bodies form urban cooling islands (UCI) in the vicinity to mitigate the UHI and significantly introduce humidity/water vapor into the atmosphere under tropical climatic conditions. Elucidating the dynamic interactions between the water surface and urban canopy layer provides useful insights in the urban studies; this interaction influences the heat fluxes (latent heat flux) and affects the movement of air masses. Zoning of wind direction is necessary for assessing the benefits of evaporative cooling from the water bodies. The wind making contact with the water surface carries the water droplets along and that is spread throughout the downstream urban environment, which causes temperature reduction and increases the absolute humidity. Computational experiments show that the downwind bank of a river of 230 m wide is 0.5 °C colder and 0.4 g/m^3 higher in absolute humidity than the upwind bank (Masiero and de Souza 2015). UCI intensity and efficiency of water bodies are studied in Beijing City by Sun and Chen (2012) using the parameters, viz., area of water bodies (also reported by Peng et al. 2020), landscape shape index (LSI), location of water bodies in relation to the urban center, and built-up proportion surrounding the water bodies. Peng et al. (2020) showed that UHI intensity in Pearl River Delta, China, ranged between 1.1 and 5.54 °C according to the water body patch size and the built-up intensity in the surrounding area of the water bodies. Mean UCI intensity increased along with the increase in urbanization (or socio-economic development) in the surrounding area of water bodies. Satellite observation of LST over a transect crossing a lake in Chandigarh City, India, has shown a reduction of 3.12–7.51 °C; similarly, 0.65–1.71 °C dip is observed in the vicinity of the Sabarmati River, India (Gupta et al. 2019). Steeneveld et al. (2014) have shown contrasting results that the UHI is predominant near water bodies, because water bodies remain at higher temperature due to high heat capacity, and it is reflected in higher air temperature that is 2 m over the surface of water bodies.

18.7 Sustainable Urban Design

There is a need to mainstream the NbS and nature-based infrastructure (NbI) into urban policymaking through evidence-based studies highlighting their benefits. Quantification of NbS benefits in terms of direct and indirect benefits is essential for appreciating the benefits along with co-benefits. Identification of additional land within the urban limits for conversion into green infrastructure by application of local survey and satellite-based survey provides the opportunity to harvest the benefits of NbS. Due to rapid urbanization and haphazard development, the available green spaces are being rapidly converted into built-up land use. This declining trend in the green cover is observed in most of the urban centers across the world. However, utilization of buildings, rooftop, and walls as a potential area for green cover provides additional benefits. Sunshine hours, solar radiation, rooftop slope, and area are some of the factors that are considered for the identification of the potential green terrace spaces. There are well-defined guidelines in European countries for the rooftop implementations. An area greater than 100 m^2 is considered as a potential site for green rooftop in Munich and Linz cities (Santos et al. 2016). Similarly, Green Area Ratio (GAR) has been used in Germany since 1997 as an urban site sustainability metric to quantify the GI in a private property. Santos et al. (2016) showed that an additional 8.5% green cover can be added through the flat rooftops in Lisbon City. High-resolution lidar imaging, digital terrain and surface model data, 3D building geometry data, and imaging through unmanned aerial vehicles are utilized to delineate the potential rooftops that are suitable for vegetation growth. Recently, a few countries like Spain, Denmark, the United Kingdom, and Finland have made the lidar data open access (Santos et al. 2016). But, carrying out similar studies in developing countries is nearly not possible owing to the lack of urban building information and unregulated expansion of urban areas. Nevertheless, Kadaverugu et al. (2021a, b) have utilized the built-up land-use pixel information for the generation of 3D building polygons (by assuming a fixed size of buildings) within the built-up pixels and derived it as an alternative methodology. The height of the building polygons generated by such workaround methods can be assigned randomly with a specified range of the values measured through field observations. Such workaround methods have to be justified and validated in the absence of the availability of essential urban information in developing countries.

Extreme heat events or heat waves are triggered by trapped air due to high-pressure systems over a regional scale, and the usual heating of the trapped air due to sunlight causes high temperatures for several days. The frequency and intensity of these heatwaves triggered due to extreme heat events are on the increase due to climate variability. The rise in the heat along with the UHI in the cities is posing a threat to the livelihood and sustainability of people, especially that these effects disproportionally harm the marginalized sectors of the cities. Urban-rural migration driven by the economic opportunities in the cities is causing the haphazard expansion of the cities, often in a more fragile manner, that is pushing the cities toward increased risk to the extreme events. Settlements of marginal labor in and around the cities inevitably turn into unmanageable urban slums, which are developed in often urban open spaces in the riverbeds or mostly catchments of the urban lakes/water bodies (Kadaverugu et al. 2019), and hence further pushing them into vulnerable zones. Natural hazards like extreme heat events and urban floods are expected to increase in the future due to climate change (Larsen 2015). Sustainable urban landscape design aspects should go beyond the implementation of NbS at micro-level or at building level (like cool pavements, permeable roads, permeable pavements, cool roofs, green roofs, green walls, rainwater harvesting pits, etc.) but should also consider them in designing, at the landscape level by modifying the land use, to optimize the benefits.

Through the development of progressive urban sustainability metrics like GAR, the fraction of impervious surface on private property, number of trees in the premises in individual houses, rainwater harvesting structures, etc., the locals can be incentivized through tax benefits to adopt these GI measures. For instance, the municipality of Toledo, Ohio, incentivizes stormwater utility in exchange for the expansion of GI (Larsen 2015). City planners of Philadelphia have aimed to convert 10,000 acres of an imperious surface into GI to capture the on-site rainfall as stormwater management. It is estimated that the city has invested $1 billion over a 25-year program in GI and has avoided $8 billion in retrofitting the existing gray/ stormwater infrastructure (Larsen 2015). See Larsen (2015) for similar case studies on cost saving through NbS implementation for stormwater reduction and heat stress mitigation.

18.8 Resilience Toward Climate Change

NbS have synergetic trade-offs in mitigating climate impacts at the urban scale and, overall, provide ecosystem services and ameliorate the impacts of extreme weather events related to hydrometeorological disasters (Chausson et al. 2020). Chinese researchers have been supporting the ambitious sponge city model for Beijing that was launched in 2015, and it is based on NbS to reduce urban flash flood issues by natural infiltration, retention, and natural cleaning (Qiao et al. 2019). The ecological, social, economical, psychological, and cultural benefits delivered by the urban green spaces and other nature-based solutions are tremendous in comparison with alternatives (hard-engineered interventions). Mainstreaming of NbS has not been picked up as expected from low-income countries (Chausson et al. 2020), and evidence supporting the NbS is majorly empirically based, compared to the scenario-based projections. Environmental situations in the future years due to the warming world can only be understood by projecting the future climate; hence there should be more emphasis on scenario-based modeling. Changes in urbanization patterns, land use, and other sociopolitical behavior cannot be exactly projected using mathematical models owing to the high complexity of the human systems; however, developing future scenario narration is quite possible by considering the drivers of change (Kadaverugu et al. 2021a, b). Govindarajulu (2014) supported the concept of urban green space design for enhancing climate adaptation for reducing vulnerability in developing countries (Govindarajulu 2014). There are clear evidences that depleting green spaces in urban sprawls are jeopardizing nature's contributions for human well-being (Padigala 2012; Imam and Banerjee 2016). Integration of ecosystem benefits through NbS and future urban systems provides vital information for climate adaption preparedness. Kadaverugu et al. (2021a, b) have projected the urban cooling demand energy conservation due to future plausible land-use changes due to the driver of change—economic development and commitment toward the protection of UGS. The future scenarios are framed according to the combination of the abovementioned drivers of change into four scenarios as per the two axes scenario methodology, viz., (a) scenario in which economic development is promoted by expanding the green spaces; (b) scenario in which economic development is promoted at the cost of green spaces; (c) scenario in which both the economic development and green spaces are not promoted, which is a fictitious scenario; and, lastly, (d) scenario in which green spaces are promoted while economic development is not kept at business-as-usual scenario. Land-use changes in the future scenarios (a–d) are shown in Fig. 18.3, and the corresponding effects on the heat mitigation is presented in Fig. 18.4 (Kadaverugu et al. 2021a, b). It can be observed that significant reduction in the heat mitigation and temperature reduction in the vicinity of the green spaces can be observed from the analysis. These kinds of scenario analysis help in quantifying the role of green rooftops and walls in heat mitigation which is already getting worse due to the climate change.

Localization of generalized national action plan on sustainable development of urban areas is very much needed to avoid the entropy losses in the policy effectiveness. The participatory approach of all stakeholders in urban centers such as residential communities, urban local bodies, nongovernmental organizations, and self-help groups should be encouraged, right from the policy initialization and till the realization of the benefits out of these policies. The effectiveness of the implementation of local actions and their midcourse correction strategies should be regularly monitored by the local stakeholders for attaining high efficiency in policy actions.

Conversion of open spaces into green cover in the urban area depending upon the possibility of land use and cover and by promoting the urban green roof and walls will not only provide local-scale benefits in UHI and air pollution reduction but also offset carbon dioxide (a Green House Gas (GHG)). Trees directly remove atmospheric CO_2 through photosynthesis (sequestration) and storage of C in tree biomass and soil pools. However, apart from these benefits, trees also contribute to CO_2 generation through decomposition and soil respiration and by accounting for the maintenance-related costs. Studies on the carbon sequestration potential of urban trees should consider both the capture and release potentials across different timescales. Several studies have highlighted the role of urban vegetation as an effective CO_2 sink (Nowak et al. 2013a; Reynolds et al. 2017), and the UGS have the potential to offset the majority of city's GHG emissions. Nowak et al. (2013a) have shown that trees in US urban areas have estimated storage of 643 million tonnes of C (as of 2005) with an annual rate of sequestration of 25.6 million tonnes. Yao et al. demonstrated urban and peri-urban green areas have encouraging impact on biomass carbon, while tree and shrub density have even greater impact (Yao et al. 2017). Reynolds et al. assessed carbon sink potential and emission offsets by green

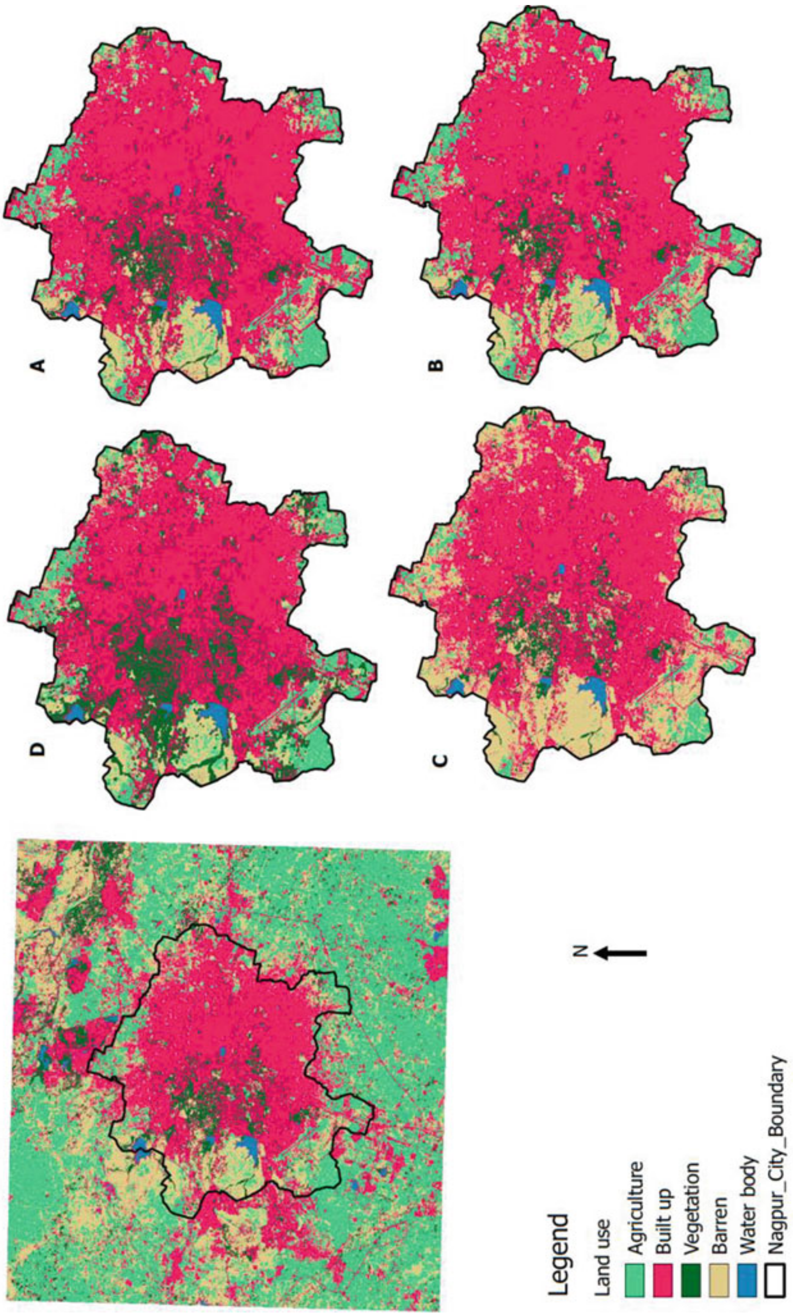


Fig. 18.3 Land-use changes in the present and future scenarios (**a–d**) in Nagpur City (Kadaverugu et al. 2021a, b)

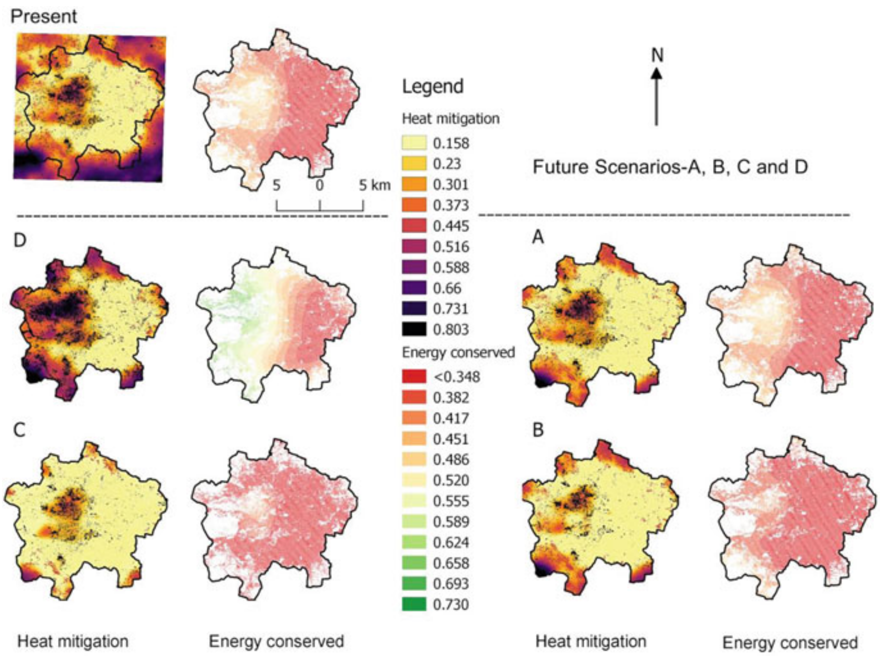


Fig. 18.4 Heat mitigation due urban green spaces in various scenarios (**a**–**d**) of land-use changes in Nagpur City (Kadaverugu et al. 2021a, b)

spaces in the Medellin Metropolitan Area in Colombia and forecasted the potential of NbS (Reynolds et al. 2017).

It was found that carbon offsets may be much more inexpensive if available space is used for dedicated green spaces that can also bring multitude of co-benefits for urban residents.

Large-scale conversion of the built-up roof into green roofs is a potential alternative to offset the land degradation in the urban areas. The additional green space converted into greenery will add multiple benefits in terms of air purification, water retention, heat mitigation, reduction in UHI, and space cooling/heating energy savings and also promotes ecosystem and biodiversity. Several international agencies have issued design guidelines for implementation of the green roofs, for instance, "Design Guidelines and Maintenance Manual for Green Roofs in the Semi-Arid and Arid West" by Tolderlund (2010), "Design Guidelines for Green Roofs" by Peck and Kuhn (2020), and "Green Roof Design: State of the Art on Technology and Materials," a review of scientific literature by Cascone (2019). The major design aspects are bearing strength of the buildings, roof slope, area available, depth of soil (extensive or intensive type), type of vegetation, sunshine requirements, etc. A framework mechanism based on approximately 1700 research papers was developed for addressing ten important societal challenges for evaluating the costs and co-benefits of NbS (Raymond et al. 2017). Growing research on benchmarking

NbS for resilient cities with reference to improved liveability as per SDG 11 indicators framework is relevant. Strategic approach for identifying NbS that carefully supports maximum sub-goals of urban SDG 11 can improve outputs by developing synergies in diverse NbS assessment schemes (Wendling et al. 2018).

18.9 Conclusions and Way Forward

The combined effect of wind movement, urban green spaces (and infrastructure), and water bodies (that provide moisture into the atmosphere) needs to be considered for optimization as they are mutually interdependent, in urban design and planning (for air quality improvement, heat mitigation, stormwater management, etc.). The lack of guidelines for implementation of the NbS at urban level is an area of interest, where significant work needs to be done for achieving measurable and quantifiable work. The mechanism for a regular evaluation of any green projects as NbS and verifying their benefits to nature or the public is very much essential for urban planning and objective decision-making. The utilization of mathematical models with robust ground-based parameterizations will be of help in quantifying the evidence at the urban scale. Scientific studies that gather the evidences should be synthesized and cataloged with real case studies of NbS benefits and should be made available for decision-makers for mainstreaming of the NbS in urban design. There is a need to push further the studies on urban air quality improvement due to the green infrastructure, and the results should be harmonized for deriving conclusions from the multitude of studies performed on varying urban and meteorological settings. Last but not the least, mainstreaming the NbS and supporting their maintenance will require a viable economic model at individual city scale and need customization as per microclimate and species availability. Though promoting NbS for growing urban sprawls is gaining momentum with growing consideration for mainstreaming NbS in international dissuasions and policy dialogues, there are not enough discussions happening to address lack of availability of sufficient financial support for its implementation in developing and underdeveloped countries. Public expenses on NbS are relevant considering limited financial sufficiency of municipal corporations and city administrations. Mainstreaming NbS requires greater partnerships among diverse sectoral policy areas and multiple stakeholder groups. Leadership from private sector for developing public-private partnership (PPP) models of NbS and significant involvement of citizen including citizen scientists can enhance benefits for urban areas and largely ensure human well-being for urban dwellers.

Acknowledgments The authors sincerely thank the director of Council of Scientific and Industrial Research (CSIR)-National Environmental Engineering Research Institute (NEERI), Nagpur, for motivation. Manuscript processing services of Knowledge Resource Center of NEERI is acknowledged with the reference number **KRC/XXX**.

Conflict of Interest The authors declare no conflict of interest for this publication.

References

Abhijith KV, Kumar P, Gallagher J et al (2017) Air pollution abatement performances of green infrastructure in open road and built-up street canyon environments – a review. Atmos Environ 162:71–86. https://doi.org/10.1016/j.atmosenv.2017.05.014

Andersson E, Borgström S, McPhearson T (2017) Double insurance in dealing with extremes: ecological and social factors for making nature-based solutions last. 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 51–64

Armson D, Stringer P, Ennos AR (2013) The effect of street trees and amenity grass on urban surface water runoff in Manchester, UK. Urban For Urban Green 12:282–286. https://doi.org/10.1016/j.ufug.2013.04.001

Baik J-J, Kwak K-H, Park S-B, Ryu Y-H (2012) Effects of building roof greening on air quality in street canyons. Atmos Environ 61:48–55. https://doi.org/10.1016/j.atmosenv.2012.06.076

Balakrishnan K, Dey S, Gupta T et al (2019) The impact of air pollution on deaths, disease burden, and life expectancy across the states of India: the Global Burden of Disease Study 2017. Lancet Planet Health 3:e26–e39. https://doi.org/10.1016/S2542-5196(18)30261-4

Bennett EM, Cramer W, Begossi A, Cundill G, Díaz S, Egoh BN, Geijzendorffer IR, Krug CB, Lavorel S, Lazos E, Lebel L, Martín-López B, Meyfroidt P, Mooney HA, Nel JL, Pascual U, Payet K, Harguindeguy NP, Peterson GD, Prieur-Richard A-H, Reyers B, Roebeling P, Seppelt R, Solan M, Tschakert P, Tscharntke T, Turner B, Verburg PH, Viglizzo EF, White PC, Woodward G (2015) Linking biodiversity, ecosystem services, and human well-being: three challenges for designing research for sustainability. Curr Opin Environ Sustain 14:76–85. https://doi.org/10.1016/j.cosust.2015.03.007

Calfapietra C, Barbati A, Perugini L, Ferrari B, Guidolotti G, Quatrini A, Corona P (2015) Carbon mitigation potential of different forest ecosystems under climate change and various managements in Italy. Ecosyst Health Sustainab 1:1–9. https://doi.org/10.1890/EHS15-0023

Cameron RWF, Brindley P, Mears M et al (2020) Where the wild things are! Do urban green spaces with greater avian biodiversity promote more positive emotions in humans? Urban Ecosyst 23: 301–317. https://doi.org/10.1007/s11252-020-00929-z

Cascone S (2019) Green roof design: state of the art on technology and materials. Sustainability 11: 3020. https://doi.org/10.3390/su11113020

Chausson A, Turner B, Seddon D et al (2020) Mapping the effectiveness of nature-based solutions for climate change adaptation. Glob Change Biol 26:6134–6155. https://doi.org/10.1111/gcb.15310

Connop S, Vandergert P, Eisenberg B, Collier MJ, Nash C, Clough J, Newport D (2016) Renaturing cities using a regionally-focused biodiversity-led multifunctional benefits approach to urban green infrastructure. Environ Sci Pol 62:99–111

de Oliveira FL, Mell I (2019) Planning cities with nature: theories, strategies and methods. Springer, New York

Dhyani S, Thummarukuddy M (2016) Ecological engineering for disaster risk reduction and climate change adaptation. Environ Sci Pollut Res 23:20049–20052. https://doi.org/10.1007/s11356-016-7517-0

Dhyani S, Lahoti S, Khare S, Pujari P, Verma P (2018) Ecosystem based Disaster Risk Reduction approaches (EbDRR) as a prerequisite for inclusive urban transformation of Nagpur City, India. Int J Disaster Risk Reduct 32:95–105. https://doi.org/10.1016/j.ijdrr.2018.01.018

Dhyani S, Karki M, Gupta AK (2020a) Opportunities and advances to mainstream nature-based solutions in disaster risk management and climate strategy. In: Dhyani S, Gupta A, Karki M (eds) Nature-based solutions for resilient ecosystems and societies. Disaster resilience and green growth. Springer, Singapore. https://doi.org/10.1007/978-981-15-4712-6_1

Dhyani S, Gupta AK, Karki M (eds) (2020b) Nature-based solutions for resilient ecosystems and societies, Disaster resilience and green growth. Springer Nature, Cham. https://www.springer.com/gp/book/9789811547119

Giannakis E, Bruggeman A, Poulou D, Zoumides C, Eliades M (2016) Linear parks along urban rivers: perceptions of thermal comfort and climate change adaptation in Cyprus. Sustainability 8:1023. https://doi.org/10.3390/su8101023

Gill SE, Handley JF, Ennos AR, Pauleit S (2007) Adapting cities for climate change: the role of the green infrastructure. Built Environ 33:115–133. https://doi.org/10.2148/benv.33.1.115

Govindarajulu D (2014) Urban green space planning for climate adaptation in Indian cities. Urban Clim 10:35–41. https://doi.org/10.1016/j.uclim.2014.09.006

Gupta N, Mathew A, Khandelwal S (2019) Analysis of cooling effect of water bodies on land surface temperature in nearby region: a case study of Ahmedabad and Chandigarh cities in India. Egypt J Remote Sens Space Sci 22:81–93. https://doi.org/10.1016/j.ejrs.2018.03.007

Imam AUK, Banerjee UK (2016) Urbanisation and greening of Indian cities: problems, practices, and policies. Ambio 45:442–457. https://doi.org/10.1007/s13280-015-0763-4

Jeanjean APR, Hinchliffe G, McMullan WA et al (2015) A CFD study on the effectiveness of trees to disperse road traffic emissions at a city scale. Atmos Environ 120:1–14. https://doi.org/10.1016/j.atmosenv.2015.08.003

Jiang S, Lee X, Wang J, Wang K (2019) Amplified urban heat islands during heat wave periods. J Geophys Res Atmos 124:7797–7812. https://doi.org/10.1029/2018JD030230

Kadaverugu R (2015) Framework for mathematical modeling of Soil-Tree system. Model Earth Syst Environ 1:17. https://doi.org/10.1007/s40808-015-0017-2

Kadaverugu A, Kongre DN, Goyal R, Gupta AB (2011) Urban heat island in Rajasthan. In: Challenges of urbanization in the 21st century. Concept Publishing Company, Hyderabad, pp 251–258

Kadaverugu R, Sharma A, Matli C, Biniwale R (2019) High resolution urban air quality modeling by coupling CFD and mesoscale models: a review. Asia-Pac J Atmos Sci. https://doi.org/10.1007/s13143-019-00110-3

Kadaverugu A, Nageshwar Rao C, Viswanadh GK (2021a) Quantification of flood mitigation services by urban green spaces using InVEST model: a case study of Hyderabad city, India. Model Earth Syst Environ. https://doi.org/10.1007/s40808-020-00937-0

Kadaverugu R, Gurav C, Rai A et al (2021b) Quantification of heat mitigation by urban green spaces using InVEST model—a scenario analysis of Nagpur City, India. Arab J Geosci 14:82. https://doi.org/10.1007/s12517-020-06380-w

Keeley M (2011) The Green Area Ratio: an urban site sustainability metric. J Environ Plan Manag 54:937–958. https://doi.org/10.1080/09640568.2010.547681

Lahoti S, Kefi M, Lahoti A, Saito O (2019) Mapping methodology of public urban green spaces using GIS: an example of Nagpur City, India. Sustainability 11:2166. https://doi.org/10.3390/su11072166

Larsen L (2015) Urban climate and adaptation strategies. Front Ecol Environ 13:486–492. https://doi.org/10.1890/150103

Majidi AN, Vojinovic Z, Alves A, Weesakul S, Sanchez A, Boogaard F, Kluck J (2019) Planning nature-based solutions for urban flood reduction and thermal comfort enhancement. Sustainability 11:6361. https://doi.org/10.3390/su11226361

Makido Y, Hellman D, Shandas V (2019) Nature-based designs to mitigate urban heat: the efficacy of green infrastructure treatments in Portland, Oregon. Atmosphere 10:282. https://doi.org/10.3390/atmos10050282

Masiero É, de Souza LCL (2015) Among winds, water bodies and urban elements. http://www.meteo.fr/icuc9/LongAbstracts/udc3-3-6131517_a.pdf. Accessed 19 Feb 2021

Nowak DJ, Crane DE, Stevens JC (2006) Air pollution removal by urban trees and shrubs in the United States. Urban For Urban Green 4:115–123. https://doi.org/10.1016/j.ufug.2006.01.007

Nowak DJ, Greenfield EJ, Hoehn RE, Lapoint E (2013a) Carbon storage and sequestration by trees in urban and community areas of the United States. Environ Pollut 178:229–236. https://doi.org/10.1016/j.envpol.2013.03.019

Nowak DJ, Hirabayashi S, Bodine A, Hoehn R (2013b) Modeled PM2.5 removal by trees in ten U.S. cities and associated health effects. Environ Pollut 178:395–402. https://doi.org/10.1016/j.envpol.2013.03.050

OECD (2016) The economic consequences of outdoor air pollution. OECD Publishing, Paris. https://www.oecd-ilibrary.org/environment/the-economic-consequences-of-outdoor-air-pollution_9789264257474-en. Accessed 22 Feb 2021

Padigala B (2012) Urbanization and changing green spaces in Indian cities (Case study - city of Pune). Int J Geol Earth Environ Sci 2:148–156

Pascal M, Corso M, Chanel O et al (2013) Assessing the public health impacts of urban air pollution in 25 European cities: results of the Aphekom project. Sci Total Environ 449:390–400. https://doi.org/10.1016/j.scitotenv.2013.01.077

Peck S, Kuhn M (2020) Design guidelines for green roofs. https://www.eugene-or.gov/DocumentCenter/View/1049/Design-Guidelines-for-Green-Roofs. Accessed 16 Feb 2021

Peng J, Liu Q, Xu Z et al (2020) How to effectively mitigate urban heat island effect? A perspective of waterbody patch size threshold. Landsc Urban Plan 202:103873. https://doi.org/10.1016/j.landurbplan.2020.103873

Perez G, Perini K (2018) Nature based strategies for urban and building sustainability. Butterworth-Heinemann, Oxford, UK

Pugh TAM, MacKenzie AR, Whyatt JD, Hewitt CN (2012) Effectiveness of green infrastructure for improvement of air quality in urban street canyons. Environ Sci Technol 46:7692–7699. https://doi.org/10.1021/es300826w

Qiao X-J, Liao K-H, Randrup T (2019) Sustainable stormwater management: a qualitative case study of the Sponge Cities initiative in China. Sustain Cities Soc 53:101963. https://doi.org/10.1016/j.scs.2019.101963

Raymond CM, Frantzeskaki N, Kabisch N, Berry P, Breil M, Nita MR, Geneletti D, Calfapietra C (2017) A framework for assessing and implementing the co-benefits of nature-based solutions in urban areas. Environ Sci Pol 77:15–24. https://doi.org/10.1016/j.envsci.2017.07.008

Reynolds C, Escobedo F, Clerici N, Zea-Camaño J (2017) Does "greening" of neotropical cities considerably mitigate carbon dioxide emissions? The case of Medellin, Colombia. Sustainability 9:785. https://doi.org/10.3390/su9050785

Rozos E, Makropoulos C, Maksimović Č (2013) Rethinking urban areas: an example of an integrated blue-green approach. Water Supply 13:1534–1542. https://doi.org/10.2166/ws.2013.140

Salmond JA, Williams DE, Laing G et al (2013) The influence of vegetation on the horizontal and vertical distribution of pollutants in a street canyon. Sci Total Environ 443:287–298. https://doi.org/10.1016/j.scitotenv.2012.10.101

Santos T, Tenedório J, Gonçalves J (2016) Quantifying the city's green area potential gain using remote sensing data. Sustainability 8:1247. https://doi.org/10.3390/su8121247

Seddon N, Turner B, Berry P et al (2019) Grounding nature-based climate solutions in sound biodiversity science. Nat Clim Change 9:84–87. https://doi.org/10.1038/s41558-019-0405-0

Speak AF, Rothwell JJ, Lindley SJ, Smith CL (2012) Urban particulate pollution reduction by four species of green roof vegetation in a UK city. Atmos Environ 61:283–293. https://doi.org/10.1016/j.atmosenv.2012.07.043

Steeneveld GJ, Koopmans S, Heusinkveld BG, Theeuwes NE (2014) Refreshing the role of open water surfaces on mitigating the maximum urban heat island effect. Landsc Urban Plan 121:92–96. https://doi.org/10.1016/j.landurbplan.2013.09.001

Stone B, Vargo J, Liu P et al (2014) Avoided heat-related mortality through climate adaptation strategies in three US cities. PLoS One 9:e100852. https://doi.org/10.1371/journal.pone.0100852

Suárez M, Manuel BFD, Méndez-Fernández L, Onaindia M, Gómez-Baggethun E (2018) Nature-based solutions and resilience as complementary strategies for urban governance and planning: a review of assessment methodologies. 1. https://doi.org/10.3390/ifou2018-05959

Sun R, Chen L (2012) How can urban water bodies be designed for climate adaptation? Landsc Urban Plan 105:27–33. https://doi.org/10.1016/j.landurbplan.2011.11.018
Tan PY, Jim CY (2017) Greening cities: forms and functions. Springer, New York
Tan PY, Sia A (2005) A pilot green roof research project in Singapore. Third annu. green. rooftops sustain. commun. conf. http://citeseerx.ist.psu.edu/viewdoc/summary?doi=10.1.1.461.2129. Accessed 19 Feb 2021
Tiwari A, Kumar P, Kalaiarasan G, Ottosen T-B (2020) The impacts of existing and hypothetical green infrastructure scenarios on urban heat island formation. Environ Pollut 2020:115898. https://doi.org/10.1016/j.envpol.2020.115898
Tolderlund L (2010) Design guidelines and maintenance manual for green roofs in the semi-arid and arid west. https://www.epa.gov/sites/production/files/documents/GreenRoofsSemiAridAridWest.pdf. Accessed 16 Feb 2021
Tong Z, Whitlow TH, MacRae PF et al (2015) Quantifying the effect of vegetation on near-road air quality using brief campaigns. Environ Pollut 201:141–149. https://doi.org/10.1016/j.envpol.2015.02.026
UNDESA (2018) UN Department of Economic and Social Affairs. https://www.un.org/development/desa/en/news/population/2018-revision-of-world-urbanization-prospects.html. Accessed 6 Jul 2018
Ward K, Lauf S, Kleinschmit B, Endlicher W (2016) Heat waves and urban heat islands in Europe: a review of relevant drivers. Sci Total Environ 569–570:527–539. https://doi.org/10.1016/j.scitotenv.2016.06.119
Wendling LA, Huovila A, zu Castell-Rüdenhausen M, Hukkalainen M, Airaksinen M (2018) Benchmarking nature-based solution and smart city assessment schemes against the sustainable development goal indicator framework. Front Environ Sci 6. https://doi.org/10.3389/fenvs.2018.00069
WHO (2018) WHO Global Ambient Air Quality Database (update 2018). WHO. http://www.who.int/airpollution/data/cities/en/. Accessed 12 Jun 2018
Wu Y, Wang W, Liu C et al (2020) The association between long-term fine particulate air pollution and life expectancy in China, 2013 to 2017. Sci Total Environ 712:136507. https://doi.org/10.1016/j.scitotenv.2020.136507
Yao X, Zhao M, Escobedo FJ (2017) What causal drivers influence carbon storage in Shanghai, China's urban and peri-urban forests? Sustainability 9:577. https://doi.org/10.3390/su9040577
Yu Z, Yang G, Zuo S et al (2020) Critical review on the cooling effect of urban blue-green space: a threshold-size perspective. Urban For Urban Green 49:126630. https://doi.org/10.1016/j.ufug.2020.126630

Rakesh Kadaverugu is an Environmental Engineer working as Senior Scientist in CSIR-National Environmental Engineering Research Institute (CSIR-NEERI), Nagpur, India.

Shalini Dhyani is a Senior Scientist at Critical Zone Group (CZO) of Water Technology and Management Division (WT&MD), CSIR-National Environmental Engineering Research Institute (CSIR-NEERI), Nagpur, India.

Rajarshi Dasgupta is a Senior Policy Researcher in the Institute for Global Environmental Strategies (IGES), Kanagawa, Japan.

Pankaj Kumar is a Senior Policy Researcher in the Institute for Global Environmental Strategies (IGES), Kanagawa, Japan.

Chandrasekhar Matli is a Professor at the Civil Engineering Department of the National Institute of Technology (NIT), Warangal, Telangana, India.

Disaster Risks and Resilience of Urban Bangladesh: Role of Blue-Green Infrastructure

19

Gulsan Ara Parvin, Md. Esraz-Ul-Zannat, Reazul Ahsan, and Ishrat Islam

Abstract

Bangladesh is ranked as the fifth most disaster-prone country in the world. It is also the eighth most populous in the world, where the annual rate of urbanization is around 3%, which is one of the highest in South Asia. In this densely populated disaster-prone country, rapid and unplanned urbanization is causing severe changes to vegetation, water bodies, and soil properties. These changes are heightening disaster risks and vulnerabilities of urban areas. There needs a proper balance among the blue (water), green (vegetation), and gray (built) space to ensure quality living in an urban area. However, in Bangladesh, especially in metropolitan cities like Dhaka and Chittagong, due to rapid and unplanned urbanization, blue and green spaces are decreasing tremendously. From 2006 to 2016, the agricultural land cover of Dhaka was reduced by 16%. Therefore, urban areas of Bangladesh, especially metropolitan cities, are facing different hazards and risks. Though environmental challenges are getting attention in the recent

G. A. Parvin (✉)
Rural Planning and Sustainable Rural Development, Graduate School of Global Environmental Studies, Kyoto University, Osaka, Japan

Collage of Policy Science, Ritsumeikan University, Osaka, Japan
e-mail: parvin.gurusanara.7x@kyoto-u.ac.jp

M. Esraz-Ul-Zannat
Faculty of Civil Engineering, Department of Urban and Regional Planning (URP), Khulna University of Engineering and Technology (KUET), Khulna, Bangladesh

R. Ahsan
Department of City and Metropolitan Planning, The University of UTHA, Incheon, South Korea

I. Islam
Department of Urban and Regional Planning, Bangladesh University of Engineering and Technology (BUET), Dhaka, Bangladesh

S. Dhyani et al. (eds.), *Blue-Green Infrastructure Across Asian Countries*,
https://doi.org/10.1007/978-981-16-7128-9_19

planning processes, the balanced incorporation of blue-green infrastructures (BGI) in urban planning practices is not yet noticed. Different sociopolitical, economic, and institutional issues are associated with it. This study intends to examine the trend of changes in BGI in metropolitan cities and how different factors including planning policy and practices are contributing to shaping these changes. Thus, it highlights the significance and role of BGI in urban disaster risk reduction and resilience of urban Bangladesh.

Keywords

Disaster risks · Resilience · Urbanization · Blue-green infrastructure · Bangladesh

19.1 Introduction

Increasing population densities and consequent urbanization are critical issues of the world, especially in Africa and Asia, where urbanization has accelerated in the last few decades (Liu et al. 2020). It is reported that already in 2020, over 55% of the world population was urbanized and by 2050 approximately 68% of the world's population will live in cities (Welford and Yarbrough 2021). Over the past decades, the global growth rate of urban land is 80%, while the population growth rate is 52%. To accommodate the augmented population and to provide services to the increased population, urban lands are rapidly encroaching agricultural areas and green and blue spaces within and around the cities. However, according to the urban development experts, green spaces, green infrastructure, and blue spaces are essential for biodiversity, ecological environment, and socio-economic development (Vargas-Hernández and Zdunek-Wielgołaska 2021; Cai et al. 2021). Green spaces (areas dominated by vegetation cover) and blue spaces (areas dominated by surface water bodies or watercourses) of cities are under threat from increasing population densities (Gunawardena et al. 2017) despite their substantial role in securing biological diversity, ecosystem stability, and human comfortability (Kanniah 2017). In addition to the socio-economic and environmental benefits, urban blue-green infrastructures (BGI) are recognized as crucial for disaster risk reduction. Existing literature argues that green spaces have emerged as a potential option to reduce urban flood risks of cities (Bai et al. 2018; Kim et al. 2016; Šakić Trogrlić et al. 2018; Liu et al. 2019). Also, BGI is considered as a tool to mitigate urban heat island intensity (Gunawardena et al. 2017).

Despite having a crucial role and importance all over the world, especially in Asia, rapid urbanization is happening at the expense of essential green and blue spaces (Liu et al. 2020). In Asia, Bangladesh is one of the fastest-growing urbanized countries, where the annual rate of urbanization is 3.05% (World Bank 2020). It is estimated that by 2050 about 57% of Bangladesh's population will live in urban areas (Bajracharya and Sultana 2020). In Bangladesh, which is the eighth most populous and fifth most disaster-prone country in the world, rapid and unplanned urbanization is causing severe changes in vegetation, water bodies, and bare soil

(Hassan 2017). These changes are enhancing disaster risks and vulnerabilities of the urban areas. Urban areas are a composition of blue (water), green (vegetation), and gray (built) spaces. There needs a proper balance among these three spaces to ensure better living and quality of life in an urban area. However, in Bangladesh, due to rapid and unplanned urbanization, blue and green spaces are tremendously decreasing which leads to different hazards and risks, especially in metropolitan cities. Considering all these issues, this study aims to construct an overview of disaster risks of urban Bangladesh and to explore how the risks and vulnerabilities are increasing over the period with the change of blue-green infrastructure (BGI). This study intends to examine the trend of changes in BGI in metropolitan cities and how different factors, planning policies, and practices are contributing to shaping these changes. Thus, it highlights the significance and role of BGI in urban disaster risk reduction and resilience of urban Bangladesh.

19.2 Disaster Risks and Vulnerabilities in Urban Bangladesh

Rapid urbanization is often blamed as a driving force of urban hazards and disasters. Different natural and man-made hazards and disasters, such as urban flooding, sea-level rise, drought, geo-hazards, and heat waves, are increasing all over the world (Tauhid 2018, Ramiaramanana and Teller 2021). Sun et al. (2020) stated that rapid population growth, unplanned urbanization, and climate extremes are the major triggering factors behind frequent urban disasters in recent years. It is more than a decade since UN-Habitat (2007) warned that rapid urbanization and global environmental change are turning different human settlements into potential hot spots for disaster risk. Literature supports that urbanization is linked with geo-hazards which can cause loss and damage in life, property, and environment (Cui et al. 2019). Sharma et al. (2011) also argued that every process of rapid urbanization matters for high risks. This rapid urbanization is gradually becoming a key concern of disaster risk reduction and urban resilience efforts all over the world, especially in Asia (Shaw et al. 2016).

In Asia, Bangladesh is experiencing an unplanned and rapid rate of urbanization which is one of the highest in the world (Hassan 2017; Bashar and Rashid 2012). This rapid and unplanned urbanization is considered as the key cause of urban risks and vulnerabilities in Bangladesh. The geographical location of Bangladesh is also a contributing factor that has enhanced geological and climatic disaster risks and vulnerabilities of most of all cities of Bangladesh. Furthermore, poverty, low income, and rural-urban migration are also aggravating urban disaster risks and vulnerabilities in the context of Bangladesh (Parvin et al. 2016). Among these risks and vulnerabilities, urban flooding and waterlogging are gradually turning into a critical issue. Since cities are growing on flood-prone low-lying areas by destroying green and blue spaces, urban flooding is becoming a consistent problem in many cities of Bangladesh (Parvin and Shaw 2011; Moniruzzaman et al. 2021).

Dhaka, the capital of Bangladesh, is highly vulnerable to flooding during the monsoon season due to heavy rainfall (Parvin and Shaw 2011). Studies corroborate that flood-inundated areas of Dhaka are rapidly growing. From the year 1978 to 2018, the high runoff area of Dhaka City has increased from 24% to 57% (Moniruzzaman et al. 2021). Another study (Sayed and Haruyama 2016) also claimed that 70% of the Greater Dhaka area is under moderate to very high flood hazard zone. Every year, during the monsoon, waterlogging and flooding are common and cause serious suffering for the residents of Dhaka. The rapid unplanned growth of Dhaka by destroying green spaces and water bodies is identified as the principal reason for such flooding (Moniruzzaman et al. 2021; Parvin and Shaw 2011). Along with flooding, a study claims that the magnitude of land surface temperature (LST) intensity of urban heat island (UHI) is higher in Dhaka compared to some other cities in South Asia (Maharjan et al. 2021). Flooding, waterlogging, high LST, and intensity of UHI are the main hazard risk and vulnerabilities of Dhaka. Due to high population density, any risk or vulnerability-related hazard might turn into a catastrophe. Diminishing BGI of Dhaka is directly blamed as the main reason for flooding, waterlogging, and high LST and intensity of UHI. Apart from these, air pollution and associated health hazards (Siddiqui et al. 2020), geo-hazard and environmental hazard (Rashied and Mahmud 2019), and fire (BFSCD 2020) are also emerging as crucial hazardous events in Dhaka City, and all these are indirectly associated with BGI balance of the city.

Along with capital city Dhaka, all other small city corporations, municipalities, and small towns of Bangladesh are prone to different hazards and vulnerabilities which are directly or indirectly associated with rapid and unplanned urbanization by destroying BGI. From the perspective of land coverage, population, and economic activities, Chittagong City is the second largest city of Bangladesh (Mia et al. 2015), which is repeatedly affected by devastating landslides in recent years that caused casualties, physical damages, and loss. In addition, this situation is aggravated by increased population pressure, rapid urban growth, improper land use, weak governance, hill cutting, indiscriminate deforestation, and agricultural practices (Ahmed and Dewan 2017). A recent study by Hassan and Nazem (2016) also warns about the emerging high risks of landslide, flooding, and waterlogging of Chittagong City due to land cover changes and unplanned urban growth. Chittagong City dwellers are experiencing increasing waterlogging and consequent economic losses, health problems, and sufferings in daily life (Akter et al. 2017). Other studies are also implying high concern to the severe and regular waterlogging problem faced by the Chittagong City dwellers, and these studies are repeatedly pointing to unplanned and rapid urbanization, hill cut, deforestation, and land cover changes as the reason behind such sufferings of the people (Papry and Ahmed 2015; Akter et al. 2017). Along with floods, cyclones, and tornados, Chittagong has a long history of earthquakes. Chittagong and its surrounding hilly districts are located in a moderately seismic zone.

Urban flooding and waterlogging, which are directly related to urbanization, and land cover changes of cities are also key problems in other city corporations and small towns of Bangladesh. A study claims that Khulna, the third largest city of Bangladesh (Alam and Mondal 2019), is also highly vulnerable to the waterlogging problem. Every year, the city dwellers face waterlogging problems which are gradually increasing (Rahman et al. 2009; Sarkar et al. 2021). Being a coastal city, Khulna is highly vulnerable to climate change–induced risks and vulnerabilities, which are aggravating by accommodating climate change and disaster migrants from surrounding rural areas. To accommodate the increased population and supporting services and facilities, the city is expanding in the low-lying areas by destroying the natural drainage systems. Therefore, along with city residents, experts identified that encroachment of the canals, unplanned development, narrow artificial drains, and conversion of natural drains to built-up surfaces are enhancing waterlogging of Khulna City (Sarkar et al. 2021).

After Dhaka, Chittagong, and Khulna, Rajshahi City is the fourth largest city of Bangladesh (Hamidul Bari et al. 2012). This city's climatic condition is characterized by monsoons, high temperature, and humid and moderate rainfall. The annual rainfall of the city is about 100 mm less than the national average. Urban flooding or waterlogging is not yet a critical issue for this city. However, land surface temperature (LST) is increasing in the city, and hence, urban heat island (UHI) effects are becoming frequent. A recent study forecasted that if Rajshahi City continues to grow like its present unplanned and rapid way, 70% of the city corporation area will have to face more than 38 °C temperature by 2029 (Kafy et al. 2020). Environmental degradation, water pollution, waste management, etc. are the other risks and challenges for Rajshahi City. But academic research related to different hazards, risks, and vulnerabilities of Rajshahi City Corporation are not so available.

Studies related to disaster risks and vulnerabilities of small cities and towns are also not common in Bangladesh. However, some local-level studies identified the association between urbanization and waterlogging problems of small municipalities and towns of Bangladesh. These studies reported that in the rainy season, rainfall-induced waterlogging and problems of city dwellers are becoming critical problems of the Noakhali Pourashava area (Rahaman et al. 2020), Sylhet (Rahman et al. 2009), Pabna (Hasan et al. 2018), Tangail (Latif et al. 2016), Jessore (Adri and Islam 2010), and Cox's Bazar (Anisha and Hossain 2014). In addition to these, after analyzing the location of the urban centers, it is found that Mymensingh and Sylhet are the highest-level earthquake-vulnerable cities (Zone 1). However, due to high density and unplanned growth, Dhaka and Chittagong are cities of Bangladesh that are considered as the highest-level earthquake-risk cities, despite their position in Zone 2 (Parvin et al. 2013).

Urban flooding; waterlogging; urban heat island; geo-hazards like landslides, earthquakes, and liquefaction; and even fire hazards of different cities of Bangladesh are somehow related to rapid urbanization and change of land use and land cover of cities. Especially, the transformation of blue and green spaces into the built area is identified as the key factors of urban risk and vulnerabilities by different studies. Hence, it is essential to understand the status of BGI in urban growth, planning, and practices.

19.3 Urban Growth and Blue-Green Infrastructures (BGI) in Urban Bangladesh

19.3.1 Urbanization in Bangladesh

Globalization, change in income patterns, and natural disasters will cause rapid urbanization in most developing nations (Hossain 2013). It also projected that 80% of the world's largest cities will be in Asia, Africa, and Latin America and that the majority of the population of developing countries will be living in urban areas by 2030. Three out of five will be in Asia and Africa, with a total urban population of five billion by 2030. Dhaka, Bangladesh's capital, has been growing at an estimated rate of 4% annually since 1971, while national population growth has been 2.4% since 1971 (Ahmed and Meenar 2018). Dhaka is now the world's leading megacity, with approximately 18 million people (UN-Habitat 2020). The city, which was ranked the 24th largest megacity in the world in 1990, is currently in 11th place and is expected to be the sixth largest city with a population of 27.37 million by 2030 (Ahmed and Meenar 2018). The increasing population in the capital clearly reflects the rapid urbanization and concentration of population in the capital city of Bangladesh.

Urbanization plays a vital role in the growth and development of any country including Bangladesh. The modern urbanization process started in Bangladesh at the end of the British colonial period and gained momentum in independent Bangladesh (Rouf 2018). Urbanization was increasing invariably, and in 1941, it was increased to 3.66% from 2.43% in 1901, and the number of urban centers increased to 59 from 48 (BBS 2014). In 1974, the rate of urbanization was reached at 8.78% (Rouf and Jahan 2017). The urban population grew after 1974, mainly as a result of rural-urban migration, influenced by economic factors but also caused by natural dangers. Figure 19.1 denotes that the urban population of Bangladesh increased from 7.9% in 1971 to 38.2% in 2020 growing at an average annual rate of 3.29% (Moore 2021).

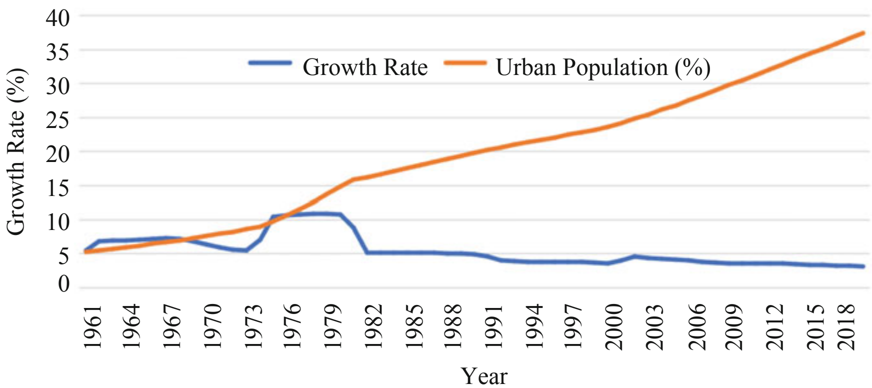


Fig. 19.1 Urban growth during 1960 and 2019. (Source: The World Bank 2021)

Table 19.1 Urban population for major cities in Bangladesh

Name of the city	Population			Population Growth rate (2011)	Density (population/km^2) (2011)
	1991	2001	2011		
Dhaka	3,612,850	5,333,571	6,970,105	+2.67	55,169
Chittagong	1,392,958	2,023,489	2,582,401	+2.43	16,618
Khulna	663,340	770,498	663,342	−1.47	13,107
Rajshahi	294,056	388,811	449,756	+1.45	4628
Sylhet	117,396	263,197	479,837	+6.10	18,107
Rangpur	191,398	241,310	294,265	+1.98	5805
Barisal	170,232	192,810	328,278	+5.39	5655
Mymensingh	188,713	227,201	258,040	+1.26	11,875
Gazipur	...	738,000	1,592,053	+7.88	5018
Narayanganj	276,549	369,954	709,381	+6.63	15,197
Comilla	135,313	166,519	326,386	+6.86	7709

Source: BBS (1991, 2001, 2014)

In Bangladesh, there are 37 cities including the city corporations with a population of over 100,000 (BBS 2014). The rest of the urban areas are smaller towns including 188 *upazila* headquarters (nonmunicipality) and some *Union Parishad* headquarters. More than 60% of Bangladesh's urban population is concentrated mainly in four metropolitan cities – Dhaka, Chittagong, Khulna, and Rajshahi (The Daily Dhaka Tribune 2018). Dhaka itself shares more than 40% of the total urban population, and the remaining 20% live in Chittagong, Rajshahi, the Khulna. Table 19.1 shows the population for the years 1991, 2001, and 2011 with population growth rate and population density for the 12 city corporations of Bangladesh. The urban population density in Bangladesh is 23,738/km^2, which is three times the density in rural areas of the country. Only in Dhaka, the population density is 47,400/km^2 (Amin 2018). This high population density and rapid urban growth are rapidly encroaching green and blue spaces of urban Bangladesh. Uncontrolled and unplanned growth of urban areas are consuming the BGI of almost all cities of Bangladesh, and thus they are gradually becoming the hub of risks and hazards.

19.3.2 BGI in Urban Bangladesh

Blue, green, and gray infrastructures are the crucial and inevitable parts of the city to function properly where a balance among these infrastructures is indispensable. Blue infrastructure mainly refers to the water elements like rivers, canals, ponds, wetlands, floodplains, and water treatment facilities. Green infrastructure commonly denotes trees, lawns, hedgerows, parks, fields, forests, etc. Gray infrastructure refers to buildings, roads, and other urban constructions.

Almost all major cities of Bangladesh were developed on the banks of the major rivers, namely, Padma, Meghna, Karnafully, Bhairab, and Surma. During the colonial period, cities were developed as commercial and administrative hubs. Over time, cities kept expanding as the commercial activities increased and as per administrative priorities. On the other hand, the population was gradually increasing, and cities became the hub of opportunities for employment, civic facilities, and amenities, which provoke people to migrate from the rural areas. To accommodate the growing population and to provide the services and facilities, urban expansion in the form of building houses, roads, shops, industries, etc. is occurring invariably in most of the major cities. Cities accommodate the increased population through the transformation of land from nonurban areas to built-up areas. In the existing urban areas, fallow land is occupied by physical infrastructures, and water bodies are filled up to establish new infrastructures. Further, agriculture as a major source of green infrastructure is continuing to decrease with the expansion of cities. The rate of transformation and decline of green and blue spaces is different for the various urban areas in Bangladesh, which are stated in the following.

19.3.2.1 Dhaka City

It has been observed that in Dhaka City, water bodies, both canals and ponds, and flood flow zone declined significantly over the years. A study showed that the water bodies and lowlands were reduced by 32.57% and 52.58%, respectively, during 1960 and 2008 (Islam et al. 2010). Green infrastructures in the form of open spaces, agricultural lands, parks, and playgrounds have also lessened gradually. It is reported in Dhaka Metropolitan Development Plan (DMDP) (RAJUK 2016) that agricultural areas were reduced dramatically from 46% to 30%, and water bodies decreased from around 8% to 5% in 10 years. Figure 19.2 demonstrates that agricultural lands declined significantly and sharply for the Part A of the DMDP area. Surprisingly, it claimed that the water body area stepped up to 2%, which is deemed to be a positive impact on land-use transformation. The situation is worse in the western part of the DMDP area in terms of decreasing the agricultural land and water bodies.

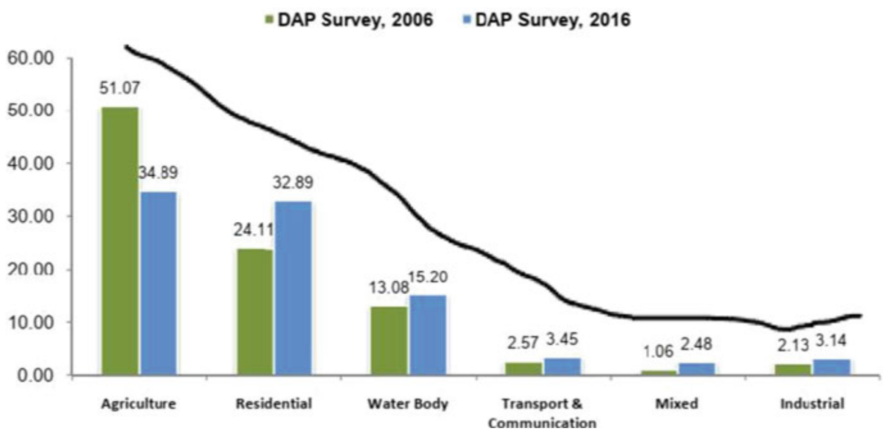


Fig. 19.2 Comparison of major land-use changes between 2006 and 2016 (within Part A). (Source: RAJUK 2010, 2016)

However, the draft Detailed Area Plan (2016–2035) of Dhaka City proposed to preserve around 30% agricultural land, which is undoubtedly a major source of green infrastructure along with the other green features like parks, playgrounds, and 8% water bodies, and 2.5% open space and forests.

19.3.2.2 Chittagong City

Chittagong City has similarities in various aspects with Dhaka City. Several studies argued that water bodies and green spaces of the city are declining alarmingly over the years. As per the District Fisheries Department, the city had 19,250 water bodies in 1991. After 15 years, in 2006, the number of water bodies under the Chittagong City Corporation (CCC) area is reduced to 4700 (CDA 2008), which comprised 5.5% of the total land area. The rate of disappearing water bodies is alarming due to the transformation of uses for many reasons. On the other hand, development plans under Chittagong Development Authority (CDA 2008) recognized that there is a scarcity of open spaces and greeneries in the city. The city has its special features, the green hills, which are the main sources of its beauty. Unfortunately, cutting off the green hills depletes the greeneries and leads to biodiversity loss. A study showed that the maximum hill cutting was at 63.6% in Chittagong City at Khulshi area and the lowest from Lallchan Bazar (33.0%) (Hassan et al. 2015).

19.3.2.3 Khulna City

Khulna City is situated on the western bank of the Bhairab-Rupsha River. The development plan in the year 2001, prepared by Khulna Development Authority (KDA), admitted Khulna City's planning area as 233.35 km^2. The city is poorly drained and approximately 2.5 m above mean sea level (Esraz-Ul-Zannat and Islam 2015). Like Dhaka and Chittagong, Khulna City is too experiencing a decline in water bodies and green spaces. Over the years, these features are diminishing significantly due to the increasing pressure of the urban population without efficient planning and control. According to a survey conducted in 2012 by the consultants under the Detailed Area Plan (KDA 2018), a significant land cover of the Khulna Development Authority area consists of water bodies (10.50%), urban green space (0.64%), and agricultural land (36%). However, the scenario is different for Khulna City Corporation area which has remarkably less area covered by agriculture (13%), water body (approximately 6%), and urban green space (0.30%). The major sources of water bodies of the city are two rivers, nearly thousands of ponds, and about twenty canals. Area covered by water bodies and open spaces with greeneries is varying with time especially in the last 20 years. Agricultural land which is the major source of green infrastructure decreased by about 49% between 1998 and 2012 (KDA 2018). A study claimed that vegetation together with the open agricultural field is dominant in the city and it has diminished from 69% in 2005 to 52% in 2019 due to rapid urbanization along with other factors (Esraz-Ul-Zannat et al. 2020). The study also showed that there was an increasing trend of the water body, which is augmented from 7% to 14% in the last 14 years due to the transformation of agricultural land into water bodies for shrimp culture, retention of water during the rainy seasons, and inundation (Fig. 19.3).

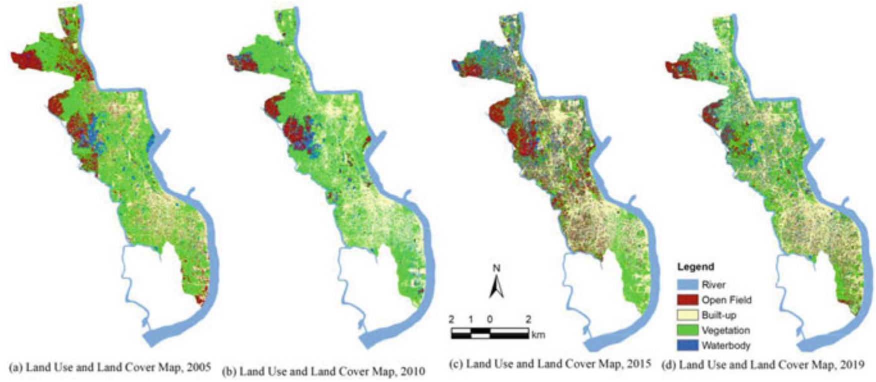


Fig. 19.3 Land use-land cover changes for 2005, 2010, 2015, and 2019 for Khulna City. (Source: Esraz-Ul-Zannat et al. 2020)

19.3.2.4 Rajshahi City

Rajshahi, also called the Silk City or the City of Education, is one of the major metropolitan cities in Bangladesh. The city officially started its development control over an area of 127 km^2 through the preparation of the Master Plan in 1984. There was a master plan in 1968 for Rajshahi which indicated only the major proposals, and there was no indication of specific proposals and implementation strategies. Though the Master Plan in 1984 was more comprehensive compared to the plan in 1968, it also focused on future urban growth with major proposals. Blue and green infrastructures were not studied and included in the Master Plan at that time. Rajshahi Development Authority (RDA), for the first time in Bangladesh, prepared the development plan title “Rajshahi Metropolitan Development Plan (RMDP), 2004–2024” using modern planning techniques and tools, especially surveying and mapping technologies for an area of 364.19 km^2. Rajshahi City Corporation area is within the plan, which encompasses approximately 48.06 km^2. Specific land uses were characterized in this plan, which reflects water bodies and green open spaces along with other land uses. As per the Physical Feature Survey conducted by the consultant in 2003, the RDA planning area encompasses about 43% agricultural land, 18% water body, and 0.16% open space, where the city corporation area covers 19%, 11%, and 1.10%, respectively. Due to the slow urbanization rate and lack of road networks, land use transformation from agriculture is tardy. The development plan anticipated the vast agricultural land to remain unchanged for a long time (RDA 2004). There are various types of open spaces including parks for passive recreation, amusement parks, and areas of public gathering for recreational purposes. The embankment on the Padma River serves as a major open space. In the city corporation area, a large number of water bodies, mostly ponds, are found (about 1050 in number). However, the trend of water bodies and greeneries is getting downward in Rajshahi like other cities of Bangladesh. A study asserted that the city has lost its 35.64 acres of open spaces between 2008 and 2018 (Kafy et al. 2018). Another study claimed that 14% of water bodies were diminished due to rapid urbanization within 25 years (1992–2017) within the city corporation area (Kafy et al. 2019).

19.4 BGI in Urban Planning and Practice

In Bangladesh, accurate capturing of physical features and their digital storage started after 2000 with the advancement of technology especially surveying and mapping for the development plan projects. Blue and green infrastructures were not prioritized separately in the development plans in past. In other words, these features were included along with other features like residential, commercial, and industrial. Adequate consideration was not given to ensure the maximum environmental benefits. There was also a lack of proper attention on the risks and vulnerabilities of cities during plan preparation. Nevertheless, the scenario is altering steadily. Drainage and environmental component are added nowadays in the plan. The environmental benefits of the BGI are of much concern in the recent planning processes.

Comprehensive planning practices started from the 1960s in Bangladesh with the preparation of the Master Plan in 1959 for Dhaka City for the rapid anticipated urban growth. But it was a blueprint plan and static in nature over the planning periods. Consequently, this plan cannot be overstated; however, the plan is quintessential regarding many aspects especially its comprehensiveness. The plan felt the necessity of the green spaces and recommended different amounts of open spaces for different areas, e.g., Hajiganj Fort area, Sonakanda Fort area, Bandar Housing area, and old parts of Dhaka. Overall, the plan recommended three to four acres (two acres for public parks and two acres for community areas) per 1000 people for Dhaka City (Dhaka Improvement Trust 1959). In the case of water bodies, the plan showed the pattern of land uses and zoning, water bodies, and flood-prone areas. However, there was a lack of study related to water bodies like ponds and lakes. Only a few proposals were made for waterfront development, the coexistence of green space, and water bodies.

DMDP Structure Plan (1995–2015) for Dhaka City was a strategic plan which was a more comprehensive plan than the previous plans. There were a couple of planning policies with a focus on watershed management. The plan recognized the agricultural area, high-value agricultural land, flood flow zone, main flood flow zone, sub-flood flow zone, and proposed water retention pond, which comprised 66% of the total planning area (RAJUK 1997). But this plan did not provide any specific policy for the conservation of the water bodies like ponds and lakes.

Detailed Area Plan (DAP) (2010) kept a provision of a large number of water retention ponds and marked flood flow zones in Dhaka City. It emphasized the protection of green spaces and water bodies. Yet, Dhaka lost its green spaces and water bodies remarkably in the last 10 years, and the residents of Dhaka City are suffering from amplified risks and hazards, especially urban flooding and long waterlogging in rainy reasons. Consequently, residents, civil societies, and experts have high expectations of the recent draft of the Detailed Area Plan (DAP)

(2016–2035). In this draft plan, a lot of environment-friendly solutions, viz., rain gardening (playfield will be used as water retention area), creating blue-green infrastructure network, water-based eco-park, revitalizing the existing canals with waterfront development, the greening of road island, green brick instead of the old brickfield, green fringe area for cultivation, green building, rainwater harvesting, and rooftop gardening, are mentioned to enhance the environmental, cultural, social, and economic well-being.

Despite having such different environment-friendly approaches and BGI options in draft DAP (2016–2035), careful observation of urban planners and experts found many of these as superficial, and the proposed DAP is facing severe criticism by urban planners and experts. Different national newspapers and media have published the concerns and worries related to DAP. According to experts' critical observation, DAP threatens 70% of the natural water bodies of Dhaka City. According to experts, there is no hydrological model and no plan for flora and fauna in the present DAP. Further, it is warned that implementation of the DAP will increase flooding and waterlogging in Dhaka City (Staff Correspondent, The Daily Star 2020; Imam 2020).

On the contrary, the Master Plan of 1961 in Chittagong made twenty-six proposals for various types of open spaces, and the Structure Plan in 1995 also agreed to previous propositions. The current Detailed Area Plan of 2008 acknowledged that there is a severe deficiency of all types of recreational open spaces, public plazas, and public amenity spaces in the city. There is a policy in the Structure Plan of 1995 to protect and enhance significant areas of open space within the city. This policy facilitates the protection of open spaces in the city (CDA 2008). The plan includes intensive generic policies about protecting and increasing open spaces. The plan also recommended a tree-planting scheme to cover a minimum of 15% of the total land cover. Waterfront development, especially the greening of edges of *khals* and greening of railway tracks, is also mentioned in the Detailed Area Plan of Chittagong City. The plan provided a policy to encourage the use of the rivers, canals, and other large water bodies for recreational facilities, angling, and making them clean. Further, the plan recognized the flood flow and sub-flood flow zones for watershed management and provided policies for flooding and drainage.

Similarly, Khulna City adopted the first development plan in 1961 which highlighted more on the physical settings than providing specific propositions. Hence, a detailed analysis of the blue and green infrastructures was missing. Both the Master Plan in 2001 recommended about 2008 acres of blue-green spaces, viz., park, playground, green space, river and roadside green space and botanical garden, and highway forest. Unfortunately, there is no visible implementation of such recommendations in the city planning of Khulna. Few projects related to open space, pond management, riverfront development, etc. with a focus on climate change impacts have already been initiated. Nonetheless, there are several good aspects in the existing Detailed Area Plan of 2018 (KDA 2018). The plan included the future need assessment of the recreational facilities, open space, parks, etc. based on Detailed Area Development Planning (DADP) Zones and made proposals for those zones showing the priority of implementation. There is no specific water body management plan for Khulna City and no separate proposals for preserving/conserving the water bodies, especially ponds based on analysis and assessment. The drainage master plan is a good aspect of the city for water management, and several studies were carried out about water resilience, urban flooding, etc. at the city scale. There are proposals for canal restoration, river dredging, and waterfront development in several studies including the present development plan.

Rajshahi is one of the divisional and metropolitan cities located in drought-prone areas. Considering the overall environmental condition and well-being of the city, a couple of specific proposals were reflected in the development plan (RDA 2004). Augmentation of open spaces and preservation, maintenance, management, and enhancement of existing open spaces are encouraged. Conversely, the plan sets proposals for restricted flood protection reserves in the form of flood retention ponds to fulfill the primary functions of water storage at the time of flooding. Preservation of ponds and canals is also mentioned in the development plan. In recent years, the city has been a model for reducing air pollution and offering cleaner ambient air. According to the WHO, the city observed a 67.2% decline in PM10 concentration from 2014 to 2016. The city had to go through a couple of timely initiatives to achieve this success, like introducing battery-powered rickshaws, banning the trucks in the downtown during the day, modernizing brick kilns, and a tree-planting campaign. The construction of the cycle lane in the city was the country's first initiative in her history. For the first time in Bangladesh, Rajshahi City has taken a project solely dedicated to the preparation of a plan for open spaces. The project is ongoing, which is titled "Baseline assessment of floral wealth in the city and development of a plan for open green spaces in Rajshahi, Bangladesh" under accelerating climate action through the promotion of Urban Low Emission Development Strategies (Urban-LEDS II). The plan will include long-term strategies along with short-term and midterm directions, which are expected to enhance the overall well-being of the city environment.

19.5 Factors Shaping BGI in Urban Bangladesh

The shaping of blue-green infrastructure (BGI) in urban Bangladesh needs to be perceived from a pair of confronting forces. These forces can be identified as a set of factors in support of saving BGI and another package of factors associated with the destruction of BGI. Again, a comprehensive understanding of these bundles of factors can be viewed from three perspectives: sociopolitical, economic, and institutional. All global, national, and sectoral commitments/goals/policies unanimously declared the importance of conserving and expanding the BGI to ensure the social, health, and environmental benefits particularly considering the climate change scenario and disaster resilience. Along with the alarming loss of BGI in urban areas, there is inspiring evidence of efforts to make cities greener and more blue by adopting policies, acts, and projects. "Hatirjheel Integrated Development Project" and "Park and Playground Modernization Project of Dhaka South City Corporation" are such examples. A complex set of stakeholders is active in the process of shaping

BGI of urban areas of Bangladesh. The rate of loss of water bodies and green areas is alarming. At the same time, it needs to be noted that people from different corners of the country are raising voices and working hard to save dying rivers, choking canals filled with domestic and industrial waste, and urban wetlands in Bangladesh. The following discussion elaborates on the sociopolitical, economic, and institutional context of urban Bangladesh linked with the shaping of BGI in the urban landscape.

19.5.1 Sociopolitical Factors

Relevant sociopolitical aspects can be viewed from individual, family culture to a broader extent of the bureaucratic, and political culture of the country. Land is considered one of the most valuable, profitable, and long-lasting assets. Traditionally, ownership of land is associated with the social status and power of an individual or family. Especially with the widespread activity of private developers, lucrative advertisement of these companies and the provision of bank loans against land attract buyers of the land market. In urban fringe areas, agriculture is no longer an attractive profession for the younger generation considering the economic return and social status. This includes urban wetlands that are also used as fertile agricultural land in dry seasons. Haque (2012) presented an in-depth picture of the role and strategies practiced by different individuals and interest groups in the game of converting BGI to other uses. Corruption, the exercise of power, lack of enforcement of laws, regulations, and plans are common. The research findings of Mahmood and Islam (2019) show that many local residents, who are the owner and users of wetlands and agricultural lands, are residing there from generation to generation and thus have a strong attachment to the land and the milieu as a whole. These researches also portrayed exploitation and sufferings of original landowners by the land developers, often supported by the government machinery.

People, in general, now apprehend the importance of BGI to address urban flooding, heat stress, the value of agricultural land for food security, and the need for open spaces for physical and mental well-being. Electronic and print media also play an important role to promote awareness regarding the conservation of BGI in Bangladesh. There are many examples of local residents who are united to protect BGI in their locality. Moreover, global documents like Sustainable Development Goals (SDGs) (2016–2030) set specific targets to safeguard the blue-green network.

19.5.2 Economic Factors

Economic factors are connected with a wide range of stakeholders which include officials from government regulatory bodies, political leaders, real estate developers, land brokers, and buyers and sellers of the land market. The study of Alam (2018) reported that a substantial increase of about 74% of the land value per year during the period 2000–2010 resulted in land speculation among real estate developers and individual buyers. Large parcels of low-lying land, agricultural land, and open spaces are prime locations for development projects, particularly real estate as the profit margin is high mentioned that lack of political will and strategies to ensure implementation of plans and enforcement of regulation is responsible for the destruction of BGI in urban areas of Bangladesh. Adoption of regulatory measures such as the Land Ceiling Act and gift tax/inheritance tax can control the prevailing trend of land speculation in urban areas. Advancement of options of secured investment opportunity in industrial or other business sectors may act as a disincentive to invest in land. Moreover, well-designed incentive programs; transfer of development rights (TDR); and, if necessary, land acquisition programs can be introduced to address the economic benefit issues of the landowners of BGI.

19.5.3 Institutional Factors

There is no dearth of policies and regulations to protect BGI in Bangladesh. Further, enforcement of different policy instruments, laws, and acts is limited. Even the development plans prepared by government agencies often ignore the policies, acts, and rules. The evidence of the fast pace of destruction of BGI in urban areas of Bangladesh questions the role of regulatory bodies and law enforcement agencies. Haque (2012) elaborated this issue by emphasizing corruption, the exercise of power, and lack of accountability as factors responsible for such situations. The study by Islam (2014) showed that designated wetlands and pond retention areas, mentioned in the Detailed Area Plan (2010–2015), disappeared in the eastern part of Dhaka.

Local people, who are traditionally the owner, user, or custodian of BGI, are not included in the plan preparation and implementation phases. However, a study claims that the sociocultural values of key stakeholders are curtailed before planning (Kati and Jari 2016). Mahmood and Islam (2019) revealed the process of involuntary displacement of people in the fringe of Dhaka and portrayed the sufferings of local people.

Ayon et al. (2020) identified some factors that are responsible for land-use change at the fringe area of the Dhaka Metropolitan area. The study had also identified factors like proximity to the central business district, good road connectivity, and availability of large tracts of undeveloped land that attract the developers to convert BGI into urban residential land use. Further, low earnings from agricultural land and limitations of local government institutions are identified as responsible factors for the conversion of BGI into residential areas (Ayon et al. 2020). The research of Akther and Islam (2020) presents an analytical discussion on ethical culture and professionalism in planning practice in Dhaka, and it unveiled many sociopolitical and institutional aspects linked with the blue-green infrastructure of the city. These complex and intertwined issues need to be addressed in a comprehensive way with the active participation of all the stakeholders to safeguard the remaining blue-green network of the urban landscape of Bangladesh.

19.6 Role of Blue-Green Infrastructure (BGI) in Disaster Risk Reduction and Resilience of Urban Bangladesh

Blue-green infrastructure (BGI) is relatively a new term, which is closely associated with the concept of green infrastructure (GI). In different parts of the world, including the USA, the United Kingdom, Australia, and China, there is a shift of focus in urban planning and management from green or natural infrastructure to BGI (Ahmed et al. 2019). GI or BGI includes both green and blue (water bodies) spaces in urban areas. The US Environmental Protection Agency (2019) argues that GI, which is considered as the lungs of a city (Jim and Chen 2006), provides services to improve water quality and quantity, air quality, climate resiliency, habitat, and wildlife connectivity as well as benefiting communities by green jobs opportunities and health aspect, providing recreation space, and improving property values. Different studies claim that water bodies and green spaces contribute to the resilience of urban areas and provide a wide range of social, economic, and environmental benefits (Voskamp and Van de Ven 2015; Demuzere et al. 2014).

Despite such importance and necessity of BGI, in Bangladesh urban areas, especially, all main cities are rapidly losing their water bodies and green spaces. As discussed in the previous section, the capital city Dhaka had a reduction of 16% of its agricultural land, which is considered as green spaces; Rajshahi City had a reduction of 14% of water bodies in 25 years; Khulna had a reduction 17% agricultural land in last 14 years; and in Chittagong, hill cutting was found to be around 64% in some areas. Due to this rapid reduction of BGI, the intensity of urban heat islands, landslides, urban flooding, waterlogging, health hazards, and potentiality of soil amplification is noticed in different cities of Bangladesh that are discussed in Sect. 2.

Since high risks are associated with the unplanned growth of cities and the rapid decline of BGI, scholars warn that green space management in urban Bangladesh, especially in Dhaka, should be prioritized. As BGI management is observed as negligible, academics and scholars are advocating for the importance of green spaces and advising for proper planning with adequate and efficient incorporation of BGI (Byomkesh et al. 2012; Nahyan 2017; Ahmed et al. 2019).

Since sufferings related to different hazards are swelling in different cities of Bangladesh, the realization about the importance of proper planning and BGI management is improving. Policy planners, civil societies, academics, media, and even local communities are urging action planning by incorporating BGI. For the last several years, Dhaka, Chittagong, Rajshahi, Khulna, and some other cities are trying to move forward with the slogan and actions of the "clean and green city." Along with the Dhanmondi Lake Project, few recent projects in Dhaka, like Hatirjheel Lake Project and Gulshan-Banani Lake Project, are the initiatives of incorporating BGI in the city planning process. Rajshahi City Corporation has launched a "zero soil" plan for the city, with planting a lot of grass to cut down dust. Further, in Rajshahi City, large numbers of trees have been planted over the last few years. Therefore, the city has been awarded different national awards and recognition from the World Health Organization (Abdullah 2020). Residents and

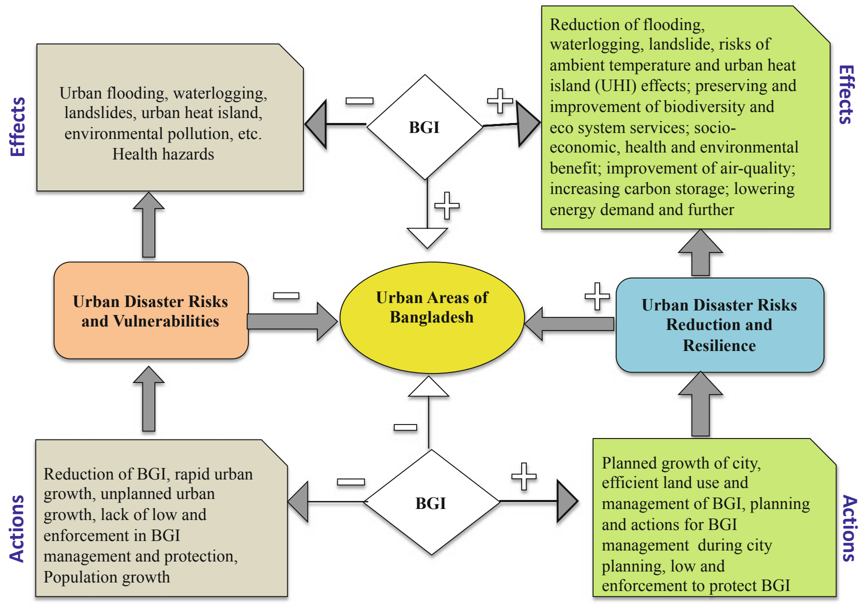


Fig. 19.4 Role of blue-green infrastructure (BGI) in urban Bangladesh. Note: + means contributing positively; – means contributing negatively

communities of these project areas have also approved the benefits from these projects. Respondents confirmed that the recent Hatirjheel Lake Project has significantly reduced the waterlogging due to rainfall. Other environmental and socio-economic benefits (e.g., household and industrial waste and mosquito reduction, an increase of house rent, visitors, food shop, etc.) are also recognized by the restoration of the existing lake (Nahyan 2017).

Scholars advised that BGI network, which incorporates both natural (blue and green) and man-made (gray), can be a more financially and spatially efficient solution for Dhaka. Further, this approach of BGI that promises achieving a more sustainable urban form can be implemented in other cities (Ahmed et al. 2019). Figure 19.4 demonstrates that an increase in BGI can positively contribute to urban disaster risk reduction and resilience. Still, achieving this requires efficient action planning and law and enforcement to protect BGI. In contrast, the reduction of BGI with rapid and unplanned urban growth will enhance urban disaster risks and vulnerabilities in Bangladesh. Therefore, mainstreaming BGI in city planning, policy, and action plans is a foremost requirement for countries across the world, more specifically for rapidly growing developing countries like Bangladesh.

Conflict of Interest Statement The authors report no conflict of interest for this publication.

References

Abdullah D (2020) Rajshahi: A city fresh and green. Dhaka tribune, January 4, 2020

Adri N, Islam I (2010) Water logging in Keshabpur: a focus to the coping strategies of the people. In: International Conference on Environmental Aspects of Bangladesh (ICEAB) Kitakyushu, 4 September 2010 2010. University of Kitakyushu, Kitakyushu, pp 33–36

Ahmed B, Dewan A (2017) Application of bivariate and multivariate statistical techniques in landslide susceptibility modeling in Chittagong city corporation. Bangladesh Remote Sens 9: 304

Ahmed S, Meenar M (2018) Just sustainability in the global south: a case study of the megacity of Dhaka. J Dev Soc 34:401–424. https://doi.org/10.1177/0169796X18806740

Ahmed S, Meenar M, Alam A (2019) Designing a blue-green infrastructure (BGI) network: toward water-sensitive urban growth planning in Dhaka, Bangladesh. Land 8(9). https://doi.org/10.3390/land8090138

Akter A, Mohit SA, Chowdhury MAH (2017) Predicting urban storm water-logging for Chittagong city in Bangladesh. Int J Sustain Built Environ 6(1):238–249. https://doi.org/10.1016/j.ijsbe.2017.01.005

Akther S, Islam I (2020) Ethics and professionalism in planning practice: an experience from Dhaka. In: Thakur RR, Dutt AK, Thakur SK, Pomeroy GM (eds) Urban and regional planning and development, 1st edn. Springer, Cham

Alam MJ (2018) Rapid urbanization and changing land values in mega cities: implications for housing development projects in Dhaka, Bangladesh. Bandung 5:2–19

Alam MS, Mondal M (2019) Assessment of sanitation service quality in urban slums of Khulna city based on SERVQUAL and AHP model: A case study of railway slum, Khulna, Bangladesh. J Urban Manag 8(1):20–27. https://doi.org/10.1016/j.jum.2018.08.002

Amin MA (2018) Dhaka remains the world's most densely populated city. Dhaka Tribune, 14 October

Anisha NF, Hossain S (2014) A case study on WaterLogging problems in an urban area of Bangladesh and Probable Analytical Solutions. 2nd International Conference on Advances in Civil Engineering 2014 (ICACE-2014). Chittagong University of Engineering & Technology, Chittagong

Ayon BD, Shubho MTH, Islam SR, Islam I (2020) Determinants of land use change in urban fringes: a study of Dhaka. In: Thakur RR, Dutt AK, Thakur SK, Pomeroy GM (eds) Urban and regional planning and development, 1st edn. Springer, Cham

Bai T, Mayer AL, Shuster WD, Tian G (2018) The hydrologic role of urban green space in mitigating flooding (Luohe, China). Sustainability 10(10). https://doi.org/10.3390/su10103584

Bajracharya P, Sultana S (2020) Rank-size distribution of cities and municipalities in Bangladesh. Sustainability 12(11). https://doi.org/10.3390/su12114643

Bashar T, Rashid S (2012) Urban microfinance and urban poverty in Bangladesh. J Asia Pac Econ 17(1):151–170. https://doi.org/10.1080/13547860.2012.640019

BBS (Bangladesh Bureau of Statistics) (1991) Bangladesh Population Census 1991. Ministry of planning, Peoples Republic of Bangladesh, Dhaka

BBS (Bangladesh Bureau of Statistics) (2001) Bangladesh Population Census 1991. Ministry of Planning, Peoples republic of Bangladesh, Dhaka

BBS (Bangladesh Bureau of Statistics) (2014) Bangladesh Population Census 1991. Ministry of Planning, Peoples republic of Bangladesh, Dhaka

Byomkesh T, Nakagoshi N, Dewan AM (2012) Urbanization and green space dynamics in Greater Dhaka, Bangladesh. Landsc Ecol Eng 8(1):45–58. https://doi.org/10.1007/s11355-010-0147-7

BFSCD. (2020). Fire incident statistics, Bangladesh fire service and civil defence. http://fireservice.portal.gov.bd/sites/default/files/files/fireservice.portal.gov.bd/files/9574ab2f_d155_4bd7_81af_07ce19830c97/2021-02-15-14-04-5f1231b8b0e9f005fb57401ce2459b5b.pdf

Cai Z, Li W, Cao S (2021) Driving factors for coordinating urbanization with conservation of the ecological environment in China. Ambio 50(6):1269–1280. https://doi.org/10.1007/s13280-020-01458-x

CDA (2008) Preparation of detailed area plan (DAP) for Chittagong Metropolitan Master Plan (CMMP) 1995–2015. Chattogram Development Authority, Chattogram

Cui Y, Cheng D, Choi CE, Jin W, Lei Y, Kargel JS (2019) The cost of rapid and haphazard urbanization: lessons learned from the Freetown landslide disaster. Landslides 16(6): 1167–1176. https://doi.org/10.1007/s10346-019-01167-x

Demuzere M, Orru K, Heidrich O, Olazabal E, Geneletti D, Orru H, Bhave AG, Mittal N, Feliu E, Faehnle M (2014) Mitigating and adapting to climate change: multi-functional and multi-scale assessment of green urban infrastructure. J Environ Manag 146:107–115. https://doi.org/10.1016/j.jenvman.2014.07.025

Esraz-Ul-Zannat M, Islam I (2015) A study on land use policies of Khulna structure plan 2000–2020 in the light of climate change induced flood scenario. J Bangladesh Inst Planners 8:23–33. https://doi.org/10.13140/RG.2.2.29632.94722

Esraz-Ul-Zannat M, Abedin MA, Pal I, Zaman MM (2020) Building resilience fighting back vulnerability in the Coastal City of Khulna, Bangladesh: a perspective of climate-resilient city approach. Int Energy J 20:549–566

Gunawardena KR, Wells MJ, Kershaw T (2017) Utilising green and bluespace to mitigate urban heat island intensity. Sci Total Environ 584-585:1040–1055. https://doi.org/10.1016/j.scitotenv.2017.01.158

Hamidul Bari Q, Mahbub Hassan K, Ehsanul Haque M (2012) Solid waste recycling in Rajshahi city of Bangladesh. Waste Management (New York, NY) 32(11):2029–2036. https://doi.org/10.1016/J.WASMAN.2012.05.036

Haque KNH (2012) The Political Economy of Urban Space: Land and Real Estate in Dhaka City, IGS Working Paper Series No. 03/2012. Institute of Governance Studies, BRAC University, Dhaka

Hasan MR, Hossa MT, Khan LA, Afrin S (2018) Seasonal water logging problem in an urban area of Bangladesh: A study on pabna Pourashava. Paper presented at the 1st National Conference on Water Resources Engineering (NCWRE 2018), Chittagong, 21-22 March

Hassan MM (2017) Monitoring land use/land cover change, urban growth dynamics and landscape pattern analysis in five fastest urbanized cities in Bangladesh. Remote Sens Appl 7:69–83. https://doi.org/10.1016/j.rsase.2017.07.001

Hassan MM, Nazem MNI (2016) Examination of land use/land cover changes, urban growth dynamics, and environmental sustainability in Chittagong city, Bangladesh. Environ Dev Sustain 18(3):697–716. https://doi.org/10.1007/s10668-015-9672-8

Hassan MM, Ahmed S, Patwary NH, Yeasmin L, Shahidullah SM, Sattar M (2015) Environmental degradation through hill cutting in Chittagong district of Bangladesh. Int J Nat Soc Sci 1:41–54

Hossain S (2013) Migration urbanization and poverty in Dhaka, Bangladesh. J Asiatic Soc Bangladesh 58:369–382

Imam SH (2020) Dhaka's environment to be Jeopardised if draft DAP implemented: Experts. The Financial Express

Iqbal I (2013) First master plan for Dhaka City: an environmental exploration. Südasien-Chronik - South Asia Chronicle, vol 3. Humboldt-Universität zu Berlin, Berlin

Islam I (2014) Wetland management in Dhaka: institutional efforts and associated constraints. In: Choudhury GA, Nakagami KI, Li J, Fukushi K (eds) Strategic adaptation towards water crisis, vol 1. The University Press Limited, Dhaka, pp 207–224

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

Jim CY, Chen WY (2006) Perception and attitude of residents toward urban green spaces in Guangzhou (China). Environ Manag 38:338–349

Kafy AA, Rahman MS, Faisal A-A, Hasan MM, Islam M (2020) Modelling future land use land cover changes and their impacts on land surface temperatures in Rajshahi, Bangladesh. Remote Sens Appl 18:100314. https://doi.org/10.1016/j.rsase.2020.100314

Kafy AA, Faisal AA, Ferdous L (2018) A participatory assessment to identify the causes and impacts of open space reduction in Rajshahi City Corporation (RCC) area, Bangladesh. International Journal of Environmental Planning and Development 4(2):16–28. https://doi.org/10.37628/JEPD.V4I2.365

Kafy A-A, Islam M, Khan AR, Ferdous L, Hossain MM (2019) Identifying most influential land use parameters contributing reduction of surface water bodies in Rajshahi city, Bangladesh: a remote sensing approach. Remote Sensing of Land 2(2):87–95. https://doi.org/10.21523/GCJ1.18020202

Kanniah KD (2017) Quantifying green cover change for sustainable urban planning: a case of Kuala Lumpur, Malaysia. Urban For Urban Green 27:287–304. https://doi.org/10.1016/j.ufug.2017.08.016

Kati V, Jari N (2016) Bottom-up thinking—Identifying socio-cultural values of ecosystem services in local blue–green infrastructure planning in Helsinki, Finland. Land Use Policy 50:537–547. https://doi.org/10.1016/j.landusepol.2015.09.031

KDA (2018) Preparation of Detailed Area Development Plan for Khulna Master Plan (2001) Area.

Kim H, Lee D-K, Sung S (2016) Effect of urban green spaces and flooded area type on flooding probability. Sustainability 8(2). https://doi.org/10.3390/su8020134

Latif MB, Arifujjaman M, Siddick MZ, Hosen ME (2016) Effect of water logging in Tangail Paurashava. J Sci Technol 6:11–20

Liu L, Fryd O, Zhang S (2019) Blue-green infrastructure for sustainable urban stormwater management—lessons from six municipality-led pilot projects in Beijing and Copenhagen. Water 11(10). https://doi.org/10.3390/w11102024

Liu X, Huang Y, Xu X, Li X, Li X, Ciais P, Lin P, Gong K, Ziegler AD, Chen A, Gong P, Chen J, Hu G, Chen Y, Wang S, Wu Q, Huang K, Estes L, Zeng Z (2020) High-spatiotemporal-resolution mapping of global urban change from 1985 to 2015. Nat Sustain 3(7):564–570. https://doi.org/10.1038/s41893-020-0521-x

Maharjan M, Aryal A, Man Shakya B, Talchabhadel R, Thapa BR, Kumar S (2021) Evaluation of Urban Heat Island (UHI) Using Satellite Images in Densely Populated Cities of South Asia. Earth 2:86–110

Mahmood SS, Islam I (2019) Impact of involuntary resettlement on quality of life of relocated people in the eastern fringe of Dhaka, Bangladesh. In: Sinha BRK (ed) Multidimensional approach to quality of life issues: a spatial analysis. Springer, Varanasi, Uttar Pradesh, pp 253–266

Mia MA, Nasrin H, Zhang M, Rasiah R (2015) Chittagong, Bangladesh. Cities 48:31–41

Moniruzzaman M, Thakur PK, Kumar P, Ashraful Alam M, Garg V, Rousta I, Olafsson H (2021) Decadal urban land use/land cover changes and its impact on surface runoff potential for the Dhaka City and surroundings using remote sensing. Remote Sens 13(1). https://doi.org/10.3390/rs13010083

Moore M (2021) Urban population in Bangladesh from 2011 to 2020. Statista. https://www.statista.com/statistics/603402/bangladesh-urban-population/. Accessed 31 August 2021

Nahyan HM (2017) Planning green-blue infrastructure for urban climate adaptation: a study related to urban flooding issues in Dhaka. Wageningen University, Wageningen

Papry RI, Ahmed GU (2015) Drainage condition in water logged areas of central part in Chittagong city corporation. Int J Eng Sci Invent 4:24–29

Parvin GA, Ahsan R, Shaw R (2013) Urban risk reduction approaches in Bangladesh. In: Shaw R, Mallick F, Islam A (eds) Disaster risk reduction approaches in Bangladesh. Springer, Tokyo, pp 235–257

Parvin GA, Shaw R (2011) Climate disaster resilience of Dhaka City corporation: an empirical assessment at zone level. Risk, Hazards & Crisis in Public Policy 2(2):121–150. https://doi.org/10.2202/1944-4079.1069

Parvin GA, Surjan A, Atta-ur-Rahman, & Shaw, R. (2016) Urban risk, city government, and resilience. In: Urban disasters and resilience in Asia. Butterworth-Heinemann, pp 21–34. https://doi.org/10.1016/B978-0-12-802169-9.00002-1

Rahaman MS, Hossain N, Nurain A, Sarker P, Ichihara S (2020) Investigation on causes and effects of waterlogging in the Southern Part of Bangladesh. Manag Sustain Devel J 12:4–11

Rahman MM, Akteruzzaman AKM, Khan MMH, Jobber A, Rahman MM (2009) Analysis of water logging problem and its environmental effects using gis approaches in Khulna City of Bangladesh. J Socioecon Res Devel 6:572–577

RAJUK (1997) Dhaka Metropolitan Development Plan (DMDP) Structure Plan (1995 - 2015).

RAJUK (2010) Detailed Area Plan (1995 - 2015).

RAJUK (2016) Dhaka Metropolitan Development Plan (DMDP) 2016-2035.

Ramiaramanana FN, Teller J (2021) Urbanization and floods in Sub-Saharan Africa: spatiotemporal study and analysis of vulnerability factors—case of antananarivo agglomeration (Madagascar). Water 13:149

Rashied M, Mahmud MA (2019) Potential Amplifiable Areas in Dhaka City for Seismic Hazard. J Bangladesh Inst Planners 12:33–43

RDA (2004) Rajshahi Metropolitan Development Plan (RMDP) 2004-2024.

Rouf MA (2018) Twentieth century urbanization in Bangladesh and a spell of high and unsustainable urban growth. Int J Archit Urban Devel 8:5–14

Rouf MA, Jahan S (2017) Twentieth century urbanization in Bangladesh and a spell of high and unsustainable urban growth. Oriental Geographer 59:37–50

Šakić Trogrlić R, Rijke J, Dolman N, Zevenbergen C (2018) Rebuild by design in Hoboken: a design competition as a means for achieving flood resilience of urban areas through the implementation of green infrastructure. Water 10:553

Sarkar SK, Rahman MA, Esraz-Ul-Zannat M, Islam MF (2021) Simulation-based modeling of urban waterlogging in Khulna City. J Water Climate Change 12:566–569

Sayed MB, Haruyama S (2016) Evaluation of flooding risk in greater dhaka district using satellite data and geomorphological land classification map. J Geosci Environ Protect 4:110–127. https://doi.org/10.4236/gep.2016.49009

Sharma A, Surjan A, Shaw R (2011) Overview of urban development and associated risks. In: Community, environment and disaster risk management, vol 6. Emerald Group Publishing Limited, pp 1–16. https://doi.org/10.1108/S2040-7262(2011)0000006007/FULL/XML

Shaw R, Parvin GA, Surjan A, Rahman A (2016) Building community resiliency: linkages between individual, community, and local government in the urban context. In: Urban disasters and resilience in Asia. Butterworth-Heinemann, pp 287–292. https://doi.org/10.1016/B978-0-12-802169-9.00018-5

Siddiqui SA, Jakaria M, Amin MN, Al Mahmud A, Gozal D (2020) Chronic air pollution and health burden in Dhaka city. Eur Respir J:2000689. https://doi.org/10.1183/13993003.00689-2020

Staff Correspondent (2020) Dhaka's detailed area plan threatens 70% natural waterbodies: architects, urban planners. The Daily Star

Sun S, Zhai J, Li Y, Huang D, Wang G (2020) Urban waterlogging risk assessment in well-developed region of Eastern China. Phys Chem Earth Parts A/B/C 115:102824. https://doi.org/10.1016/j.pce.2019.102824

Tauhid FA (2018) Urban green infrastructure for climate resilience: a review. Nature 5:58–65

The Daily Dhaka Tribune (2018) 60% of Bangladesh urban population in metropolitan cities | Dhaka Tribune. https://www.dhakatribune.com/bangladesh/2018/11/19/60-of-bangladesh-urban-population-in-metropolitan-cities

UN-Habitat (2007) Mitigating the impacts of disasters: policy directions. Enhancing Urban Safety and Security. Global Report on Human Settlements 2007. http://www.unhabitat.org/grhs/2007

UN-HABITAT (2020) World Cities Report 2020: The Value of Sustainable Urbanization. United Nations Human Settlements Programme (UN-Habitat), Nairob

Vargas-Hernández JG, Zdunek-Wielgołaska J (2021) Urban green infrastructure as a tool for controlling the resilience of urban sprawl. Environ Dev Sustain 23(2):1335–1354. https://doi.org/10.1007/s10668-020-00623-2

Voskamp IM, Van de Ven FHM (2015) Planning support system for climate adaptation: composing effective sets of blue-green measures to reduce urban vulnerability to extreme weather events. Build Environ 83:159–167. https://doi.org/10.1016/j.buildenv.2014.07.018

Welford MR, Yarbrough RA (2021) Urbanization. In: Welford MR, Yarbrough RA (eds) Human-environment interactions: an introduction. Springer International Publishing, Cham, pp 193–214. https://doi.org/10.1007/978-3-030-56032-4

World Bank (2020) Urban population growth (annual %) | Data. https://data.worldbank.org/indicator/SP.URB.GROW

World Bank (2021) Urban population (% of total population) | Data. https://data.worldbank.org/indicator/SP.URB.TOTL.IN.ZS

Gulsan Ara Parvin is a researcher at Kyoto University, Japan. She is also serving in Ritsumeikan University, Osaka, Japan, as a researcher.

Md. Esraz-Ul-Zannat is a Faculty Member at the Department of Urban and Regional Planning at Khulna University of Engineering and Technology, Khulna, Bangladesh.

S. M. Reazul Ahsan is an Assistant Professor in the Department of City and Metropolitan Planning, University of Utah, USA.

Ishrat Islam is a Professor at the Department of Urban and Regional Planning, Bangladesh University of Engineering and Technology (BUET). She is also currently serving as the Director of Center for Regional Development Studies (CRDS), BUET.

20 Endorsing City Biodiversity Index (CBI): Assessing Ecosystem Health in Urban Sprawls and Eco-DRR-Inclusive Urban Planning

Chandan Das, Jayshree Shukla, and Shalini Dhyani

Abstract

In order to understand the complexities and trends that influence a city's biodiversity health and ecosystem services, a holistic assessment is an essential tool to capture its growth trajectory towards sustainability. The City Biodiversity Index (CBI) is one such tool that allows the evaluation of city-specific sustainable governance, local biodiversity management and their socio-ecological characteristics through an indicator-based monitoring system. In this chapter, we discuss the application of the CBI in order to address the population surge and booming industrialization within the smart city of Faridabad. Rapid decline in urban blue and green spaces was observed during the study which calls for immediate action and proper management plan by the local bodies. CBI can also act as a tool for impact assessment of various policies and ventures by the stakeholders along with providing a common ground for strategical exchange amongst cities with similar social and ecological characteristics and urban concerns. Further, suggestions and recommendations are made such as implementation of nature-based solutions (NbS) and ecosystem-based disaster risk reduction (Eco-DRR) techniques for new policies to be formulated by policymakers and stakeholders and to address the limitations of the CBI as observed during study for better biodiversity conservation in the city.

C. Das
Institute of Environment and Sustainable Development, Banaras Hindu University, Varanasi, Uttar Pradesh, India

J. Shukla · S. Dhyani (✉)
National Environmental Engineering Research Institute (CSIR-NEERI), Nehru Marg, Nagpur, Maharashtra, India

S. Dhyani et al. (eds.), *Blue-Green Infrastructure Across Asian Countries*,
https://doi.org/10.1007/978-981-16-7128-9_20

Keywords

Urban biodiversity · Ecosystem-based approach · Nature-based solutions

20.1 Introduction

Urbanization is one of the major global demographic megatrends that is rapidly growing and resulting in loss of biodiversity, ecosystems and ecosystem services (Dhyani et al. 2018). With a 30% increase in the global urban population since 1950, more than 50% of the world's population is residing in fast-expanding urban sprawls. Two-thirds (68%) of the global population is projected to be living in these urban areas by the year 2050, and China and India will be the centres of these urban expansions in Asia (Pierce et al. 2020). Recent reports suggest that the upcoming decades are going to have rampant rise and expansion in urbanization and population pressure because of low mortality rate in the urban sprawls, fast-growing migration from rural to urban areas and rapid conversion of rural areas into suburbs.[1] The transition of green spaces to built-up areas is a significant cause of biodiversity and habitat loss across the world (Turrini and Knop 2015; Nor et al. 2017). The structure and functioning of natural urban green spaces are severely affected by rapid urbanization putting green spaces under strain and adversely affecting the environment, urban cultural associations and well-being of urban dwellers. Urban green spaces are known for improving the quality of urban environments, ensuring resilience and fostering healthy lifestyles that improves health and well-being of city residents (Tian et al. 2011; Sahani and Raghavaswamy 2018). Despite the fact that the benefits offered by urban blue and green spaces are increasingly recognized and discussed academically and international targets (e.g. Sustainable Development Goal 11 that is about sustainable cities and is to be realized by 2030), there has been a tendency to underestimate and ignore such benefits in urban planning as cities continue to expand across Asia (Dhyani et al. 2020a, b). Urban green spaces provide an array of ecosystem services which are affected by the quantity and quality of the green spaces and play a major role in improving the overall environmental problems and ensuring well-being of the city (Fuller and Gaston 2009; Hartig et al. 2014; Jansson 2014; Chenoweth et al. 2018). Urban blue-green spaces, with the vegetation, help in reducing air pollution, noise levels and light pollution impact of heat islands; improving recharge of groundwater aquifers; developing resilience; and reducing disaster risks (Dhyani et al. 2020a, b). Vegetation in urban areas has proven potential for improving air quality by filtering the contaminants and reducing their concentration and minimizing the urban heat island impacts, as most Asian cities experience heavy concretization and concentration of commercial activities that increases the local temperature than surrounding areas that are either less concretized or have vegetation (Nagendra and Mundoli 2019). Unplanned urban sprawls include

[1] https://population.un.org/.

overexploitation of groundwater aquifers and steady rise in waste water and solid waste issues (Komolafe et al. 2018; Nouri et al. 2019; Ramaiah and Avtar 2019). However, urbanization provides a great number of opportunities for development and transformation for developing countries like India, by facilitating economic growth and providing more livelihood opportunities. By 2050, India's current rate of urbanization, i.e. 0.25%, is expected to double in line with annual average economic growth of about 8% in the last 15 years (Sadashivam et al. 2016; United Nations 2018; Ramaiah and Avtar 2019). India is becoming one of the most rapidly urbanizing nations in the world. Since prehistoric times, India has been primarily an agrarian and rural economy, but owing to the unprecedented population rise, the rural population in India is rapidly migrating towards cities which has resulted that by 2050 the share of urban sprawls will exceed the percentage of rural areas in the country (United Nations 2018). Booming industrialization is a major reason for this unplanned haphazard and rampant urbanization. The unsustainable nature of this rapid urbanization is expected to have greater consequences like excessive carbon emissions that will further intensify the impacts and vulnerabilities due to climate change, resulting in high levels of GHG emissions especially C, N and methane and million tons of waste produced by the urban settlements and enhancing the disaster risks. Cities with a population of more than ten million are defined as megacities by the UN, and India has currently five of its cities as megacities, amongst which New Delhi with a population of 26.5 million ranks highest followed by 21.4 million in Mumbai, 15 million in Kolkata and two rapidly expanding cities, namely, Bengaluru and Chennai, with populations of 10.5 mn and 10.2 mn, respectively. By 2030, two more cities, Hyderabad and Ahmedabad, are projected to become megacities owing to their rapid economic transformations and industrial influence (Tripathy and Kumar 2019). Urban sprawl in India's metropolitan cities, such as Delhi, Mumbai, Chennai and Kolkata, exert huge pressure on electricity, water and transportation and are wreaking havoc on the atmosphere, environment, lithosphere, biosphere, hydrosphere and land and water resources (Saini and Tiwari 2020).

Conservation of biodiversity and distribution of its resources at various levels in the society are influenced by the pattern of development of the cities, also known as the consumption centres of the world's resources. The availability of surrounding ecosystem services such as urban blue-green spaces is decreasing with the urban expansion. In fast-developing countries such as India, the major megacities have been largely affected by the unplanned population rise and lifestyle changes, thus leading to significant loss of green cover in the cities. Some cities in India have even stooped below the UN recommended standard of per capita 9 m^2 of green space. Cities such as Chennai, Visakhapatnam, Mumbai and Pune have a meagre 0.46 m^2, 0.18 m^2, 0.12 m^2 and 1.4 m^2 of per capita green space/inhabitant (Imam and Banerjee 2016; Sen and Guchhait 2021). The major factors that contribute to this loss are high population density, increased industrialization, concretization, etc. In dense megacities, diminishing blue-green spaces, poor connectivity to parks and recreational sites and diminishing ecosystem health along with challenges towards building a sustainable environment are the pressing challenges of twenty-first century (Adlakha et al. 2021). Key decisions made by the urban dwellers directly affect the biodiversity of the city, and thus the lack of city-biodiversity interactions hinders effective management strategies and proper governance by the decision makers. Despite the imperative to better understand the relationships between biodiversity and the generation of ecosystem services in relation to land use change, these connections remain poorly investigated.[2]

The present chapter attempts to analyse the state of biodiversity health of Faridabad, a Tier II[3] city which lies in the close proximity of the megacity Delhi, and to understand the impact of loss of biodiversity and also how being close to a megacity has its additional burdens on neighbouring urban sprawls. Faridabad was a relevant urban sprawl to study the impacts as it is close to Delhi, the capital and largest megacity in India, and is in Delhi National Capital Region (NCR) that has expanded multifold geographically and demographically in the last few decades. Faridabad faces tremendous growth in population which has resulted in significant loss of urban green spaces and significant loss of blue spaces that were earlier relevant sources of water and support to biodiversity. With increased urban sprawling and rapid industrialization, it is necessary to evaluate and assess the impact of urbanization on the health of biodiversity and ecosystem for the smart city of Faridabad and its consequences in the warming world. Study is expected to bring light to the pressing situation and support urban planners and policymakers to promote good governance and responsible citizenship for conserving remaining biodiversity and ecosystems of Faridabad.

20.2 City Biodiversity Health

Health has been considered a basic human right. As per the World Health Organization (WHO), it is not just being simply free from illness or diseases, but having complete physical, mental and social well-being. Biodiversity is the foundation for not only human health but every organism surviving on the planet as it maintains the functioning of the ecosystems by providing contributions for human well-being. At Conference of the Parties (COP) 10, Aichi Biodiversity targets (2011–2020) were adopted to conserve biodiversity at national and international levels. Aichi Target 14 strongly stresses on ecosystem services that contribute to health, livelihoods and well-being.[4]

Urbanization is expanding rapidly across the world; hence, there is a growing need to conserve, monitor and restore health of urban blue (lakes, wetlands, etc.) and green (gardens, green spaces, urban forests) spaces in rapidly growing urban spaces.

[2] https://unu.edu/publications/articles/cities-biodiversity-and-governance.html#info.

[3] The towns with population of 100,000 and above are called megacities and as per 'Tier Centre' nomenclature based on population criteria, Tier 1 comprises metropolitan and urban centres; Tiers 2, 3 and 4 comprise semi-urban centres; and Tiers 5 and 6 comprise rural centres (Census of India 2001). Tier 1 > four million population and Tier 2 > 1–four million population (McKinsey and Company 2010).

[4] cbd.int.

Fig. 20.1 Faridabad at a glance; infrastructure build-up in Greater Faridabad and road towards Badkhal Lake, Old Faridabad Metro Station and Multinational Company in Sarai show reduced urban green spaces and enhanced concretized area (clockwise)

Urban green spaces are home to diverse floral and faunal components including threatened species that need conservation efforts, but most of these species in urban areas are usually neglected. Faridabad (Fig. 20.1) is a fast-growing urban expansion in Delhi National Capital Region (NCR) located in the south of Delhi and west of Gurugram and has undergone rapid urbanization in the last more than two decades (2000 onwards) with a simultaneous increase in industrialization in the city. Faridabad District is located between 28°10′50“N and 28°29’04”N latitude and between 77°06′49“E and 77°33’23”E longitude at 209 m amsl[5] in the south-eastern part of Haryana state with a geographical area of 742.90 km^2.[6] Faridabad in the state

[5] elevation.city.

[6] faridabad.nic.in.

of Haryana stands highest amongst districts of Haryana in industrialization with 35.73% of industrial growth.[7] The mean maximum temperature of the city is 33.1 °C in summer months (April–July) and 13.6 °C during winter months (November–February).[8] Annual rainfall of 542 mm is received from the south-west monsoon in the last week of June to September.[9] The Yamuna River flowing on the east of the city forms two types of flood plains, viz. Khadar, a low-lying flood plain of new alluvium, and Bhangar, an upland plain made up of old alluvium.[5] The city has reserved forest area of 175.63 ha and protected forest area of 1333.72 ha that contributes to the 13% share of the total forest area of Haryana[6]. Faridabad is being developed under the Smart City Mission with a focus to promote and develop eco-friendly mobility options, revival of public green spaces and reducing road congestion followed by smart and sustainable infrastructure.[10] Blue-green infrastructure (BGI) in the city is mostly composed of urban forests, campus green spaces, public gardens, parks, playgrounds, fallow lands, lakes, ponds and water bodies. The Draft Faridabad Master Plan 2031 considers overall town density of 113 persons/hectare and will accommodate 38.86 lakh persons by 2031 within the urbanizable area of 34,368 hectares.[11] The proportion of various land uses is, under residential (14,328 ha), commercial (2069 ha), industrial (6179 ha), transport and communication (4020 ha), public utility (638 ha), public and semi-public (1299 ha), open and green spaces (5314 ha), special zone (448 ha) and mixed land use (73 ha) (Fig. 20.2).[10] The land use that covers the maximum area in the city is under residential space; due to rapid increase in the population, this is expected to further increase.

Numerous environmental problems are witnessed in Faridabad. Due to the anthropogenic activities and disturbances in the Aravali hills of Faridabad, various ecological imbalances have occurred. From 2002 to 2012, the major type of land use/land cover changes is analysed such as agriculture land decreased by 3.21%, urban land increased by 4.66% and some mining pits filled with water increased by 7.96%, whereas the surface water bodies such as ponds and lakes are depleted by 32.69% from total water bodies area (Nathalia et al. 2017). Therefore, rapid expansion of the city and increasing concretization are leading to decrease in the area of urban green and blue spaces. Rapid urbanization, increasing industrialization and changing lifestyles in Faridabad are the reasons for the increase in the generation of solid waste in the city (Pasupuleti et al. 2016). Collection and dumping of municipal wastes have a great impact on the environment leading to the pollution of groundwater and surface water because of leaching (Yadav et al. 2016). The Municipal Corporation of Faridabad is lagging in the solid waste management due to lack of sufficient funds and advanced technology simultaneously with urban expansion

[7] tcpharyana.gov.in.

[8] en.climate-data.org.

[9] cgwb.gov.in.

[10] smartcityfaridabad.co.in.

[11] assetyogi.com.

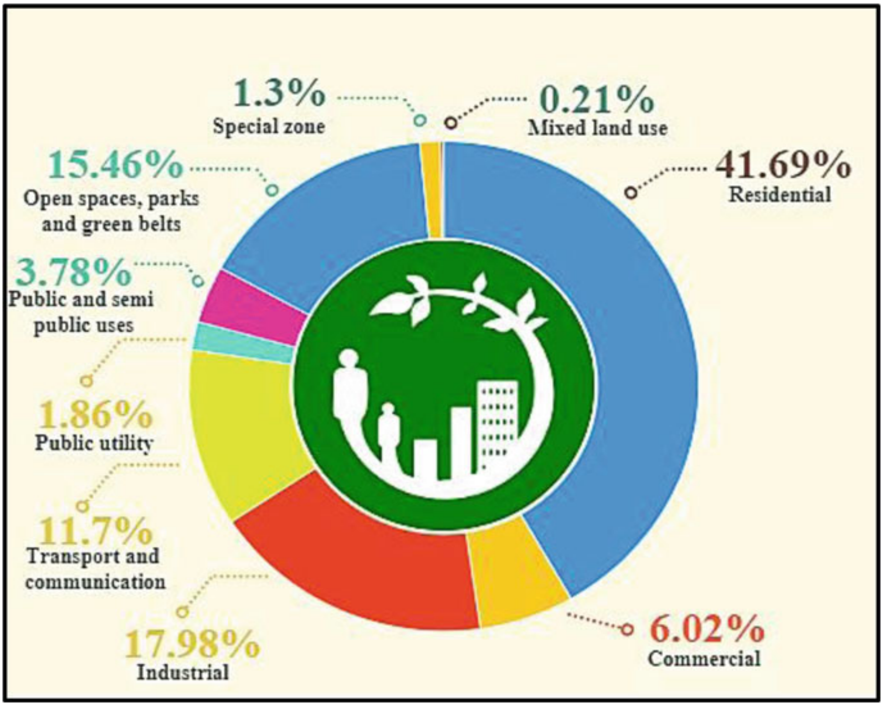


Fig. 20.2 Proportion of various land uses in fast-expanding urban sprawl of Faridabad in Delhi NCR, India (source: (Assetyogi, 2021))

(Singh and Satija 2016). Conversion of natural land cover into urban concrete has a serious impact over inter-seasonal variation of land surface temperature (LST) in the city of Faridabad which is a major threat for sustenance of the urban ecosystem (Ghosh et al. 2021). Air quality of Faridabad is worse in morning and evening times during winter months due to drop in temperature leading to temperature inversion. This traps the pollutants near the ground and does not let the pollutants disperse (Sihag et al. 2019). The open burning of waste in the city of Faridabad is causing air pollution, worsening of the air quality and reduction in visibility and making disposal sites dangerously unstable leading to various illnesses and diseases (Yadav et al. 2016). The quality of water in the Yamuna River, Agra Canal, Budhiya Nala and Gaunchi Drain is getting worse (Kumari et al. 2018). This has forced the agricultural and industrial activities to largely depend on groundwater. Leaching of fertilizers due to water logging and presence of effluents from industries are contributing to high levels of Cl and NO_3 in the groundwater (Kumari et al. 2018).

In the present circumstances, it is pertinent to conserve the city's fast-depleting urban green and blue spaces and biodiversity. At Convention on Biological Diversity (CBD) (COP 9) in May 2008 in Bonn, Germany, mayors of the Steering Committee (Bonn, Curitiba, Montreal and Nagoya) addressed the ministers and high-ranking officials from parties, followed by proposal by Mr. Mah Bow Tan,

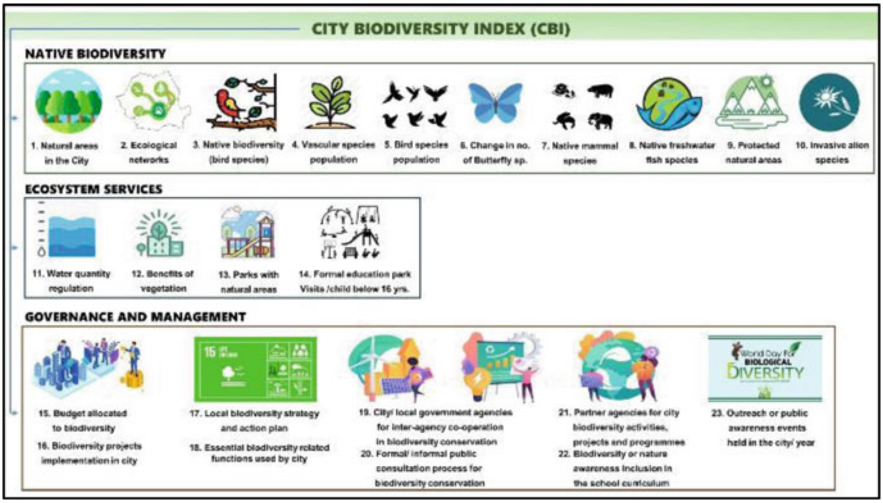


Fig. 20.3 City Biodiversity Index and its categorization of 23 indicators into native biodiversity, ecosystem services provided by biodiversity and governance and management of biodiversity

former Minister for National Development of Singapore, for the establishment of an index to evaluate biodiversity conservation efforts in the cities which further led to the formation of an evaluation tool known as City Biodiversity Index or Singapore Index on Cities' Biodiversity.[11] Due to Singapore's contribution towards leadership and formulation of the index, the index was renamed as the Singapore Index on Cities' Biodiversity or Singapore Index. City Biodiversity Index (CBI) as a biodiversity and ecosystem assessment tool can help to evaluate the city administration and citizen efforts in biodiversity and ecosystem conservation in Faridabad to reduce depletion of ecosystem services to ensure human well-being in the long run. CBI consists of the 'Profile of the City', which gives information on the background of the city and 23 indicators which can be classified under three important categories, viz. native biodiversity, ecosystem services provided by biodiversity and governance and management of biodiversity (Fig. 20.3). Each indicator is assigned a quantitative scoring range between zero and four, which sums up to 92 as total possible maximum score.[12] CBI has been evaluated as a good indicator of urban biodiversity and ecosystem health for cities around the globe like Yokohama, Kanazawa, Lisbon, Helsinki and Edmonton (Kohsaka et al. 2013). Pune, Faridabad, Raipur (Bhattacharya, 2017), Kochi,[13] Gangtok,[14] Pimpri Chinchwad[15] and Kolkata (Paul and Bardhan 2017) are some of the Indian cities where CBI has been assessed so far.

[12] cbd.int (User's Manual on City Biodiversity Index).

[13] c-hed.org.

[14] talkofthecities.iclei.org.

[15] pcmcindia.gov.in.

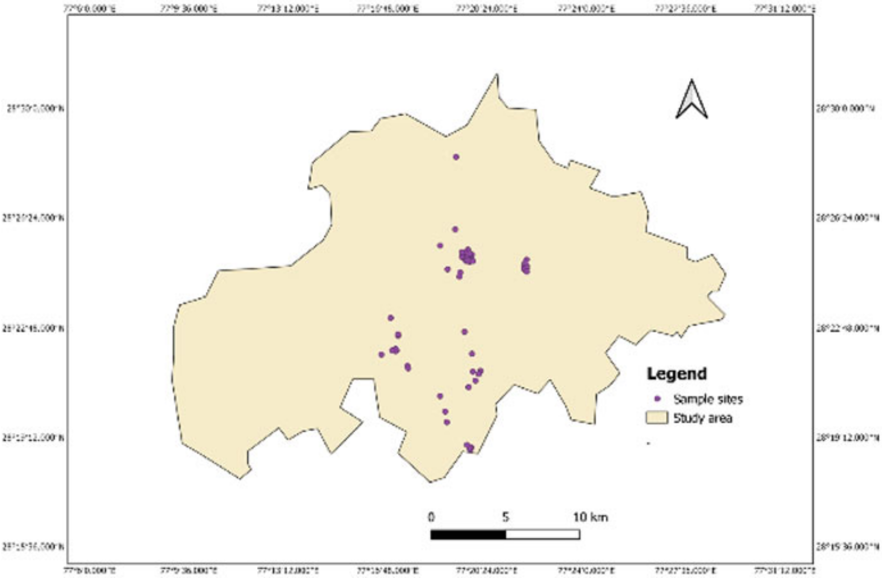


Fig. 20.4 Faridabad ward map showing survey locations in 15 wards for participatory assessment

Most of the cities in India where CBI has been assessed are Tier I, Tier II and Tier III cities.

The CBI score becomes relevant for the urban planners and policymakers to plan better urban plans and policies for conserving fast-depleting urban blue-green spaces in the city. In an attempt to assess the urban biodiversity health in a city that is close to Delhi NCR, a fast-growing city near to the capital city of India, and is almost having boundaries merged with Delhi and is centre of rapid urbanization, we chose to assess the City Biodiversity Index for Faridabad following the Singapore Biodiversity Index User Manual for CBI.[11] In our analysis, the city scored a total of 64 out of 92 for all the 23 indicators that can be considered significant despite fast urban expansion.

A participatory survey was conducted for understanding the change in the number of different kinds of species in Faridabad including birds, plants, butterflies, freshwater fishes, and mammals. Fifteen wards of Faridabad (Fig. 20.4) were targeted to understand the perception of the people (aged 20 or more) regarding change in the biodiversity of Faridabad since a decade back through a range of questions. A total of 60 individuals from 15 wards of the city were questioned in the month of March in 2021. The survey was planned and carried out at multiple places in each ward. A questionnaire was developed, and questions were asked via online Google forms as well as personal face-to-face interactions, and interviews were carried out to understand the local perceptions. Questions were translated in the local language too for better outreach and understanding. Survey respondents were selected randomly, and hence, bias was avoided.

Table 20.1 List of indicators (1–10) under category of 'Native Biodiversity in the City' with their score achieved and maximum score

Indicator number	Indicators	Score achieved	Maximum score
1	Proportion of natural areas in the city	4	4
2	Connectivity measures or ecological networks to counter fragmentation	4	4
3	Native biodiversity in built-up areas (bird species)	4	4
4	Change in number of vascular plant species	3	4
5	Change in number of bird species	4	4
6	Change in number of butterfly species	4	4
7	Change in number of native mammal species	1	4
8	Change in number of native freshwater fish species	1	4
9	Proportion of protected natural areas	1	4
10	Proportion of invasive alien species	1	4

To understand the background of key respondents in Faridabad, some basic questions were asked related to their age, gender, educational qualifications, employment status and income, i.e. points that influence their interests and responses. A total of 60% males and 40% females participated in the survey. Respondents were further segregated in four age groups starting from 20 years as the minimum target age for the survey. Of the respondents, 33.3% were in the 51–65 years age group followed by 31–50 years (31.7%) and 20–30 years (23.3%), and the least number of respondents were from >65 years age group (11.7%). Of the respondents, 31.7% were graduates, while 15% were educated till intermediate, 13.3% high school, 11.7% each diploma holders and educated till class five, 3% each educated till intermediates and other miscellaneous educational backgrounds, 10% postgraduates, 5% educated till middle school and 1.7% till class three. Of the respondents, 40% were employed, 3.3% unemployed, 6.7% students, 20% retired from various jobs, and 30% house caregivers. About 26.7% earned <3 lakh/annum, 8.3% earned 3–5 lakh/annum, 3.3% had an annual income of 5–10 lakhs, only 1.7% were earning >10 lakhs and 60% had no earnings at all.

The first set of indicators of CBI considers 'Native Biodiversity in the City' comprising indicators that contribute to the robust score to the CBI (Table 20.1). Urban green (Wadhawa and Ahmad 2010) and blue spaces (Jawak and Chattopadhyay 2018; Siddiqui et al. 2012, 2013) of Faridabad are observed by authors to have rapidly converted into infrastructure build-up and concretized places. The lakes of Faridabad that come under urban blue spaces have mostly dried up in the last one decade. In our survey, we found urban green spaces of the city are more accessible to the residents of Faridabad than urban blue spaces. Some of the urban blue spaces which are frequently visited by locals are Badkhal Lake (Fig. 20.5) and Surajkund Lake, while the urban green spaces that are used frequented by the locals

Fig. 20.5 Dried up Badkhal Lake

Fig. 20.6 Rose Garden of sector 17

are Rose Garden (Fig. 20.6) and Town Park (Fig. 20.7). Rapid change has been observed in different species of birds (Chhabra et al. 2017; Tiwary et al. 2013; Gupta and Kaushik 2014; Kaushik et al. 2015), plants (Ahmad et al. 2013), butterflies,[16] freshwater fishes (Bhatnagar and Yadav 2016) and mammals (Ganguly and Chauhan 2018) due to the fast-expanding urban sprawl. Though the proportion of the natural areas in the city can be still considered high, the proportion of protected green areas is comparatively less (only one being Mangar Bani forest).[17] The extent of

[16] jagran.com.

[17] hindustantimes.com.

Fig. 20.7 Floral Clock in Town Park of sector 12

Table 20.2 List of indicators (11–14) under the category of 'Ecosystem Services Provided by Biodiversity in the City' with their score achieved and maximum score

Indicator number	Indicators	Score achieved	Maximum score
11	Regulation of quantity of water	4	4
12	Climate regulation: carbon storage and cooling effect of vegetation	0	4
13	Recreation and education: area of parks with natural areas and protected or secured natural areas/1000 persons	4	4
14	Recreation and education: average number of formal educational visits per child below 16 years to parks with natural areas or protected or secured natural areas per year	1	4

encroachment of invasive species is reported to increase in the city with *Lantana camara* and *Parthenium hysterophorus* being the most dominant ones (Dwivedi et al. 2018). Encroachment and spread of invasive species in urban green spaces need to be recorded and monitored to reduce the loss of native species of the region from the city green spaces.

The second set of CBI indicators considers indicators 11–14 which relate to 'Ecosystem Services Provided by Biodiversity in the City' and contribute to the score of CBI (Table 20.2). CBI score for ecosystem services is contributed primarily by the natural blue-green spaces of the city. Green spaces like in Aravali forest and parts of Asola Bhatti Wildlife Sanctuary are the lungs of the city of Faridabad (Baviskar 2018). The tree canopy cover in the city is depleting fast due to increase in the urbanization in the city. More native tree plantations are required in the city with participatory efforts of organizations and citizens to increase tree canopy cover

Table 20.3 List of indicators (15–23) under category of 'Governance and Management of Biodiversity in the City' with their score achieved and maximum score

Indicator number	Indicators	Score achieved	Maximum score
15	Budget allocated to biodiversity	1	4
16	Number of biodiversity projects implemented by the city annually	2	4
17	Policies, rules and regulations: existence of Local Biodiversity Strategy and Action Plan	4	4
18	Institutional capacity: number of biodiversity-related functions that the city uses	4	4
19	Institutional capacity: number of city or local government agencies involved in inter-agency cooperation pertaining to biodiversity matters	4	4
20	Participation and partnership: existence of formal or informal public consultation process pertaining to biodiversity-related matters	4	4
21	Participation and partnership: number of agencies/ private companies/NGOs/academic institutions/ international organizations with which the city is partnering in biodiversity activities, projects and programmes	4	4
22	Education and awareness: is biodiversity or nature awareness included in the school curriculum (e.g. biology, geography)?	4	4
23	Education and awareness: number of outreach or public awareness events held in the city per year	1	4

of the city. These can be of tree species like *Mangifera indica*, *Azadirachta indica* and *Ficus religiosa*. It was also observed that not many capacity-building and awareness generation activities and tours are organized by schools for students and children for inculcating the importance of urban green spaces from a very early age.

The third set of CBI indicators considers 15–23 that corresponds to 'Governance and Management of Biodiversity in the City' and also contributes to CBI as a measure of good governance and management to conserve biodiversity and ecosystems (Table 20.3). The budget allocated for biodiversity and ecosystem conservation is low compared to the total financial budget of the city. Total budget of Faridabad is Rs 1876 crores.[18] Budget for biodiversity conservation, ear tagging of cattle, implementation of Swachh Prangan Scheme and establishment of eco clubs in Faridabad sums up to Rs 3.133 crores.[19] A total of 5.205 crores are sanctioned for conservation and management of the environment and forest in Faridabad.[20] Although Faridabad is being developed as smart city under Atal Mission for

[18] tribuneindia.com.

[19] web1.hry.nic.in.

[20] news18.com.

Rejuvenation and Urban Transformation (AMRUT) (2015), unfortunately, it focuses on the electrification and technological development of the city. Certain biodiversity projects are implemented in the city that include Project Summer Lifeline,[21] 'Adopt a Tree' Tree Plantation Campaign,[22] Our Solutions in Nature[23] and Eco Bricks.[24] Some of the public awareness events held in the city in last two years (2019–2021) are Aravali Yatra, Dry Waste Collection Drive, Paryavaran Pathshala and Paudha Mera Dost. Some of the government agencies involved in the biodiversity-related matters are Haryana Forest Department, Department of Agriculture, Department of Animal Husbandry and Haryana State Biodiversity Board, while the NGOs involved for biodiversity activities and programmes are Save Aravali Trust, Haryana Environmental Management Society, Eco Club and Navchetna Trust. Some of the biodiversity-related arrangements with reference to open green spaces in the city are Town Park, Rose Garden and the Leisure Valley Park which are frequently visited by the people and provide diverse ecosystem services. Environmental sciences have been included in the school curriculum for generating environmental awareness to the students. The education department has directed all government schools in Faridabad to form ecological clubs to strengthen environmental learning in a more practical way and enhance a sense of belongingness for city urban green spaces.

Figure 20.8 shows the proportion of score achieved for each of the three categories, viz. native biodiversity, ecosystem services and governance and management for 2021 vs. 2017. The first CBI for Faridabad was assessed by Bhattacharya (2017) though it was not very comprehensive in data that was analysed and discussed (excluded indicators 4–8 that take into account change in number of native species). An increase in the score for all the three components of the indicators was observed during the present when compared with CBI scores for Faridabad in 2017. The highest margin of scores was observed in the governance and management aspects for city biodiversity, which was by 50%, followed by native biodiversity component in the city by 42.5%. There were insignificant changes in the city ecosystem services that were by 12.5%. The scores for governance and management of biodiversity were observed to be doubled in 4 years which reflect towards better governance approaches involving multiple stakeholder groups for biodiversity aspects in the city.

[21] pfafaridabad.com.

[22] jcboseust.ac.in.

[23] haryanaforest.gov.in.

[24] hepf.in.

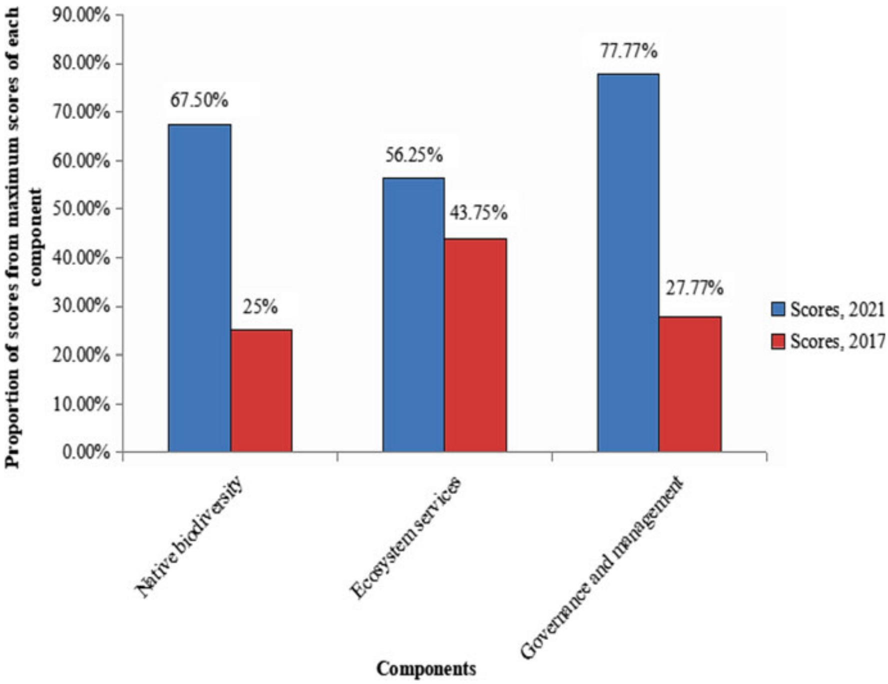


Fig. 20.8 Proportion of score achieved for each of the three categories, viz. native biodiversity, ecosystem services and governance and management (2021 vs. 2017)

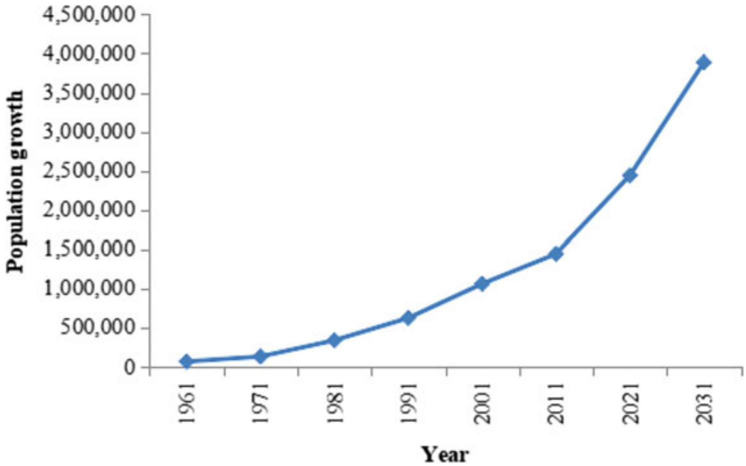


Fig. 20.9 Rise in population of Faridabad (source: masterplansindia.com)

20.3 Concerns for City Ecosystem and Biodiversity

Urban sprawl for the city of Faridabad close to Delhi has resulted in decline in size and numbers of the blue-green infrastructure in the city, an obvious observation from fast-growing urban expansions across the country (Dhyani et al. 2018). Due to the recent exponential population growth in the city (Fig. 20.9) and the rapid socio-economic changes, Faridabad has of late witnessed spatial expansion in its administrative boundaries. Rise in population and urban expansion are key factors that influence enhanced vulnerability due to climate variability. Air, water and noise pollution; increasing intensity of heat islands; and earthquakes are the important concerns for the growing city of Faridabad.

Urban green spaces especially per capita green space availability and demand and supply gap for urban publica green spaces are already affected by the increasing population of the city (Lahoti et al. 2019). Indian cities have per capita green space availability of around 2.7 m^2, which is far less than other cities of the world. WHO standards for per capita green space availability is 9 m^2, and the best is around 16 m^2 (McKinsey and Company 2010). The per capita green space availability and easy accessibility and reliability to urban green spaces are the basic factors that become important for the healthy and quality lifestyle of the urban residents.[25] There has been rapid deforestation, removal of green covers and urban green spaces in the growing cities due to not only natural increase in the population but also a huge rate of immigration (Malik et al. 2017). Faridabad has also followed this exponential rise in population also because of rapid increase in immigrants due to increased industrialization in the city.

Urban blue spaces in Faridabad have many important functions, and they also help in sustaining fish and other aquatic flora and fauna; securing water availability, food and other materials and biodiversity; controlling floods; and recharge of groundwater, followed by climate change mitigation and adaptation.[26] Wetlands are called kidneys in these urban landscapes, but they have been receiving water and waste both from natural and non-natural sources (Mitsch et al. 2015). Land area cover affects rivers, wetlands and lakes, while climate change as a mega driver affects them too (Xu et al. 2019). The serious cause of concern for wetlands of Faridabad is that they are rapidly getting converted into construction and dumping sites which have a deteriorating impact largely on the city atmosphere. Area of Badkhal Lake in Faridabad is continuously decreasing due to an increase in the number of immigrants and temporary settlements, mostly slums near the lake area (Jawak and Chattopadhyay 2018). The non-permeable/heaving concretized area adjoining Badkhal Lake has increased from 6.34 km^2 in 1999 to 17.04 km^2 in 2017, and now the Badkhal Lake has no water in it, and locals living close to Badkhal Lake are using the dried-up lake basin for grazing their domestic animals (Jawak and Chattopadhyay 2018). This dried-up lake during heaving monsoon rains

[25] unfpa.org.

[26] ramsar.org.

again gets some water, and if it is used for infrastructure, build-up can lead to disaster risks as well.

Decrease in the number of different species like plants, birds, butterflies, mammals and freshwater fishes in the city of Faridabad is a serious cause of concern that needs conservation priority. Prominent plants rarely observed in the city of Faridabad now are *Azadirachta indica*, *Mangifera indica*, *Syzygium cumini*, *Artocarpus heterophyllus*, *Carica papaya*, *Lawsonia inermis*, *Saraca asoca*, *Vachellia nilotica*, *Ziziphus mauritiana*, *Morus alba*, *Ficus religiosa*, *Ficus benghalensis*, *Dalbergia sissoo*, *Psidium guajava*, *Aegle marmelos*, *Tectona grandis*, *Butea monosperma*, *Ficus racemosa*, *Madhuca longifolia*, *Pithecellobium dulce*, *Tamarindus indica*, *Limonia acidissima*, *Moringa oleifera*, *Phoenix dactylifera*, *Salvadora persica*, *Sapindus mukorossi* and *Citrus limon.* These are the common plants that were observed in most areas, but due to the urban expansion, the status of these native plants is dwindling. The prominent birds rarely observed in the city of Faridabad now are *Passer domesticus*, *Psittacula krameri*, *Ardeola grayii*, *Pavo cristatus*, *Gyps indicus*, *Spilopelia chinensis*, *Columba livia*, *Alcedo atthis*, *Turdus migratorius*, *Acridotheres tristis*, *Grus antigone*, *Coracias benghalensis*, *Bubo bengalensis*, *Pycnonotus cafer* and *Clanga hastata*. The birds are observed migrating towards green spaces and forests on the outskirts of Faridabad. However, many bird species are observed randomly in the built-up areas of Faridabad especially in gardens, lawns and public lakes. A total of 95 bird species are reported from the built-up areas of Faridabad.[27] Butterflies are rarely observed in the built-up areas of Faridabad due to decrease in the number of plant species in which butterflies prefer to lay eggs. The prominent mammals rarely observed in the city of Faridabad now are *Sus scrofa domesticus* (domestic pig)**,** *Equus africanus asinus* (donkey), *Ovis aries* (sheep)*,* *Mus musculus* (house mouse), *Funambulus palmarum* (Indian palm squirrel), *Felis catus* (cat), *Boselaphus tragocamelus* (nilgai), *Axis axis* (spotted deer), *Paraechinus micropus* (Indian hedgehog), *Vulpes vulpes* (red fox), *Oryctolagus cuniculus* (coney), *Herpestes edwardsii* (Indian grey mongoose), *Canis aureus* (golden jackal), *Bubalus bubalis* (water buffalo), *Suncus murinus* (Asian house shrew) and *Bos taurus* (cattle). *Sus scrofa domesticus* has tremendously shown a decrease in their numbers due to a ban by the government for rearing them. An interesting fact is that the number of *Macaca mulatta* has increased to a large extent in the expanding city of Faridabad. Due to increased deforestation, *Macaca mulatta* are shifting to built-up areas of the city which is leading to human-animal conflict. The freshwater fishes rarely observed in the city of Faridabad now are *Ailia coila*, *Cyprinus rubrofuscus*, *Labeo bata*, *Hypophthalmichthys molitrix*, *Heteropneustes fossilis*, *Lates calcarifer*, *Notopterus notopterus*, *Mastacembelus pancalus*, *Solea solea*, *Sperata aor*, *Mystus tengara* and *Chitala chitala.* From the Aravali hill area, many threatened bird species are documented, viz. *Aythya nyroca*, *Mycteria leucocephala*, *Ephippiorhynchus asiaticus*, *Threskiornis melanocephalus*, *Anhinga melanogaster*, *Perdicula argoondah*, *Ardeotis nigriceps*, *Vanellus*

[27] ebird.org.

duvaucelii, *Aegypius monachus*, *Numenius arquata*, *Psittacula eupatria*, *Falco jugger* and *Aquila nipalensis* and also other animals like *Herpestes edwardsii* (Indian grey mongoose) and *Sceloporus undulatus* (eastern fence lizard) and the plant *Boswellia serrata* (Verma et al. 2019). These species require immediate conservation efforts and strict enforcement of conservation policies so that they can be saved from going extinct from the city boundaries.

20.4 Suggestions and Way Forward

CBI is a tool for establishing appropriate management of native biodiversity, ecosystem services and governance and management in the city. The issues and challenges of CBI are required to be addressed to ensure conservation of biodiversity, ecosystems by appropriate policy planning and enforcement. Three main technical issues with CBI that should be looked upon include comprehensive collection of data for understanding the criteria and indicators, establishment of spatial territories and elucidation of the different ecological backgrounds of the city (Uchiyama et al. 2015). These three major thrust areas should be precisely defined while working with the indicators of CBI. Following based on our comprehensive study for the urban expansion of Faridabad can help improve the situation and can also be replicated and used for other 100 smart cities especially Tier II and Tier III cities which still have scope to be improved by incorporating suggestions to improve the health of urban blue and green spaces:

- Ecosystem services include a social dimension, as they are produced by an interconnected social-ecological system. The term nature-based solutions (NbS), introduced by IUCN as an umbrella term especially using natural infrastructure and green infrastructure, can help urban expansions (Dhyani et al. 2020a, b). However, this will require active participation of urban planners and local city dwellers. In addition to this, a keen interest in mainstream environmental engineering approaches to cope up with the environmental challenges in the cities and resilience of the urban landscapes by using site-specific solutions to address societal environmental challenges can help. Ecosystem-based approach and ecosystem-based disaster risk reduction approaches (EbDRR) which includes management of the ecosystem in combination with disaster risk reduction strategies are key solutions to these issues that Indian cities are facing in a very significant scale (Dhyani et al. 2018). Citizen science approaches should be focussed where communities and individuals can learn about management and conservation of ecosystem and biodiversity in a more scientific manner. Species lists tend to be cumulative and need to be well documented and updated every year so that monitoring can help to assess the change in the number of different species. More focus should be on the common species like vascular plants, birds and butterflies which are present almost everywhere, and citizen scientists can play a big role in these local monitoring programmes. Eco clubs of schools can be great contributors for these important city-level cities and can also help capacity building.

- More detailed baseline biodiversity surveys can help to evaluate the results for indicators 3–8 (i.e. native biodiversity). Garden department of the city administration should take contributions from wildlife and nature enthusiasts in the city for developing the city biodiversity database.
- While native species need to be conserved, efforts should also focus on reducing the encroachment of invasive alien species by batch-wise removal and restoration of these patches by native tree, shrub and herbs. Protection and conservation of the protected natural areas by the local people of the city can help implement and enforce conservation strategies and plans.
- Focusing on avenue plantations can be considered as a priority as these are important corridors for city wildlife movement for birds, small mammals, etc. Planting tolerant fast-growing and preferably native species along roadsides helps in the reduction of air pollution and heat island effect.
- The annual budget allocated to biodiversity conservation is far less than what is expected. More projects and programmes related to biodiversity need to be conducted by the governmental organizations and non-governmental organizations in the city including municipalities as they can explore the possibilities of launching citizen science projects with active support from academic and research institutes in the city and school children as volunteers that can help in developing well-planned LBSAP. Besides teaching environmental sciences to the students, this practical exposure can inculcate the values of nature and environment conservation from a very early age. Some of the indicators, particularly in the governance and management section, can be merged because institutional arrangements such as the budget, number of projects and programmes and existence of departments overlap with one another. Hence, convergence of government line department activities can find relevance and better outputs.

20.5 Conclusion

In line with the current biodiversity conservation trends and international biodiversity targets, this chapter presents a baseline account of the urban biodiversity status of the rapid urban expansion of Faridabad, which will further serve as a benchmark for future assessments of concerned stakeholders. Based on the index and performance of the indicators, with a score of 64 out of 92 for all the 23 indicators, Faridabad demonstrates the features of good governance, but ongoing rapid industrialization and immigration have led to continuous decline in the area of urban blue and green spaces in the city. A large number of native plants are being lost due to deforestation, and exotic species are being introduced into the city. This unplanned urbanization has led to local habitat loss for various wildlife species and microfauna. There is an immediate need to prioritize the conservation of wetlands in Faridabad and prevent them from becoming dumping grounds which has great repercussions in the near future in the form of serious climate change.

Conflict of Interest Statement The authors report no conflict of interest for this publication.

References

Adlakha D, Chandra M, Krishna M, Smith L, Tully MA (2021) Designing age-friendly communities: exploring qualitative perspectives on urban green spaces and ageing in two Indian megacities. Int J Environ Res Public Health 18(4):1491. https://doi.org/10.3390/ijerph18041491

Ahmad J, Malik AA, Shakya L (2013) Urban development: a threat to wild species of medicinal and aromatic plants. Middle-East J Sci Res 1(7):947–951

AssetYogi (2021) Faridabad master plan 2031. https://assetyogi.com/faridabad-master-plan/#:~:text=Faridabad%20Master%20Plan%202031%20has,2031%20in%20faridabad%20master%20plan. Accessed 5 June 2021

Baviskar A (2018) Urban jungles wilderness, parks and their publics in Delhi. Econo Political Weekly l(2)

Bhatnagar A, Yadav AS, Neeru (2016) Fish diversity of Haryana and its conservation status. J Appl Nat Sci 8(2):1022–1027.doi: https://doi.org/10.31018/jans.v8i2.915

Bhattacharya T (2017) Comparative assessment of ecosystem and biodiversity conservation measures in Indian smart cities: a city biodiversity index approach. J-SustaiN 5(2):59–76. https://doi.org/10.24910/jsustain/5.2/5976

Chenoweth J, Anderson AR, Kumar P, Hunt WF, Chimbwandira SJ, Moore TLC (2018) The interrelationship of green infrastructure and natural capital. Land Use Policy 75:137–144. https://doi.org/10.1016/j.landusepol.2018.03.021

Chhabra S, Kirola H, Sethi N (2017) Song Thrush Turdus philomelos: a first record for Delhi NCR. Indian Birds 13(2):55

Dhyani S, Lahoti S, Khare S, Pujari P, Verma P (2018) Ecosystem based Disaster Risk Reduction approaches (EbDRR) as a prerequisite for inclusive urban transformation of Nagpur City, India. Int J Dis Risk Reduct 32:95–105. https://doi.org/10.1016/j.ijdrr.2018.01.018

Dhyani S, Fulwadhani P, Gujre N, Wate S (2020a) A Score-based Method for Assessing the Importance of Urban Forest and its Ecosystem Services. IJPE 6(01):35–36

Dhyani S, Karki M, Gupta AK (2020b) Opportunities and Advances to Mainstream Nature-Based Solutions in Disaster Risk Management and Climate Strategy. In: Dhyani S, Gupta A, Karki M (eds) Nature-based solutions for resilient ecosystems and societies. Disaster resilience and green growth. Springer, Singapore. https://doi.org/10.1007/978-981-15-4712-6_1

Dwivedi MD, Meena DS, Rather SA, Danda S, Kasana S (2018) Floristic diversity at Asola Bhatti wildlife sanctuary, Delhi, India. phytomorphol: Int J Plant Morphology 68(1&2):15–29

Fuller RA, Gaston KJ (2009) The scaling of green space coverage in European cities. Biol Lett. https://doi.org/10.1098/rsbl.2009.0010

Ganguly I, Chauhan NS (2018) Daily behavioural activity patterns and reproductive ecology of urban rhesus macaques (*Macaca mulatta*) in human dominated landscape and its implication in management. J Appl Nat Sci 10(4):1101–1108. https://doi.org/10.31018/jans.v10i4.1886

Ghosh S, Kumar S, Midya K (2021) Seasonal contrast of land surface temperature in faridabad: an urbanized district of Haryana, India. In: Tenedório J, Estanqueiro R, Henriques C (eds) Methods and applications of geospatial technology in sustainable urbanism, IGI Global, pp 217–250. https://doi.org/10.4018/978-1-7998-2249-3.ch008

Gupta RC, Kaushik TK (2014) Total and abrupt elimination of a population of Egyptian Vultures (Neophron percnopterus) on Delhi—Agra highway in India. Int J Life Sci 8(1):18–22. https://doi.org/10.3126/ijls.v8i1.8084

Hartig T, Mitchell R, Vries SD, Frumkin H (2014) Nature and health. Annu Rev Public Health 35: 207–228. https://doi.org/10.1146/annurev-publhealth-032013-182443

Imam AU, Banerjee UK (2016) Urbanisation and greening of indian cities: problems, practices, and policies. Ambio 45(4):442–457. https://doi.org/10.1007/s13280-015-0763-4

Jansson M (2014) Green space in compact cities: the benefits and values of urban ecosystem services in planning. Nordic J Arch Res 2:139–160

Jawak S, Chattopadhyay S (2018) Haryana's disappearing lakes. Geography and You (9)

Kaushik TK, Gupta RC, Vats PK (2015) Saras Cranes in Palwal District in Southern Haryana are asking for immediate attention for their last rescue effort. J Trop Life Sci 5(2):80–83

Kohsaka R, Pereira HM, Elmqvist T, Chan L, MorenoPeñaranda R, Morimoto Y, Inoue T, Iwata M, Nishi M, Mathias ML, Cruz CS, Cabral M, Brunfeldt M, Parkkinen M, Niemelä J, Kulkarni-Kawli Y, Pearsell G (2013) Indicators for management of urban biodiversity and ecosystem services: city biodiversity index. In: Elmqvist T et al (eds) Urbanization, biodiversity and ecosystem services: challenges and opportunities. Springer, Dordrecht, pp 699–718. https://doi.org/10.1007/978-94-007-7088-1_32

Komolafe A, Herath S, Avtar R (2018) Methodology to assess potential flood damages in urban areas under the influence of climate change. Nat Hazards Rev 19:05018001. https://doi.org/10.1061/(ASCE)NH.1527-6996.0000278

Kumari R, Datta PS, Rao MS, Mukherjee S, Azad C (2018) Anthropogenic perturbations induced groundwater vulnerability to pollution in the industrial Faridabad District, Haryana, India. Environ Earth Sci 77:187. https://doi.org/10.1007/s12665-018-7368-8

Lahoti S, Lahoti A, Saito O (2019) Benchmark assessment of recreational public urban green space provisions: a case of typical urbanizing Indian city, Nagpur. Urban Forest Green Spacing 44: 126424. https://doi.org/10.1016/j.ufug.2019.126424

Malik M, Siwach P, Prakash P (2017) Urban green spaces: a comparison of the Delhi NCR region and Kolkata municipal region. Int J Res Human Soc Sci 5(1)

McKinsey & Company (2010) India's Urban awakening: Building inclusive cities, sustaining economic growth. https://www.mckinsey.com/~/media/mckinsey/featured%20insights/Urbanization/Urban%20awakening%20in%20India/MGI_Indias_urban_awakening_full_report.ashx

Mitsch WJ, Bernal B, Hernandez ME (2015) Ecosystem services of wetlands. Int J Biodivers Sci Ecosyst Serv Manage 11(1):1-4. doi: https://doi.org/10.1080/21513732.2015.1006250

Nagendra H, Mundoli S (2019) Cities and canopies: trees in Indian cities. Penguin Random House India Private Limited

Nathalia D, Kumar KEM, Kishore N, Krishnan G (2017) Environmental change detection using geo—spatial techniques in Aravalli hills and environs (Faridabad District, Haryana). International Journal of Applied Environ Sci 12(5):865–875

Nor ANM, Corstanje R, Harris JA, Brewer T (2017) Impact of rapid urban expansion on green space structure. Ecol Indic 81:274–284. https://doi.org/10.1016/j.ecolind.2017.05.031

Nouri H, Borujeni SC, Hoekstra AY (2019) The blue water footprint of urban green spaces: an example for Adelaide. Australia Landsc Urban Plan 190:103613. https://doi.org/10.1016/j.landurbplan.2019.103613

Pasupuleti DNS, Sharma A, Lathwal S, Jagdish PS (2016) Sustainable smart solutions for City of Faridabad – a case study addressing Urban Infrastructure Problems. Int J Civil Eng Res 7(1): 33–40

Paul S, Bardhan S (2017) Biodiversity accounting of cities: a case study of Kolkata, India. Sustain Dev Plan IX 226. https://doi.org/10.2495/SDP170711

Pierce JR, Barton MA, Tan MMJ, Oertel G, Halder MD, Lopez-Guijosa PA et al (2020) Actions, indicators, and outputs in urban biodiversity plans: a multinational analysis of city practice. PLoS One 15(7):e0235773. https://doi.org/10.1371/journal.pone.0235773

Ramaiah M, Avtar R (2019) Urban green spaces and their need in cities of rapidly urbanizing India: a review. Urban Sci 3(3):94. http://dx.doi.org/https://doi.org/10.3390/urbansci3030094

Sadashivam T, Tabassu S (2016) Trends of Urbanization in India: issues and challenges in the 21 St century. Int J Inf Res Rev 3(5):2375–2384

Sahani S, Raghavaswamy V (2018) Analyzing urban landscape with City biodiversity index for sustainable urban growth. Environ Monit Assess 190:471. https://doi.org/10.1007/s10661-018-6854-5

Saini V, Tiwari RK (2020) A systematic review of urban sprawl studies in India: a geospatial data perspective. Arab J Geosci 13(17):1–21

Sen S, Guchhait SK (2021) Urban green space in India: Perception of cultural ecosystem services and psychology of situatedness and connectedness. Ecol Indic 123:107338. https://doi.org/10.1016/j.ecolind.2021.107338

Siddiqui R, Mahmood G, Ali SR (2012) Analysis of revitalization of Badkhal Lake using innovative GIS technique. Int J Sci Eng Res 3(11)

Siddiqui R, Mahmood G, Ali SR (2013) Analysis of sustainability of Surajkund Lake and determination of hydrodynamics of Delhi ridge with special reference to urbanization impact assessment. Int J Manage IT Eng 3(1)

Sihag P, Kumar V, Afghan FR, Pandhiani SM, Keshavarzi A (2019) Predictive modeling of PM2.5 using soft computing techniques: case study—Faridabad, Haryana, India. Air Qual Atmos Health 12:1511–1520. https://doi.org/10.1007/s11869-019-00755-z

Singh D, Satija A (2016) Municipal solid waste generation forecasting for Faridabad city located in Haryana State, India. In: Pant M, Deep K, Bansal J, Nagar A, Das K (eds) Proceedings of fifth international conference on soft computing for problem solving. Advances in intelligent systems and computing, vol 437. Springer, Singapore, pp 285–292. https://doi.org/10.1007/978-981-10-0451-3_27

Tian Y, Jim CY, Tao Y, Shi T (2011) Landscape ecological assessment of green space fragmentation in Hong Kong. Urban For Urban Green 10(2):79–86. https://doi.org/10.1016/j.ufug.2010.11.002

Tiwary NA, Sharma BB, Urfi AJ (2013) Two new nesting colonies of Painted Stork *Mycteria leucocephala* from northern India. Indian Birds 9(4):85–88

Tripathy P, Kumar A (2019) Monitoring and modelling spatio-temporal urban growth of Delhi using cellular automata and geoinformatics. Cities 90:52–63. https://doi.org/10.1016/j.cities.2019.01.021

Turrini T, Knop E (2015) A landscape ecology approach identifies important drivers of urban biodiversity. Glob Chang Biol 21(4):1652–1667. https://doi.org/10.1111/gcb.12825

Uchiyama Y, Hayashi K, Kohsaka R (2015) Typology of cities based on city biodiversity index: exploring biodiversity potentials and possible collaborations among Japanese cities. Sustainability 7(10):14371–14384

United Nations Department of Economic and Social Affairs(2018) Revision of world urbanization prospects. https://wwwunorg/development/desa/publications/2018-revision-of-world-urbanization-prospectshtml. Accessed 5 June 2021

Verma S, Kumar S, Amit, Rahul, Choudhary D (2019) Changes in biodiversity of Aravalli hills due to anthropogenic interventions in Haryana. Biodiversity and Climate change: impacts, adaptation and mitigation

Wadhawa M, Ahmad S (2010) Changes in land use pattern due to mining in Faridabad (Haryana). Paper presented at the 11th ESRI India User Conference 2010

Xu T, Weng B, Yan D, Wang K, Li X, Bi W, Li M, Cheng X, Liu Y (2019) Wetlands of international importance: status, threats, and future protection. Int J Environ Res Public Health 16:1818. https://doi.org/10.3390/ijerph16101818

Yadav K, Kaushik SP, Bansal ML (2016) Existing municipal solid waste management scenario in Faridabad city. Environ Ecol 34(4A):1907–1912

Chandan Das is a postgraduate student from the Institute of Environment & Sustainable Development, Banaras Hindu University (BHU), Varanasi, India.

Jayshree Shukla is a Researcher and Project Associate in Critical Zone Group (CZO) of Water Technology and Management Division (WT&MD), CSIR-National Environmental Engineering Research Institute (CSIR-NEERI), Nagpur, India.

Shalini Dhyani is a Senior Scientist at Critical Zone Group (CZO) of Water Technology and Management Division (WT&MD), CSIR-National Environmental Engineering Research Institute (CSIR-NEERI), Nagpur, India.

Greenhouse Gas Mitigation by Integrating Waste Treatment System Toward Low-Carbon City in Vietnam

21

Song Toan Pham Phu, Takeshi Fujiwara, Dinh Cuong Le, and Duy Bao Nguyen

Abstract

Environmental pollutions and greenhouse gas (GHG) emissions are among the dark sides of development and have been one of the critical driving forces of climate change. GHG is emitted from various activities, of which the waste treatment system is a significant source. This chapter describes the results of mitigating GHG by enhancing the solid waste management (SWM) system toward a low-carbon society in Hoi An City (HAC), Vietnam. The results showed that landfilling has the highest GHG emission with 808 kg CO_2-eq per tonne of waste, while incineration and composting emit on average 438 and 172 kg CO_2-eq/tonne of waste, respectively. The average carbon footprint value of waste in optimal SWM system (S3 and S4) is 337 and 307 kg CO_2-eq per tonne of solid waste treated. The GHG amount emitted from the minimalist SWM system (S1 and S2) is higher by 547 and 536 kg CO_2-eq/tonne of waste treated, respectively. The higher the solid waste management practice, the lower the GHG emission. This study also builds the oriented planning on improving the SWM system in HAC (Vietnam in general) in the next decade. The optimal SWM scenarios (S0-S3-S4) will significantly contribute to mitigating GHG emissions.

Keywords

Greenhouse gas · Solid waste management · Hoi An City

S. T. Pham Phu (✉) · D. C. Le · D. B. Nguyen
The University of Danang, University of Technology and Education, Danang City, Vietnam

T. Fujiwara
Graduate School of Environment and Life Science, Okayama University, Okayama, Japan

S. Dhyani et al. (eds.), *Blue-Green Infrastructure Across Asian Countries*,
https://doi.org/10.1007/978-981-16-7128-9_21

21.1 Introduction

Vietnam is a developing country in Southeast Asia, and one of the countries that are affected significantly by climate change. Low-carbon society (LCS) is a model that has been implemented in many developed countries; however, this concept is still very nascent in Vietnam. Urban and industrial activities are believed to be the primary source of carbon dioxide (CO_2) emissions into the atmosphere. However, greenhouse gases (GHG) from waste treatment systems are also a significant source (Calabrò 2009; Maria et al. 2020). According to the Vietnamese Ministry of Natural Resources and Environment (MONRE) report in 2020, the total GHG emission was 284 million tonnes of CO_2-eq, of which 6.69% was from the waste management system. In Vietnam, landfilling and incineration are the primary solutions to handle municipal solid waste (MSW). Landfilling, in particular, is an indirect driver for loss of green spaces in urban areas, and a proper waste management strategy is imperative to protect, preserve, and sustainably manage green open spaces. In Hoi An City (HAC), the location of the present study, landfilling and incineration are the primary solutions to handle municipal solid waste (MSW). Pham Phu et al. (2016) revealed that around 8855 tonnes of CO_2-eq were emitted from the MSW disposal sites in HAC, in which composting accounted for 90% of the total GHG emission.

Over the last decade, the MSW amount in Vietnam has increased significantly. In 2011, the total MSW generated was 44,400 tonnes per day. The quantity of solid waste soared up and reached 64,658 tonnes daily in 2019, increasing by 46% (Vietnam Ministry of Natural Resources and Environment 2020). The municipal solid waste management (MSWM) system in Vietnam is still sketchy; landfilling is the primary mitigation strategy for the MSWM system to reduce pollution. Especially in a tourism city, the significant amount of waste generated from tourism activities is the burden of the MSWM system; also, the SWM in the tourism area is a significant challenge faced by the government (Verma et al. 2016). The development of the SWM system in the tourism city should be based on the current status of the municipal SWM system, the feature of the tourism activities in implemented SWM practice, the consensus of business sectors and society, and the agreement of the government. Also, the sustainability in SWM, which should be considered in strategy-oriented planning, is defined as the appropriation and compatibility of the SWM model with the region's aim to reach the synchronous achievement of the environment-economy-society. Building an integrated MSW management system may contribute to mitigating GHG emissions toward a low-carbon city with conservation of green spaces.

21.2 Study Site and Methodology

21.2.1 Study Site: Hoi An City

Hoi An City (HAC) is a small ancient city located in the center of Vietnam. HAC has 13 administrative communes and wards with three regions: urban, suburban, and rural areas corresponding to the average population density of 8987, 2754, and

601 people/km^2, respectively. Hoi An City was famous as an international trading port in the early seventeenth century, along with many Chinese and Japanese architectural buildings. Thus, in 1998, HAC was recognized as a world cultural heritage by UNESCO. Since then, the tourism industry in HAC has flourished rapidly and has become a key economic driver of the city.

Currently, the MSWM system in HAC is facing several challenges. The rapid increase of municipal waste, the overload of waste in the tourism area, the disruption of the waste collection system, and the inefficiency in the waste treatment process are the major problems of the municipal SWM system (Pham Phu et al. 2017). These problems are caused by the nonperformance of the SWM practice at the source to the end of the waste flow. Thus, the improvement of SWM practice is considered as a radical solution to solve these problems. In which, enhancement of waste separation at the source is a priority. It may provide homogenous material for composting and obtains the higher calorific value of waste for incineration. This would also help minimize the amount of waste transported to the dumping site and save green spaces. For municipal SWM, which encompasses the functions of collection, transfer, treatment, recycling, resource recovery, and disposal of municipal solid waste, these problems should be addressed synchronously. The primary waste sources of tourism waste and hotel waste should be considered urgently.

21.2.2 Analyzing the Waste Flow of SWM Practice Models by Scenarios

Solid waste management practice in Hoi An City is developed into two directions as minimalism and optimization. The minimalism of SWM practice at sources in S1 and S2 is shown by the simple flow of the MSWM system in Fig. 21.1. Notably, the mixed waste flows directly from waste sources to the treatment area by trucks. While recyclables are sorted at source by the intention rate (S1) and optimal rate (S2), they are then collected by itinerant buyers or recycling carts. Collection crews pick out a part of recyclable residue in the mixed waste before loading it to the trucks. The recyclables are recovered by formal and informal sectors and sold to junk shops. Undeniably, being a part of the municipal SWM system, SWM practices in tourism activities must be implemented synchronously with that of the municipal.

Although HAC has deployed waste separation at the source since 2012, the waste sorting efficiency is still low, which was justified by many barriers (Pham Phu et al. 2018, 2019b). In the context of facing significant problems and challenges in the SWM system, specifically in tourist areas, the minimalism on SWM practice in S1 and S2 may be considered timely and consistent solutions for current situations.

In other aspects, the MSWM system has advantages and opportunities for improving the performance of SWM practice toward sustainability, an inevitable trend of development. The enhancement of the MSWM system that is simulated in S3 and S4 may create a more complicated waste stream. Figure 21.2 shows solid waste out of the sources with three separated directions due to segregation at source enhancement. The recovery flow of recyclables is a priority in all scenarios of the

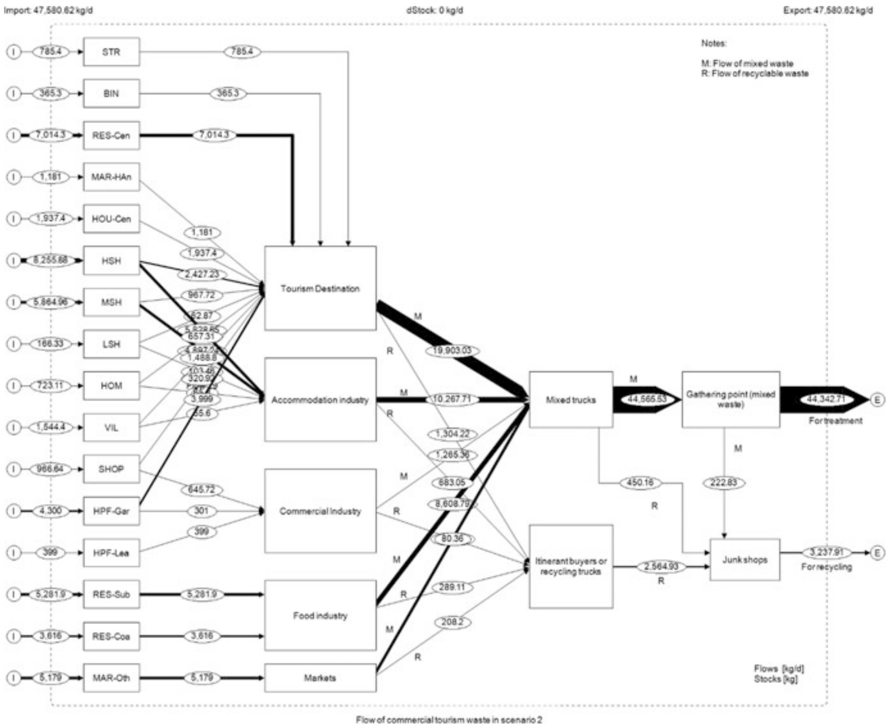


Fig. 21.1 The waste flow of the MSWM practice model in minimalism orientation

MSWM system in HAC and is handled by formal and informal sectors. Besides, one of the light points in S3 and S4 is the stock of waste in the flow by home composting. The improvement of composting practice at the source with the intention rate (S3) and optimal rate (S4) may reduce 3.7 tonnes and 8.8 tonnes of waste, respectively.

Notably, Fig. 21.2 indicates that a significant daily amount of waste is recycled at sources by composting in hotels and restaurants with a garden such as accommodation and restaurants. For Commercial sectors that have garden, biowaste is required to be sorted for home-composting, biowaste and non-biowaste are required to be sorted for daily collection by separate trucks. By enhancing the SWM practice, solid waste are gathered to the treatment area separately as biowaste for composting and non-biowaste for incineration.

In general, the more minimal the implementation of the MSWM practices at source, the higher is the consensus from communities. This may release barriers to the implementation of SWM practice at source and reduce challenges of the SWM system in the tourism destination. Also, the minimalism in SWM practice at source may bring the neatness to municipal waste flow and simplicity to the collecting system that may increase the collecting rate of tourism waste. Nevertheless, minimalism in the SWM system aims to maximize collection rate and minimize the

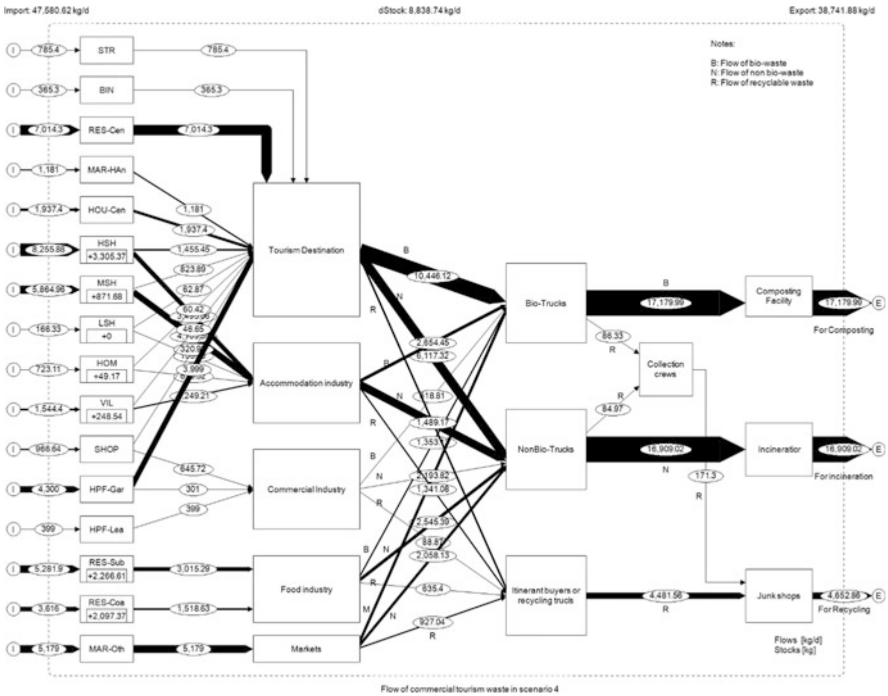


Fig. 21.2 The waste flow of SWM practice model in sustainable orientation

stagnation of solid waste in urban areas. The primary purpose of the MSWM system in developing countries in waste generation, health, and environmental problems is mounting urgency. For long-term strategy, the gradual improvement of the MSWM system is the necessary task toward sustainability, whereby the enhancement of waste separation at source, minimization of waste generation, and development of recycling practice are said to be the fundamental solutions of sustainable SWM system. Hence, to choose the optimal solutions for oriented planning of SWM practice, the effectiveness and suitability of the MSWM practice models should be analyzed and evaluated.

21.3 Results and Discussion

21.3.1 Evaluation of GHG Emission from Waste Treatment by Scenarios

The level of the MSWM practice may lead to the reduction of waste to treatment, the changes in waste composition, and characterization. Therefore, the emission from treatment is expected to be mitigated. Figure 21.3(a) presents that landfilling emits the highest amount of GHG with 808 kg CO_2-eq per tonne of waste. This is a

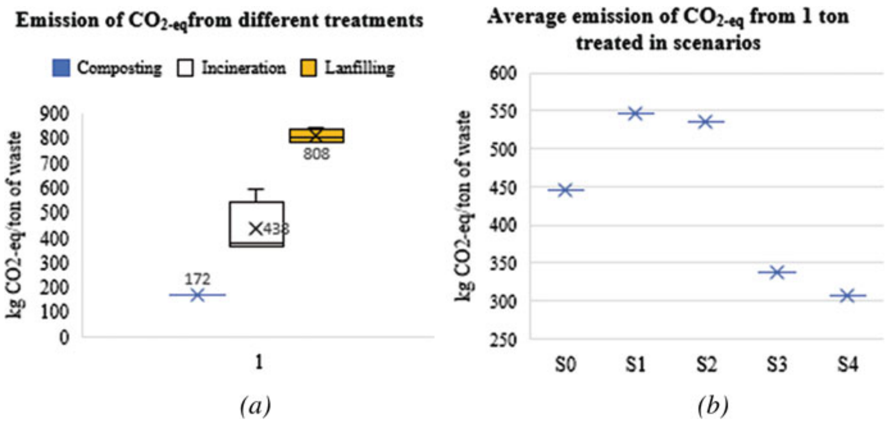


Fig. 21.3 Emission from waste treatment methods (**a**) and scenarios (**b**)

low-cost and straightforward disposal that is quite common in developing countries. At the same time, incineration and composting emit on average 438 and 172 kg CO_2-eq/tonne of waste treated, respectively. The low burning technology and inefficiency of exhaust gases treatment may be the reasons for the high emission from incineration in HAC. Composting may be an environmentally friendly solution. Composting is also an appropriate treatment method with solid waste that has a high content of organic components; that is the feature of solid waste in developing countries.

Nevertheless, the paradox is that waste separation at the source is not considered in these countries, and this is the biggest obstacle in operating composting. The role of composting in emission mitigation from waste treatment is demonstrated in Fig. 21.3b. The average carbon footprint value of the tourism waste in S3 and S4 is lower than that of S1 and S2. The higher the composting rate, the lower the emission. The differences in the value of the carbon footprint of the tourism waste in scenarios indicate that the improvement of the SWM practice may contribute to reducing the GHG emission from treatment than that of the minimalism.

21.3.2 Oriented Solid Waste Management Practice Planning for Hoi An City

This study presents the advantages and disadvantages of the minimalist and improved models of the SWM practice in HAC. The minimalism model in SWM practice seems to be quite popular in developing countries due to its compatibility with the flawed SWM system, the low level of SWM practice, and the restriction on facilities and lack of support (Khajuria et al. 2008). Besides, this study indicates that the tourism SWM system in HAC has a high potential for upgrading SWM practice toward sustainability. Notably, the municipal SWM system in HAC is more completed than other areas by abundant waste treatment plants such as composting

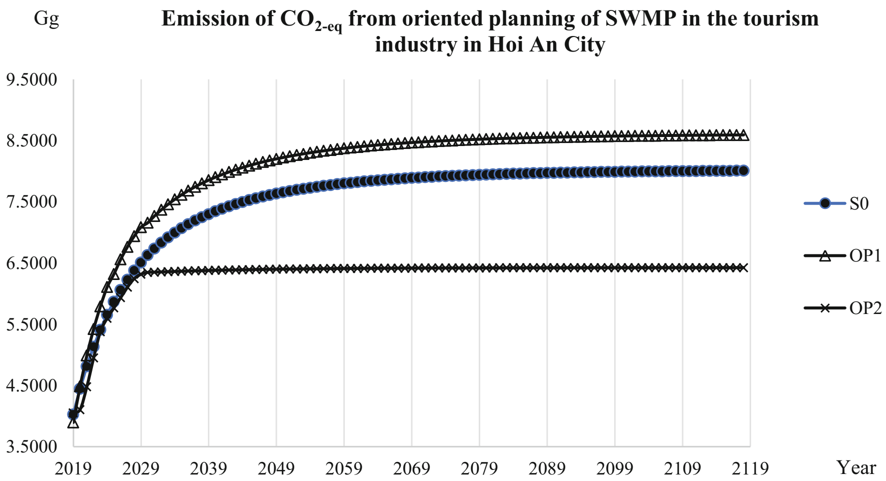


Fig. 21.4 GHG emission from projects of SWM practice in HAC

facilities and incineration plants. Also, waste is required to be sorted at the source and separately collected. These are the favorable condition for developing a municipal SWM system. Therefore, the development of SWMP for the TI in HAC can be planned by the project that consists of two phases with two different strategic directions in 10 years: notably, the minimalist SWMP project (OP1 – from S0 to S1 and S2) and the sustainable SWMP (OP2 – from S0 to S3 and S4) in 10 years.

OP1 has the advantage in the economic aspect; however, OP1 emits more GHG than other projects in terms of the environmental aspect. Figure 21.4 illustrates the estimation of GHG emissions from the treatment of tourism waste in 100 years. The development of SWMP in different orientations may affect the emission. Notably, the minimalism in SWM practice at source emits much GHG emission than that of the sustainability. This difference in emission may be explained by the reduction of waste to the landfill, which is the most polluted disposal in a long time, and the development of home composting that is an eco-friendly solution. Thus, OP2 proves that upgrading SWM practice plays an important role in emission mitigation in terms of the environment.

21.4 Conclusion

This chapter analyzes the situation of the SWM system, develops the scenarios for improving the SWM system in HAC, and evaluates GHG emission from SWM scenarios. As already mentioned, improvement of SWM system has direct consequence on GHG emission and conservation of green open spaces. This research revealed that:

(i) Composting emits 172 kg CO_2-eq/tonne of waste treated, less than that of incineration (438 kg) and the landfill (808 kg). So, reduction of waste to a landfill site by developing composting at source is a suitable solution to mitigate GHG emissions from the municipal SWM system.
(ii) The current model (S0) and the minimalism models (S1 and S2) of the SWM system emit more GHG than the optimal models (S3 and S4). The higher the SWM practice, the lower the GHG emission is.
(iii) The approaching pathway for improving the SWM system in HAC in the next decade is from S0 to S3 (5 years) and S3 to S4 (5 years), whereby the GHG emission from the SWM system is estimated to be lower than the BAU and OP1.

Conflict of Interest Statement The authors report no conflict of interest for this publication.

References

Calabrò PS (2009) Greenhouse gases emission from municipal waste management: the role of separate collection. Waste Manag 29(7):2178–2187. https://doi.org/10.1016/j.wasman.2009.02.011

Khajuria A, Yamamoto Y, Morioka T (2008) Solid waste management in Asian countries: problems and issues. WIT Trans Ecol Environ 109:643–653

Maria C, Góis J, Leitão A (2020) Challenges and perspectives of greenhouse gases emissions from municipal solid waste management in Angola. Energy Rep 6:364–369. https://doi.org/10.1016/j.egyr.2019.08.074

Pham Phu ST, Tran MT, Tran Thi NL (2016) Greenhouse gas emissions from municipal solid waste disposal sites – a case study in Hoi An City. Sci J Thu Dau Mot Univ 6(31):67–74

Pham Phu ST, Fujiwara T, Minh Giang H A (2017) Comparison of solid waste generation rate between types of hotel in Hoian Ancient City, Vietnam. In: The 28th Annual Conference of Japan Society of Material Cycle and Waste Management, Japan, 2017

Pham Phu ST, Hoang MG, Fujiwara T (2018) Analyzing solid waste management practices for the hotel industry. Global J Environ Sci Manage 4(1):19–30. https://doi.org/10.22034/gjesm.2018.04.01.003

Pham Phu ST, Fujiwara T, Hoang MG, Pham VD, Tran MT (2019a) Waste separation at source and recycling potential of the hotel industry in Hoi An city, Vietnam. J Mater Cycles Waste Manage 21(1):23–34. https://doi.org/10.1007/s10163-018-0807-5

Pham Phu STP, Fujiwara T, Hoang Minh G, Pham Van D (2019b) Solid waste management practice in a tourism destination – the status and challenges: a case study in Hoi An City, Vietnam. Waste Manage Res 37(11):1077–1088. https://doi.org/10.1177/0734242X19862042

Verma RL, Borongan G, Memon M (2016) Municipal solid waste management in Ho Chi Minh City, Viet Nam, current practices and future recommendation. Procedia Environ Sci 35:127–139. https://doi.org/10.1016/j.proenv.2016.07.059

Vietnam Ministry of Natural Resources and Environment (2020) Report on current status of Vietnam environment. Municipal Solid Waste, Vietnam

Song Toan Pham Phu, PhD is a Lecturer in the Environmental Engineering Department of the University of Danang (UD), Danang, Vietnam.

Takeshi Fujiwara is a Professor of the Graduate School of Environmental and Life Science, Okayama University, Japan.

L. E. Dinh Cuong is a staff of the Environmental Center at the University of Danang, Vietnam.

Duy Bao Nguyen is a staff member at the Environmental Center of the University of Danang, Vietnam.

Part VI

Policy Concerns for BGI

The Roles of Non-governmental Actors in Facilitating Urban Blue-Green Infrastructures: A Comparative Review of the Community Initiatives in Taipei City, Taiwan

22

Hsin-Hua Chiang, Tze-Luen Lin, and Pin-Ju Shih

Abstract

In the development of urban blue-green infrastructures (BGI), the involvement of the civil society has been emphasised in recent policy paradigms. Despite governmental efforts encouraging local residents to participate, in order to more fully identify demands and devise solutions, at the grassroots level, challenges still remain regarding stakeholder partnerships. Non-governmental actors are expected to facilitate top-down policy communication and bottom-up civil participation. Consequently, a deeper understanding of the problematics, functions and characteristics in action may help to suggest a better framework for stakeholder integration. The case study takes place in the Wenshan District, an urban settlement in Taipei City, Taiwan. From 2014 to 2019, in order to better cope with flood risk, BGI projects have been conducted by various non-governmental actors with divergent problematics and approaches. The chapter provides comparisons among diverse actors from three sectors: a local community group that offers local-based educational programmes, a consulting firm that focuses on participatory planning and design, and the researchers in a project team—representing civil society, private sector and academia, respectively. The details of each project are collected from meetings with the actors, as well as secondary data such as project reports and related materials. To illustrate the roles non-governmental actors play in facilitating urban BGIs, the study undertakes comparisons among the three actors in terms of their strategies of mobilising and networking with other stakeholders, along with patterns for upscaling the effects. Through the

H.-H. Chiang (✉)
Graduate School of Agriculture, Kyoto University, Kyoto, Japan
e-mail: chiang.hsinhua.52w@kyoto-u.jp

T.-L. Lin · P.-J. Shih
Department of Political Science, National Taiwan University, Taipei, Taiwan

S. Dhyani et al. (eds.), *Blue-Green Infrastructure Across Asian Countries*,
https://doi.org/10.1007/978-981-16-7128-9_22

comparative study, the chapter further implies an alternative framework for stakeholder integration

Keywords

Non-governmental actor · Urban blue-green infrastructure · Civil participation · Stakeholder integration · Community initiative

22.1 Introduction

The blue-green infrastructures (BGI) approach has been adopted to solve problems related to disaster mitigation and climate change adaptation in urban areas. Nonetheless, particularly when applying new approaches, reluctance and resistance to changing the status quo can hinder the implementation of urban BGIs (O'Donnell et al. 2017). Overcoming social-institutional barriers requires correspondence among various public and private sectors at different levels, in terms of such things as legislation, administration, enterprise and civil society. In addition, improvements in education, knowledge and awareness can further help bridge networks among stakeholders (O'Donnell et al. 2017). At the same time, achieving such social change requires negotiations and facilitations by intermediate actors, either through a bottom-up or top-down approach. With the bottom-up approach, raising civil awareness and consciousness not only enhances the stewardship of local communities in maintaining the infrastructures (Lamond and Everett 2019) but also helps to initiate policy advocacy within the authority (Schipper et al. 2014). On the grassroots level, community-based adaptation (CBA) has been promoted worldwide as an alternative solution for climate hazards and disaster preparedness (Aylett 2010; Picketts et al. 2012; van Aalst et al. 2008). Numerous participatory methods have been carried out in the process, such as risk assessment and vision development (Bennett et al. 2016; Picketts et al. 2012, 2013), which particularly highlight the function of non-government organisations (NGOs) in promoting grassroots participation and empowering local people to discover their own solutions to the local problematics (Bennett et al. 2016; Lassa 2018; van Aalst et al. 2008). Collaborative action has been carried out among academia, government and other organisations (Picketts et al. 2013), even though the grassroots experiences of those facilitators can differ from case to case. Previous studies have highlighted the benefits resulting from the involvement of community stakeholders. At the stage of planning, grassroots gatekeepers help to promote greater understanding and awareness, as well as to indicate local concerns that may not be included with the conventional approaches of scientific positivism. In addition, at the stage of implementation, community stakeholders can encourage the engagement of residents, which leads to the sustainability of positive outcomes (Chou 2013; McNaught et al. 2014; Mercer et al. 2012; Picketts et al. 2012).

For the top-down approach, issues regarding communication in terms of risk governance have also attracted attention (Chiang 2018; Howes et al. 2015), with increased demands to focus on cultural and political processes that shape risk perception and management among stakeholders (Granderson 2014; Schipper et al. 2014). Nonetheless, on the grassroots level, variation in personal experiences concerning climate change can make the construction of a collective narrative challenging. On the other hand, new technologies and strategies also depend on effective communication and interpretation between experts and the grassroots community. The roles of facilitating actors are particularly important if the gaps in knowledge and awareness between technocrats and non-expert stakeholders are to be erased. Meanwhile, despite the shifting of focus from governmental authorities to private actors, for policies designed to cope with climate change adaptation, implementation still tends to be dominated by the public sector, especially in European cases (Klein et al. 2017).

This chapter presents a comparative study of cases which differ from the governmental-oriented implementation for urban BGIs, with particular consideration being given to community-based climate change adaptation. Although the projects examined in the study area have been directly or indirectly funded by the public sector, the main actors for facilitating the planning and implementation are non-governmental. The chapter compares the experiences of moderating BGIs in an urban district for climate change adaptation among three sectors: non-profit organisations, academia and private enterprises. By identifying the possibilities and limitations of each sector regarding facilitation of urban blue-green infrastructures, the chapter aims to identify alternatives for stakeholder integration in a grassroots community.

22.1.1 Case Study Community: Wenshan District, Taipei City

The study takes place in several communities in Taipei City, Taiwan. Taiwan, a self-governing entity located in East Asia, and nearby islands are prone to typhoons and heavy rainfall, resulting in ongoing high risk of floods and landslides (Chiang and Chang 2011; Hsu and Chen 2002). The central government has issued a policy framework for climate change adaptation in 2012, with diverse objectives in the areas of disasters, infrastructure, water resources, land use, coastal environment, energy, biodiversity, agriculture and public health (Council for Economic Planning and Development 2012). With almost 80% of the population living in urban areas (Ministry of the Interior 2019), Taiwan has particularly emphasised adaptation strategies for urban communities (Council for Economic Planning and Development 2012). Governance guidelines stress the construction of participatory partnerships in decision-making, involving residents, experts, enterprises and authorities, as well as the mobilisation of existing networks in grassroots communities for promoting public awareness (Council for Economic Planning and Development 2012). However, the implementation of the national framework has still focused on municipal or national strategies, while practices related to grassroots community or common residents continue to take the form of top-down communication and education (National Development Council 2018). Consequently, a review of bottom-up initiatives can help to discover practical implications for community-based adaptation.

The chapter reviews the community BGI projects in Wenshan District, Taipei City, as examples to compare the function of non-governmental actors in introducing BGI and CBA to grassroots civil society. Taipei City is the centre of the largest metropolis in Taiwan. It has a population of 2.6 million within an area of 271.8 km^2, resulting in the highest population density (9575 persons per km^2) nationwide (Ministry of the Interior 2021). Wenshan District, located in the southernmost section of Taipei City, consists of an area of 3.509 km^2 and a population of 267,830 (Taipei City Government 2020b). The district has a hybrid character. It has housing, administrative and educational services but also offers suburban environments that attract tourists, thus creating a local image of integrated humanity and environment (Wang 2005). In terms of the population structure, Wenshan District boasts a young population with a lower aging index (129.54%) compared to the average of Taipei City (143.86%), as well as a lower dependency ratio (42.43%) compared to the municipal average (46.01%) in 2019 (Taipei City Government 2021). The location of Wenshan District is shown in Fig. 22.1.

Roughly 75% of the district is covered by hills, and the Jingmei River flows through the area (Taipei City Government 2009). This geography results in comparatively higher frequency of flooding events (Sung et al. 2017), while pressure from housing development is constantly increasing, creating the emergent need to build structures resilient to potential disasters (Huang and Cheng 2019). Enhancements in the Jingmei River embankments were carried out based on flooding estimates for the next 200 years, while several communities in Jingmei remain prone to floods due to the limited capacity of the drainage system (Wenshan District Office 2019). Although the mayor announced in 2017 that Wenshan District had been removed from the list of flood-prone areas within Taipei City (Central News Agency 2017), raising grassroots awareness towards climate change is still imperative. In particular, the Jingmei area, acknowledged as the area most vulnerable to flood risks within Taipei City, has the most intensive commercial activities and population density (Wenshan District Office 2019). Thus, strategies for coping with climate change adaptation remain essential there alongside infrastructure. Small-scale BGIs have been recommended as a way to mitigate flood hazards (Carter et al. 2018). They also echo the shift in municipal policy from comprehensive water management to construction of a “sponge city” that has been ongoing since 2015 for enhancing the resilience to floods (Hydraulic Engineering Office 2019).

On the other hand, Wenshan District also has its long history of bottom-up community action. Organised community initiatives in Wenshan District can be traced back to the mid-1990s, and there are 44 registered community associations at the township scale today (Ministry of Culture 2021; Taipei City Government 2020a). The bottom-up approach was first applied in the city’s project for improvement of the local environment in 1996, which encouraged citizens to propose projects for environmental reformation (Taipei City Urban Regeneration Office 2019). In addition, the community planner system established in 1999 invites professional planners to facilitate at the grassroots level (Classic Design and Planning 2019). Such

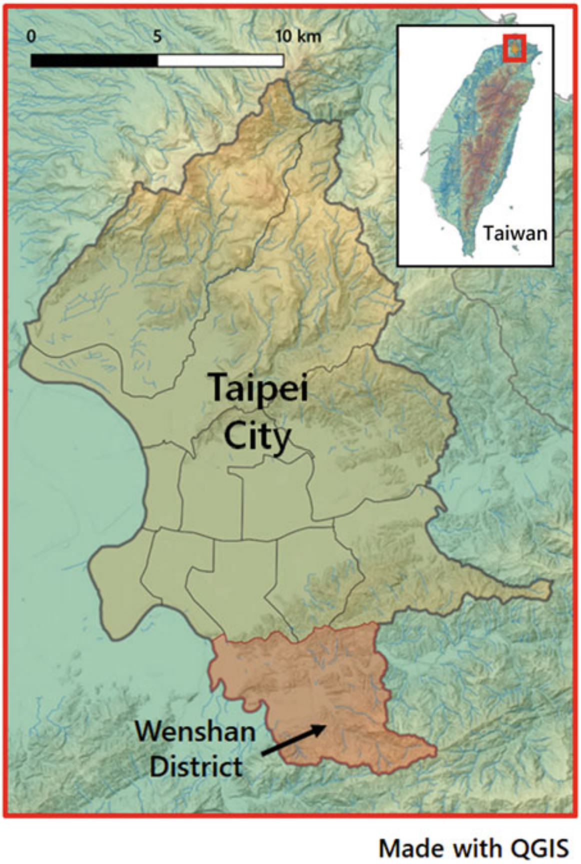


Fig. 22.1 Location of Wenshan District (map source: National Land Surveying and Mapping Center (2015a, b))

participatory planning projects have been conducted by professional planners, local groups, academics and the municipal government (Luo 2004). Concerning empowerment of civil society, Wenshan Community College has been one of the most active groups, and increasing engagement by the academics and consultant companies has also been observed. In considering the activities of community-based climate change adaptation in Wenshan District, this chapter focuses on the flood risk and highlights three actors which represent the main non-governmental facilitators in BGI implementation. They are Wenshan Community College as a civil group, the Classic Design and Planning Company as a private enterprise and the project team formed by research fellows at National Taiwan University and related research institutes as an academic group.

22.1.2 Non-governmental Facilitators in Community BGIs

The Community College has been one of the most active grassroots actors in community affairs in the district. As a type of non-governmental organisation committed to promoting life-long learning, community colleges have often been established at the level of districts or villages. Many of them offer courses about local history or the environment and otherwise seek to maintain intimate connections with grassroots society. Wenshan Community College was established in 1998 under the supervision of the National Association for the Promotion of Community Universities (NAPCA) (Wenshan Community College 2021). As a non-governmental organisation, the Community College offers programmes that explore local knowledge (dubbed "Wenshanology") and cultivate a civil society (Wenshan Community College 2021). Besides, it is worth emphasising that although the Community College provides educational programmes, the organisation is not considered part of academia as such. Instead, it often plays a role of introducing governmental/academic resources to the grassroots society. Therefore, in order to avoid confusion, hereafter, Wenshan Community College is referred to as the "Local Community Group." Moreover, the Community College is also one of the early local groups introducing CBA to the communities. Its accumulated social capital with the citizens has provided the basis for grassroots mobilisation. Their deep-rooted concern about local culture has also established a channel for interpreting the ideas of CBA through common understanding with local society. In addition, Wenshan District was certified as a "safe community" in 2010 (International Safe Community Certifying Centre n.d.). It then organised a division to network with the Community for Disaster Prevention in 2011, with the Local Community Group being invited as a member. However, an officer at the Local Community Group noted that despite empowering local volunteers to participate in disaster preparedness efforts, at the grassroots level, the community still lacked awareness of climate change issues.

In the private sector, the Classic Design and Planning Company (hereafter the "Consulting Firm") has also engaged in facilitation of BGI in the Wenshan District. As an engineering and planning consulting firm, the Consulting Firm has focused on participatory planning with environmental awareness and has implemented BGI programmes, such as rain gardens and community gardens, in collaboration with communities in other districts of Taipei City (Classic Design and Planning 2021). The Consulting Firm's project in the Wenshan District started with the objective of constructing a spatial scheme in communities adjacent to mountains (Classic Design and Planning 2019).

Compared to the roles of the Local Community Group and the Consulting Firm that involved direct interaction with local citizens, the role of the academics has been more like a multi-sector facilitator. The research team was organised under a collaborative programme about risk governance for climate change-induced disasters, funded by the Ministry of Science and Technology. The team was made up of actors from two institutions: National Taiwan University and the Science & Technology Policy Research and Information Center. The latter functions as a governmental think tank that contributes to policymaking in the realm of science and technology (Science and Technology Policy Research and Information Center 2020). The project aimed at mitigating disaster risks from floods and heatwaves, with the solutions implemented including improvement of blue-green infrastructures. Based on the partnership with the two previously described actors and governmental or non-governmental stakeholders, the research team facilitated a CBA platform including actors from different sectors and regional scales.

22.1.3 Data Collection

Material for comparison was collected for all the networking activities conducted by the research team (hereafter, the "Academics"). Related governmental and non-governmental actors were invited to give presentations and participate in roundtable discussions on a monthly basis. Furthermore, workshops and symposiums were conducted in 2018 and 2019. Details of the practices for facilitating blue-green infrastructures mentioned by the actors during their presentations at the gatherings were recorded. In addition, secondary data such as reports, news articles and other documents provided by the actors served as supplemental data for the comparative study.

22.2 Local Practices by Non-governmental Actors

The Local Community Group first initiated grassroots CBA action in the Wenshan District in 2012, when it listed climate change as one of five critical issues when it was developing its "Future Hometown Agenda." It took things a step further when it started workshops and lectures on CBA and then with its BGI initiatives from 2016 to 2019 (Huang and Cheng 2019). From 2015 to 2018, the Consulting Firm also initiated participatory planning for urban green spaces in the district (Classic Design and Planning 2019). Finally, the Academics became involved between 2016 and 2019. Acting as a bridging facilitator, the Academics connected grassroots efforts to resources from the governmental authorities and other non-governmental groups. In short, the cases of community BGIs discussed in this chapter occurred in the time span from around 2015 to 2019, following upon the preparation period of CBA empowerment by the Local Community Group beginning in 2012.

22.2.1 Overview of the BGI Projects

The chapter focused on cases of community BGI, particularly in the Jingmei and Muzha areas, both of which were prone to flood risks. All the cases reviewed in this chapter were project-based initiatives, characterised by diversity of funders, objectives and approaches. The three facilitators were funded by outside governmental or non-governmental authorities. As for the scale of the BGI implementation, the term "community" here mainly overlapped with "town." This was the primary level of regional governance with an average population of 6228 (in a range between 913 and 10,111) (Wenshan District Office 2021). Participants in the workshops came from different towns, although most of the BGI implementation efforts basically focused on a single community/town.

Implementation of community BGI by the Local Community Group has been funded by the CBA education programmes of NAPCA since 2013, with two additional BGI projects funded by the “Open Green” spatial mediation programmes of Taipei City Government in 2016. As an extension of the CBA programme and its existing environmental education background, the BGI initiative encouraged the participants to apply their knowledge within community facilities. For the CBA courses conducted between 2013 and 2017, the Local Community Group invited experts from related fields to guide the local stakeholders, including residents and officers from the township or district authorities, who were also asked to assess local disaster risks and preparedness. Besides lectures and field surveys, workshops concerning rain harvesting were also conducted.

The Consulting Firm’s approach was an outgrowth of its resilient planning framework for suburban settlements in the vicinity of hills (Classic Design and Planning 2019). The Consulting Firm had been involved in the Wenshan District since 2014, with BGI projects facilitated by the Consulting Firm being funded in 2015 by the “Open Green” programme of Taipei City. These included the implementation of rain gardens on the vacant lands within the communities involved. In addition, the Consulting Firm was in charge of managing the “Open Green” program and thus engaged as a facilitator in that programme as well. The BGI practices, which were based on the methodology of participatory planning, had functioned as a supplemental procedure in empowering local networks and cultivating bottom-up strategies for urban design on a larger scale (Classic Design and Planning 2019).

The Ministry of Science and Technology supported the research project of the Academic in the Wenshan District between 2016 and 2019. Compared to the other two agents, the facilitation role of the Academics proved much more significant. The Academics focused on constructing a CBA policy model that integrated stakeholders from different sectors. Instead of guiding BGI implementation in the communities, the research team invited a highly diverse group of governmental or non-governmental agents to build a platform for sharing CBA experiences and knowledge and then offered advice about several BGI practices conducted by the community colleges (including Wenshan Community College in Taipei City and Yonghe Community College in New Taipei City). Although the Academics were engaged in facilitating on a broader scale, the research team still succeeded in collecting and interpreting knowledge and acted as a conduit for resources that supported decision-making and grassroots practices.

Last but not least, it should be mentioned that the efforts of the three facilitators were not isolated. The Local Community Group has been a critical local partner both for the Consulting Firm and the Academics in efforts to mobilise residents. Since 2015, the planners in the Consulting Firm had been providing lectures on CBA in the Local Community Group, and the Local Community Group has also acted as a representative in the workshops conducted by the Consulting Firm. In 2017, the

Local Community Group and the Consulting Firm collaborated in a workshop that empowered grassroots planners to engage in the utilisation of community idle spaces. Also, since 2017, the Academics had invited the Local Community Group to participate in the CBA platform it has organised.

22.2.2 Communication and Mobilisation

During the preparations for BGI establishment, the strategies for mobilising local stakeholders among the three facilitators presented a certain degree of similarity in terms of selections of stakeholders and mediations by related experts. For instance, the initiatives facilitated by the three agents all started from meetings with local groups and experts. Nevertheless, after diagnosing the CBA issues with support from experts, differences were revealed in the communication strategies for interacting with grassroots groups and residents.

In communicating with grassroots residents who may be unfamiliar with the CBA issues, the Local Community Group opted for a communications strategy consisting mostly of lectures by experts in climate change, supplemented by practices such as field trips within the communities and potential spots for BGI implementation. Similar field trips were also conducted by the Consulting Firm and the Academics. In particular, despite having shared experiences in previous flood events, climate change was still an abstract issue for local residents. Consequently, as an alternative strategy, the Local Community Groups ought to raise their awareness about such problems by exploring the community water environments during the field trips. Participants were able to intuitively grasp the connection between their living experiences and disaster risks, after they had become enthusiastic about local knowledge, as the result of first being shown the importance of water in local history.

On the other hand, the BGI project facilitated by the Consulting Firm resulted from a bottom-up proposal from a local leader in Jingdong town. Even before the Consulting Firm became involved, the community had been operating activities for maintaining community spaces. The suggested spots for BGI facilities were vacant lands which had been subjected to illegal dumping and parking. The BGI project made available technical support from the community planner and university students. Besides the BGI project, the Consulting Firm also conducted workshops of varied scale, and other activities ranged from planning initiatives in a single community to proposing a comprehensive urban plan.

The activities by the Academics focused on the connections among grassroots practitioners, the governmental authority and the experts in related fields as the basis for forming a small-scale think tank. As a result, the routine meetings were filled with experience sharing on different topics and intensive discussions among the guests. The founding members used their personal networks to help gather meeting participants. Besides these meetings, annual symposiums were conducted to upscale the experiences in comparison with other municipalities and the state authorities. Since the network members all had experience in CBA, no serious differences occurred during communication among the participants.

22.2.3 Action and Networking

From identification of the flood risk and vulnerability to establishment of BGI, all three facilitators helped to mediate among the experts in order to provide necessary support for designing and constructing the BGI facility, while the grassroots participants performed critical roles in implementation and follow-up actions.

In 2015, during the primary stage of identifying the climate change-induced risks, the Local Community Group organised a reading group led by a specialist, then conducted several focus group interviews and symposiums with municipal council representatives, municipal officers, town leaders and other experts. During the CBA project conducted that same year, a 20h series of workshops on rainwater harvesting systems in communities followed 12h of lectures. As a trial of community BGI, the participants then formed an engineering group and built a set of rain-harvesting system in a local junior high school (Fig. 22.2). Similarly, the Consulting Firm facilitated the formation of a civil engineer group for the purpose of installing rain gardens and permeable paving in another neighbourhood. Each of the providers of technical support performed different functions. The Local Community Group offered lectures on rain-harvesting systems; then the participants purchased and installed the pipelines essentially by themselves. On the other hand, the Consulting Firm introduced a community planner, university professors and students, who assisted the participants in the design and construction of the facilities (Taipei City Urban Regeneration Office 2016a).

The Local Community Group and the Consulting Firm collaborated in two public-space redesign projects in 2016, one of which took place in a community park in Wanhe town and the other in a school-owned vacant lot in Xingfu town. The park redesign included uncovering old waterways under the community parks, thereby creating small-scale waterfronts within the urban settlement. The initial

Fig. 22.2 Design diagram for a rain-harvesting system (left) and volunteers installing the system in a local junior high school on March 21, 2015 (right)

Fig. 22.3 On the left is the permaculture community garden in Xingfu town before renovation (November 29, 2016) and on the right after the renovation (June 28, 2017)

planning was accomplished in participatory workshops with local adults and children. The town leader later proposed implementation to the municipal government, and actual construction began in 2010. The other BGI project in Xingfu town was similar to the vacant land renovation in Jingdong town conducted in 2015, although this time the workshop applied techniques of permaculture during the participatory design. The vacant land was later reformed into a community garden, with BGI facilities such as rain-harvesting and water-recycling systems, as well as an ecological pond. It was then named the "Forest of Foods" (Taipei City Urban Regeneration Office 2016c) (Fig. 22.3).

As for increasing the scale of relevance by applying the outcomes of community BGI to CBA to broader contexts, the activities facilitated by the three actors successfully built a framework for cooperation among stakeholders from the grassroots, the governmental authorities and the specialists from academia and the private sector. In fact, most of the problematics were defined by the residents based on their past experience, and then the three actors facilitated necessary support to achieve the desired objectives. In addition, there were also projects launched by the township leaders. The local town office proposed the redesign of the park, for example, but it was carried out in collaboration with the Local Community Group, the community association, an environmental NGO and the elementary school in the neighbourhood (Taipei City Urban Regeneration Office 2016b). Likewise, the grassroots groups also initiated the vacant land redesigns but finally applied BGI as an alternative.

Different levels of the administrative hierarchy, ranging from the township authorities and neighbourhood elementary schools to the district office initiated further actions related to the BGI facilities. The new policy agenda for developing a "sponge city" also paved the way for greater access to technical and financial support for the community BGI installation. More importantly, the preparation processes not only gained support among more town leaders for further involvement of either CBA or BGI but also improved grassroots awareness of climate change hazards. For instance, in 2015, after the rain-harvesting system was installed in the school campus, the participants further visited the homeowner association of the nearby apartments to promote rain harvesting. Other extensive projects such as edible landscapes or historical landscapes were also proposed by the town offices and the Local Community Group after the CBA workshops. On the other hand, the Academics created a more far-reaching platform. The meetings and symposiums organised by the Academics not only linked community practitioners nationwide horizontally but also provided a vertical channel for grassroots actors and state agencies. They thus provided opportunities for direct reflection of local experiences in national policies.

22.3 Comparison and Discussion

Comparisons of BGI cases facilitated by three non-governmental actors showed that various functions had been performed at different levels. Previous research had stressed such things as multilevel collaboration in CBA as a way to share responsibility; networked governance that involved engagement in active citizenship, private sectors and NGOs; and more inclusive and flexible governmental policymaking and implementation (Batley and Rose 2011; Buijs et al. 2016; Howes et al. 2015; Mees et al. 2019). However, since both CBA and BGI require a certain degree of understanding, awareness and capability to ensure active engagement, gaps may emerge among different sectors horizontally or among different levels vertically. The chapter thus explored the roles of non-governmental facilitators in reducing the possibility of barriers arising during the process. Table 22.1 summarises the comparisons among the three actors reviewed in the chapter.

22.3.1 Challenges and Limitations in Facilitating Bottom-Up Actions

The CBA and BGI projects in Wenshan District have been recognised as successful examples in promoting grassroots participation in related issues. At the same time, despite the efforts by the three facilitators and local participants, the facilitators identified several challenges and limitations.

At the individual level, one of the fundamental problems was the low motivation among residents to become involved in disaster-related issues. For example, the Consulting Firm delivered invitations to shops in the neighbourhood, but the first responses came from the town leaders. The Local Community Group already had its stable number of registered students, but the officers still found it difficult to gather participants compared to enrolment in popular classes within the same organisation. Likewise, the Local Community Group officers invited the leaders of two towns that had experienced floods in the past to participate during workshop preparation. However, the memory of disasters did not directly translate into willingness to engage in CBA. This finding evidenced a mental state different from that suggested by risk-based approach discussion of CBA at the grassroots level (Picketts et al. 2012). According to two leaders, discussions about disasters were usually perceived to be negative. Consequently, local residents did not find them attractive. The other

Table 22.1 Key characteristics of the three non-governmental facilitators (adapted from Bauer and Steurer (2014); Klein et al. (2017))

Facilitator	Local community group	Private sector	Academia
Main actor	Wenshan Community College	Consulting Firm	Academia
Target	Flood hazards		
Period	2013–2019	2014–2019	2016–2019
Projects	Rain harvesting (2015)	Rain garden (2015)	CBA study group (2016–2019) CBA empowerment workshop (2018) CBA symposium (2019)
	Community park redesign (2016) Community permaculture garden (2016)		
Problem ownership	Local communities (mainly reflected by the township authorities)		Local practitioners, governmental agencies, etc.
Implementer	Citizens, engineering firms	Citizens, community planners	NAPCA, the community colleges
Funding	NAPCA, municipality	Municipality	State
Core partners	Town leaders, citizens	Town leaders, citizens, community planners	NAPCA, the community colleges
Supporters	Experts, skilled university students, municipal/ district/town authorities		Experts, state authorities
Outputs	Educational toolkits, CBA strategies	Planning frameworks for community resilience	Policy implications, multi-sector platforms, CBA toolbox

reason was the low sense of urgency regarding community solutions to the climate change risks. Since the municipal authority had fixed the drainage quickly following previous events, grassroots stakeholders exhibited limited accountability at the stage of reporting problems. A Local Community Group officer recalled, "the problem had been solved even before the residents figured out what was the issue." Since the municipal government had performed "too responsively" to the risks, the residents and local private sectors thus tended to rely on the governmental authority to deal with the issues. However, such reliance could further reduce the willingness of the grassroots stakeholders to share responsibility for CBA, which was suggested as a way to improve community resilience (Klein et al. 2017; O'Hare et al. 2016). In the cases reviewed in this chapter, although the non-governmental actors functioned as critical facilitators in promoting awareness and implementation of CBA, no matter whether the "hosts" were governmental or non-governmental actors, the grassroots citizens remained "invitees."

At the community level, one distinguishing characteristic of urban society was the weak connections between residents and the community at large, as well as among the residents themselves. This, in turn, constituted one of the main barriers to mobilising local residents. However, instead of mobilising through personal connections, it could prove more efficient to gather people with similar concerns.

Fig. 22.4 Discussions with handmade models during the 2017 park redesign workshop

For instance, the Local Community Group and the Consulting Firm used the investigation of local history and environment to introduce CBA issues, thereby attaching new problematics to the existing topics that had initially attracted local residents. In addition, building more intimate connections between the broad problematic and the everyday experience also proved critical. The strategies applied by the facilitators included guided observation on a field trip, board games about climate change hazards, and introducing tools of deliberative democracy. Also worth mentioning was the fact that making models of the community environment by hand was an efficient method to encourage and stimulate imagination in participatory planning (Fig. 22.4).

In the CBA practice, the limited time allotted for knowledge preparation was noted as a significant challenge. A college officer described the limited duration of the CBA programmes (32h in many cases) as insufficient to develop comprehensive knowledge about rain harvesting before installation, which reduced the motivation of participants to adopt BGI practices. Besides, many local participants who enrolled in the programmes were retired elders in their 60s. Thus, it was suggested that the programmes could be improved by redesigning them to include age diversity. Similar gaps also occurred in BGI projects in 2015. During the installation, both of the civil engineer groups consisted of volunteers who remained actively engaged throughout the entire process. However, since the case mediated by the Local Community Group experienced less intervention by experts during the installation, non-expert participants found it challenging to apply the acquired knowledge in actual practice.

Furthermore, when promoting BGI or CBA practices, it was necessary to shape a common incentive to be shared by the grassroots stakeholders. That was particularly true due to the fact that many of BGI facilities were small scale and embedded into the grassroots context. Meanwhile, in the CBA workshops conducted by the Local Community Group, the participants came from different communities. Accordingly, regardless of a general awareness of climate change disaster risks and the acknowledgement of the need for BGI, geographical segregation among participants created a barrier when they moved to create a collective action plan. For example, during the discussions, personal experiences and reactions tended to dominate, instead of sharing that would highlight common problematics. The space-specific characteristics of BGI also limited the motivation of participants living outside the implementing community. In achieving collective action plans for CBA, another challenge emerged in seeking support from the township administration, especially for the grassroots leaders. As a result, leadership at the community level was a critical factor in achieving a successful CBA or BGI. Nevertheless, high efficiency of municipal administration also tended to discourage grassroots stakeholders from dealing with problems themselves.

Finally, although non-governmental actors capable of connecting resources and knowledge helped to make the participatory implementation of BGI more efficient, institutional limitations still restricted the facilitating practices. In particular, the cases reviewed in this chapter were all conducted under bureaucratic supervision. As a result, although the non-governmental facilitators had made their efforts adapting to local contexts, the pre-established framework for time and budget restricted the scope of the activities. As a result, the sustainability of BGI eventually depended on the grassroots communities. Even if the networks organised by non-governmental facilitators survived project completion, the motivation and capability of both the facilitators and the grassroots practitioners became the deciding factors as to whether they would continue their activities.

22.3.2 Towards a Framework of Integrated Facilitation

Within the BGI initiatives reviewed in the previous sections, in addition to facilitating ties between the domains of experts/technocrats and non-expert citizens, non-governmental actors also mediated resources (knowledge, finance, human power, etc.) from alternative approaches that improve the flexibility of the process.

The main barriers that needed to be overcome at the preparation stage were cognitive hurdles regarding risk perception and recognition of BGI (Dhakal and Chevalier 2017). Here the experts in the private sector (represented by the planning company) and academia were able to provide the methods and information needed to raise awareness, further build a basic understanding about the climate change hazards and BGI (Derkzen et al. 2017). On the other hand, the Local Community Group (Wenshan Community College in this case study) emphasised the close connection between the hazards and the local concerns about livelihoods. Throughout the design and the delivery of BGI projects, the role of the community groups was especially necessary. With the mobilised group of citizens demonstrating strong place attachment and the township leaders enjoying accumulated trust, the community groups acted as gatekeepers when the outside agents (e.g., the Consulting Firm and the Academics) first entered the community. Besides, the community groups could also encapsulate the grassroots concerns for facilitation of understanding about them among stakeholders.

The project delivery could not be accomplished without sufficient input of resources (Dhakal and Chevalier 2017). Consequently, the participants from the private sector and academia mainly contributed by providing technical support during the process of design and implementation. Assistance in forms such as the participatory planning toolbox and the community planners helped lower the barriers to collaboration with citizens at the grassroots level. Furthermore, the professional planners also performed an important function by introducing outside resources, especially financial and human energy inputs, which further increased accessibility to resources for the community. For the maintenance of the BGI, the strategy adopted by the Local Community Group was to involve local schools in order to be able to utilise their facilities for environmental education. This approach was in line with the suggestion by Lamond and Everett (2019) for embedding extra features. However, regardless of the efforts at mediation, gaps remained in the assumption of responsibility (Klein et al. 2017; O'Hare et al. 2016).

As for upscaling the effects and experiences of the grassroots initiatives, academia functioned as an organiser of horizontal and vertical integration. For instance, the academics in the case study arranged a study group for grassroots practitioners and governmental technocrats to share knowledge and experience. The study group created a platform that horizontally connected the local actors in different communities and experts who would provide technical support; furthermore, it enlarged access to vertical communication within institutions. As a response to the governance barrier indicated by Dhakal and Chevalier (2017), involving efforts in top-down policy communication and bottom-up reflection, the academia could thereafter coordinate synergetic improvements to the current regulations.

Cognizant of the challenges and possibilities provided by previous analyses, Table 22.2 provided a participation framework to propose the roles of non-governmental facilitators in BGI implementation. The categorisation of the stages included the ladder of government participation provided by Mees et al. (2019) and the upscaling approach (Schipper et al. 2014). On the other hand, the table also presented the corresponding roles for fixing governmental barriers at different stages (Dhakal and Chevalier 2017; Willems et al. 2020).

22.4 Conclusion and Implications

The chapter has reviewed the contributions by and challenges for non-governmental actors in facilitating BGI application at the community level. The chapter focuses on BGI as a strategy for community-based adaptation in urban communities. Taking the BGI initiatives conducted in Wenshan District, Taipei, as cases for the study, the chapter highlights the potentials and the difficulties of the Local Community Group, the private sector and the academics. The implementation of BGI involves complex interactions among science, technology, institutions and the public, as well as the various concerns of diverse stakeholders. Consequently, the non-governmental actors play the role of interpreters who present scientific expertise in a way that can be commonly understood and also as mediators between different social

Table 22.2 Roles of non-governmental facilitators in BGI implementation (adapted from Dhakal and Chevalier (2017); Mees et al. (2019); Schipper et al. (2014); Willems et al. (2020))

		Facilitators		
Stages		Community group	Private sector	Academia
Preparation	1. Issue identifying	Connect the problematics to existed community issues	Introduce alternative methods for identifying issues	Provide necessary knowledge for a basic understanding
Design	2. Enabling	Facilitate the discussion and encapsulate local opinions	Provide planning tools and necessary assistance	Translate the scientific data for better communication
Delivery		Connect the gaps between the design and local concerns	Provide technical support in installation	Provide supplemental references
	3. Stimulating	Mobilise citizens	Facilitate outside assistance (students, volunteers, etc.)	
	4. Networking	Bridge local inputs at the community level	Bridge continuous financial supports	Reflect the grassroots demands to the authorities
Maintenance		Adjoin other programmes to utilise the facility	Provide a technical guideline for maintenance	Generalise the outputs and compare with other cases
Upscaling	5. Horizontal	Demonstrate and imitate among communities	Produce a replicable toolkit for similar practices	Organise platforms for multi-level/ multi-sector sharing
	6. Vertical	Provide policy feedback	Indicate policy suggestions	

domains. As for policy implications, at the grassroots level, a reliable community group can serve as a gatekeeper that connects the members of the community with outside stakeholders. During the design and the delivery of BGI projects, professional planners from the private sectors not only provide technical support but also introduce innovative methods or strategies to empower grassroots engagements. Furthermore, experts from either the private sector or academia can assist and act as a bridge among local communities regarding resource inputs. The role of academia mainly consists of helping to coordinate the understandings and practices among different sectors from a broader perspective, thus enhancing the inclusiveness and efficiency of channels or platforms for vertical and horizontal integration. In reflecting upon the cases reviewed in this chapter, we can conclude that despite the synergetic effects resulting from the facilitation by the non-governmental actors, further efforts are required to reallocate part of the responsibility to the grassroots individuals. In particular, disaster prevention or mitigation has been widely acknowledged by citizens as the responsibility of public sector, while how to divide and balance the accountability among different social domains remains questioned.

Nonetheless, the chapter highlights implications on the roles of non-governmental actors in bridging the gaps between stakeholders and institutions and thus indicates an alternative for better integration in both CBA and BGI practices.

Acknowledgements The major part of the data analysed in this chapter was collected through the research project titled "A Study for Risk Governance on Climate Change Induced Disaster," supported by the Ministry of Science and Technology, Taiwan, conducted since 2016 to 2019 (grant numbers: MOST105-2621-M002-009 (2016–2017); MOST106-2621-M002-003 (2017–2018); MOST107-2621-M002-009 (2018–2019)). The authors would like to express very great appreciation to the participants in this project who had shared their precious experiences and especially to Chia-Yu Lee, the community manager of Wenshan Community College, who kindly provided many documents and photographs. Finally, the authors wish to thank John Carroll for his patience in English editing.

Conflict of Interest Statement The authors report no conflict of interest for this publication.

References

Aylett A (2010) Conflict, collaboration and climate change: participatory democracy and urban environmental struggles in Durban, South Africa. Int J Urban Reg Res 34:478–495. https://doi.org/10.1111/j.1468-2427.2010.00964.x

Batley R, Rose P (2011) Analysing collaboration between non-governmental service providers and governments. Public Adm Dev 31:230–239. https://doi.org/10.1002/pad.613

Bauer A, Steurer R (2014) Multi-level governance of climate change adaptation through regional partnerships in Canada and England. Geoforum 51:121–129. https://doi.org/10.1016/j.geoforum.2013.10.006

Bennett NJ, Kadfak A, Dearden P (2016) Community-based scenario planning: a process for vulnerability analysis and adaptation planning to social–ecological change in coastal communities. Environ Dev Sustain 18:1771–1799. https://doi.org/10.1007/s10668-015-9707-1

Buijs AE, Mattijssen TJ, Van der Jagt AP, Ambrose-Oji B, Andersson E, Elands BH, Steen Møller M (2016) Active citizenship for urban green infrastructure: fostering the diversity and dynamics of citizen contributions through mosaic governance. Curr Opin Environ Sustain 22:1–6. https://doi.org/10.1016/j.cosust.2017.01.002

Carter JG, Handley J, Butlin T, Gill S (2018) Adapting cities to climate change – exploring the flood risk management role of green infrastructure landscapes. J Environ Plan Manag 61:1535–1552. https://doi.org/10.1080/09640568.2017.1355777

Central News Agency (2017, October 5) Wuxiang paishui gongcheng wangong Wenshanqu chuming yiyanshuiqu [Wenshan district is excluded from the flood-prone areas after the five drainage constructions]. NOWnews. https://www.nownews.com/news/2619915

Chiang Y (2018) Exploring community risk perceptions of climate change: a case study of a flood-prone urban area of Taiwan. Cities 74:42–51. https://doi.org/10.1016/j.cities.2017.11.001

Chiang S, Chang K (2011) The potential impact of climate change on typhoon-triggered landslides in Taiwan, 2010–2099. Geomorphology 133:143–151. https://doi.org/10.1016/j.geomorph.2010.12.028

Chou K (2013) The public perception of climate change in Taiwan and its paradigm shift. Energy Policy 61:1252–1260. https://doi.org/10.1016/j.enpol.2013.06.016

Classic Design and Planning (2019) Yishanxiaolüzhou gongkaiziliaoji [Wenshan Oasis open data set]. Taipei City. https://drive.google.com/file/d/1CCbzpOklgNqnP0YdkVU6dCAMJpNfhPda/view?usp=sharing. Accessed 26 February 2021

Classic Design and Planning (2021) Diandianjingshen [Core values]. https://www.classic1990.com/home/core-value/. Accessed 26 February 2021
Council for Economic Planning and Development (2012) Guojia qihoubianqian tiaoshi zhengce gangling [National framework for climate change adaptation policies]. Executive Yuan. https://ws.ndc.gov.tw/Download.ashx?u=LzAwMS9hZG1pbmlzdHJhdG9yL zEwL3JlbGZpbGUvNTU2Ni83MDgwLzAwMTcxMjRfNS5wZGY%3D&n=MTAxMTAxMOWci%2BWutuawo%2BWAmeiuiumBt%2Biqv%2BmBqeaUv%2Betlue2semgmCjkv67mraMpLnBkZg%3D%3D&icon=..pdf. Accessed 24 Feb 2021
Derkzen ML, van Teeffelen AJA, Verburg PH (2017) Green infrastructure for urban climate adaptation: how do residents' views on climate impacts and green infrastructure shape adaptation preferences? Landscape Urban Plan 157:106–130. https://doi.org/10.1016/j.landurbplan.2016.05.027
Dhakal KP, Chevalier LR (2017) Managing urban stormwater for urban sustainability: barriers and policy solutions for green infrastructure application. J Environ Manag 203:171–181. https://doi.org/10.1016/j.jenvman.2017.07.065
Granderson AA (2014) Making sense of climate change risks and responses at the community level: a cultural-political lens. Clim Risk Manag 3:55–64. https://doi.org/10.1016/j.crm.2014.05.003
Howes M, Tangney P, Reis K, Grant-Smith D, Heazle M, Bosomworth K, Burton P (2015) Towards networked governance: improving interagency communication and collaboration for disaster risk management and climate change adaptation in Australia. J Environ Plan Manag 58:757–776. https://doi.org/10.1080/09640568.2014.891974
Hsu H, Chen C (2002) Observed and projected climate change in Taiwan. Meteorog Atmos Phys 79:87–104. https://doi.org/10.1007/s703-002-8230-x
Huang D, Cheng Y (2019) Qihoubianqian yiti de juti shijian: yi dushigengxin zuowei shequ tiaoshi celüe [Practical actions for climate change issues: urban revitalization as an adaptive strategy]. In: 2019 Shequdaxue xueshu yantaohui [2019 Symposium of Community Colleges]. Yilan County, pp 199–215
Hydraulic Engineering Office (2019, November 25) Haimian chengshi [Sponge city]. Public Works Department, Taipei City Government. https://heo.gov.taipei/cp.aspx?n=F50EC7128A8D18B4. Accessed 8 March 2021
International Safe Community Certifying Centre (n.d.) ISCCC Communities. https://isccc.global/community/wenshan/186. Accessed 15 March 2021
Klein J, Juhola S, Landauer M (2017) Local authorities and the engagement of private actors in climate change adaptation. Environ Plan C: Politics Space 35:1055–1074. https://doi.org/10.1177/0263774X16680819
Lamond J, Everett G (2019) Sustainable Blue-Green infrastructure: a social practice approach to understanding community preferences and stewardship. Landsc Urban Plan 191:103639. https://doi.org/10.1016/j.landurbplan.2019.103639
Lassa JA (2018) Roles of non-government organizations in disaster risk reduction. In: Oxford research Encyclopedia of natural hazard science. Oxford University Press. https://doi.org/10.1093/acrefore/9780199389407.013.45
Luo R (2004) Let community direct the planning efforts: the Wenshan experience in Taipei. J Build Plan 12:81–108
McNaught R, Warrick O, Cooper A (2014) Communicating climate change for adaptation in rural communities: a pacific study. Reg Environ Chang 14:1491–1503. https://doi.org/10.1007/s10113-014-0592-1
Mees HLP, Uittenbroek CJ, Hegger DLT, Driessen PPJ (2019) From citizen participation to government participation: an exploration of the roles of local governments in community initiatives for climate change adaptation in the Netherlands. Environ Policy Gov 29:198–208. https://doi.org/10.1002/eet.1847
Mercer J, Kelman I, Alfthan B, Kurvits T (2012) Ecosystem-based adaptation to climate change in Caribbean small island developing states: integrating local and external knowledge. Sustainability 4:1908–1932. https://doi.org/10.3390/su4081908

Ministry of Culture (2021) Taiwan shequtong [Taiwan Communities]. https://communitytaiwan.moc.gov.tw. Accessed 28 Feb 2021

Ministry of the Interior (2019) Neizhengbu tongji nianbao [Annual statistic report of Ministry of the Interior]. Taipei City. https://ws.moi.gov.tw/001/Upload/400/relfile/0/4405/50381923-6c59-4255-b371-f67d330c64dd/year/year.html. Accessed 11 March 2021

Ministry of the Interior (2021) Population density and total area for counties and cities. Taipei City. https://www.ris.gov.tw/app/en/3910. Accessed 11 March 2021

National Development Council (2018) Guojia qihoubianqian tiaoshi xingdong jihua 102-106nian zhixing chengguo baogao [Implementation report of the national action plan for climate change adaptation 2013–2017]. Taipei City. https://adapt.epa.gov.tw/dispPageBox/files/10640.pdf. Accessed 11 March 2021

National Land Surveying and Mapping Centre (2015a) Xiangzhenshiqu jiexian [Borderlines of counties/towns]. Ministry of the Interior. https://data.gov.tw/dataset/7441. Accessed 11 March 2021

National Land Surveying and Mapping Centre (2015b) Zhixiashi xianshi jiexian [Borderlines of municipalities]. Ministry of the Interior. https://data.gov.tw/dataset/7442. Accessed 11 March 2021

O'Donnell EC, Lamond JE, Thorne CR (2017) Recognising barriers to implementation of blue-green infrastructure: a Newcastle case study. Urban Water J 14:964–971. https://doi.org/10.1080/1573062X.2017.1279190

O'Hare P, White I, Connelly A (2016) Insurance as maladaptation: resilience and the 'business as usual' paradox. Environ Plan C: Government Policy 34:1175–1193. https://doi.org/10.1177/0263774X15602022

Picketts IM, Werner AT, Murdock TQ, Curry J, Déry SJ, Dyer D (2012) Planning for climate change adaptation: lessons learned from a community-based workshop. Environ Sci Policy 17: 82–93. https://doi.org/10.1016/j.envsci.2011.12.011

Picketts IM, Curry J, Déry SJ, Cohen SJ (2013) Learning with practitioners: climate change adaptation priorities in a Canadian community. Clim Chang 118:321–337. https://doi.org/10.1007/s10584-012-0653-8

Schipper ELF, Ayers J, Reid H, Huq S, Rahman A (eds) (2014) Community-based adaptation to climate change: scaling it up. Routledge

Science Technology Policy Research and Information Center (2020) About STPI-mission. https://www.stpi.narl.org.tw/public/en/mission. Accessed 21 Feb 2021

Sung T, Shih D, Wen P, Cheng K (2017) A study drainage master plan in Taiwan. J Dis Manage 6: 23–47. https://doi.org/10.6149/JDM.2017.0601.02

Taipei City Government (2009) Wenshan quzhi [Chorography of Wenshan District]. Taipei City Government, Taipei City. https://wsdo.gov.taipei/Content_List.aspx?n=FBA554430D3C6B3B. Accessed 8 Feb. 2021

Taipei City Government (2020a) About Wenshan District. https://english.gov.taipei/cp.aspx?n=3B7EAC40F10AD184. Accessed 8 Feb 2021

Taipei City Government (2020b) 108niandu shequfazhanxiehui ji shequhuodongzhongxinshu [2019 Statistic of community associations and community activity centre]. Taipei City. https://dosw.gov.taipei/Content_List.aspx?n=2809B16B4F9596C2. Accessed 28 Feb 2021

Taipei City Government (2021) 110nian 1-12yue gequ renkoushu [Population of the administrative districts, 2020 Jan.-Dec.]. Taipei City. https://ca.gov.taipei/News_Content.aspx?n=8693DC9620A1AABF&sms=D19E9582624D83CB&s=EE7D5719108F4026. Accessed 8 Feb 2021

Taipei City Urban Regeneration Office (2016a) Jingdong ai haimian xin shequ kongjian yangchengzhi [Heading to a sponge city: reforming the vacant land by low-impact way of Jingdong Neighbourhood]. https://issuu.com/taipeiopengreen/docs/opengreentaipei_105a20130pupr. Accessed 5 Mar 2021

Taipei City Urban Regeneration Office (2016b) Xingfu Pumen lüshenghuo - shequ kongjian yangchengzhi [Permaculture green life in Xinfu - Community reformation diary]. https://issuu.com/taipeiopengreen/docs/opengreentaipei_106a60140pu. Accessed 6 Mar 2021

Taipei City Urban Regeneration Office (2016c) Wanhe shuishui lüjiayuan shequ gaizao yangchengzhi [Hometown with blues and greens in Wanhe - Community reformation diary]. https://issuu.com/taipeiopengreen/docs/opengreentaipei_106a50145pu. Accessed 6 Mar 2021

Taipei City Urban Regeneration Office (2019) Shequ jiaowang: qun yu zhong xiezuodechang suochuangsheng [Way to community: collaboration and placemaking]. Taipei City. https://gpi.culture.tw/books/1010801533. Accessed 8 Feb 2021

van Aalst MK, Cannon T, Burton I (2008) Community level adaptation to climate change: the potential role of participatory community risk assessment. Glob Environ Chang 18:165–179. https://doi.org/10.1016/j.gloenvcha.2007.06.002

Wang C (2005) Place images, locality meanings, and regimes of representation. Taiwan: Radic Quart Soc Stud 58:135–188

Wenshan Community College (2021) Guanyu Wenshansheda [About Wenshan Community College]. https://www.wenshan.org.tw/index.php/關於我們/關於文山社大. Accessed 28 Feb 2021

Wenshan District Office (2019) Taipeishi Wenshanqu diqu zaihai fangjiu jihua (108nianban) [2019 Disaster prevention project of Wenshan district, Taipei City]. Taipei City. https://www.eoc.gov.taipei/FilesManager/GetFiles?FileID=5b8fef13-a080-4948-9e8e-aa3a67e25950. Accessed 8 Feb 2021

Wenshan District Office (2021) The Population & Families Of Wenshan District, Taipei City (Jan. 2021). Taipei City. https://wshr.gov.taipei/News.aspx?n=0D10FB9C602D6389&sms=D3AC32FD34D317A8. Accessed 8 Feb 2021

Willems JJ, Molenveld A, Voorberg W, Brinkman G (2020) Diverging ambitions and instruments for citizen participation across different stages in green infrastructure projects. Urban Plan 5:22–32. https://doi.org/10.17645/up.v5i1.2613

Hsin-Hua Chiang is a PhD candidate at the Graduate School of Agriculture, Kyoto University, Japan.

Tze-Luen Lin is an Associate Professor in the Department of Political Science at the National Taiwan University, Taiwan.

Pin-Ju Shih is a Project Research Assistant at the Department of Political Science, National Taiwan University, Taiwan.

23 Mainstreaming Blue-Green Infrastructure in Policy and Planning for Urban Resilience in the Global South: Promises and Pitfalls

B. Dhanya, Samudyatha Ramananda, and Shalini Dhyani

Abstract

Blue-green infrastructure (BGI) has gained immense attention worldwide in the last few years as a planning strategy for enhancing urban sustainability. Policy interventions to promote BGI for urban resilience have gained momentum in the Global North, but such initiatives are yet to be mainstreamed in the developing world. This chapter seeks to unpack the gaps and opportunities in BGI planning for sustainable urban transformations in the Global South with a focus on Asian countries. Drawing on diverse cases of Global South cities, the chapter synthesizes the complexities of incorporation of BGI in urban planning and policies in the Asian context. We argue that a distinct approach cognizant of the heterogeneity and diversity of ecologies and livelihoods in the cities of the Global South and a focus on cross-sectoral and adaptive governance with public participation, environmental justice, and equity as cornerstones can lead to better policy integration of BGI for sustainable outcomes. The chapter further advocates a "commons" perspective, given the multiple provisioning, regulating, and cultural functions of BGI in the urban areas of the Global South, in contrast to a purely technical approach of BGI implementation that is prevalent in other parts of the world.

B. Dhanya (✉)
Faculty of Ecosystem and Environment Management and Centre for Policy Studies, Indian Institute of Forest Management, Bhopal, India
e-mail: dhanyab@iifmbhopal.edu.in

S. Ramananda
Independent Researcher, Banashankari, Bengaluru, Karnataka, India

S. Dhyani
CSIR-National Environmental Engineering Research Institute (CSIR-NEERI), Nehru Marg, Nagpur, Maharashtra, India
e-mail: s_dhyani@neeri.res.in

S. Dhyani et al. (eds.), *Blue-Green Infrastructure Across Asian Countries*,
https://doi.org/10.1007/978-981-16-7128-9_23

Keywords

Urban planning · Policy · Adaptive governance · Institutions · Sustainability

23.1 Introduction

Creating and maintaining blue-green infrastructure (BGI) have emerged as a crucial pathway for sustainable urban development, in the face of the rampant urbanization currently observed and predicted in the Global South. Diverse BGI elements such as urban parks and nature reserves, constructed wetlands, sponge gardens, permeable pavements, biopores, rooftop gardens, wetlands, lakes, and streams are increasingly valued for their multifunctional roles in ensuring diverse ecosystem services ranging from mitigation of urban floods, pollution, heat islands, disaster risks, and climate impacts to provisioning and cultural benefits. As an urban sustainability tool, BGI planning recognizes urban regions as living entities and promotes the self-regulatory potential of ecosystems (Haase 2015). BGI-based approaches such as planting street trees and sustainable drainage are ranked as the most attractive actions for urban climate adaptation in terms of feasibility and the potential to reduce risks and to offer co-benefits such as decarbonization, economic growth, and improved human health (Boland et al. 2021).

BGI as a potential nature-based solutions (NbS) for urban areas can also help in realizing the targets of many international agreements including Sustainable Development Goals (SDGs), 2015 with an urban-area-specific SDG 11; Post-2020 Global Biodiversity Framework; Sendai Framework for Disaster Risk Reduction, 2015; and UN Framework Convention on Climate Change (UNFCCC)-Paris Conference of Parties (COP) promises, 2015 (Fig. 23.1). Several BGI approaches have been formally mainstreamed in policies such as the sustainable drainage systems (SuDS) of the United Kingdom or low-impact development (LID) of the USA (Griffiths et al. 2020). Most such success stories are however confined to the Global North. Cities in developing countries face greater challenges in terms of high rates of population growth, unemployment and poverty, massive loss of urban blue-green spaces and biodiversity, and consequent decline in ecosystem services. The numerous growing urban areas of the Global South are exposed to several disaster risks not only because of decades-long exponential urban expansion but also weak enforcement of urban planning and regulatory instruments (Drosou et al. 2019). There is growing need for resilience building and disaster proofing of urban areas using site-specific BGI that have potential to solve local urban issues (Dhyani et al. 2019; 2021). In the Global South, BGI not only serves regulatory and cultural functions but also sustains livelihoods of marginalized urban residents; therefore, a distinct approach is imperative for its planning and implementation.

This chapter analyzes the opportunities and challenges in maintaining ecosystem service flows and uses from BGI through policy and planning measures at national, subnational, and city scales. We use diverse cases and examples to demonstrate the promise in leveraging policy measures for BGI implementation and management

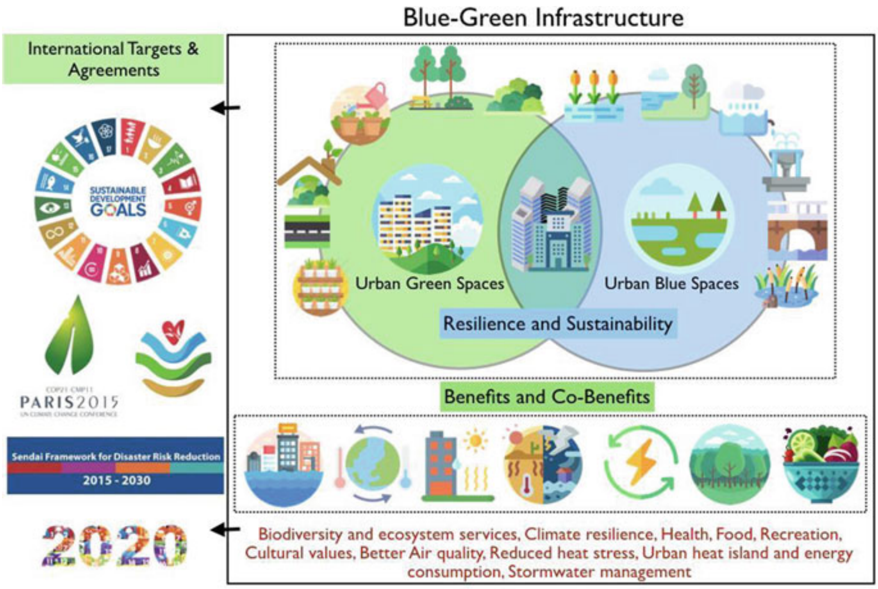


Fig. 23.1 Mainstreaming BGI in urban policy and planning and its effective implementation for meeting various international targets and agreements

with a view to inform sustainable and inclusive urban planning processes in the Global South.

23.2 Methodology

The chapter is based on a comprehensive review of literature on BGI in the Global South, with focus on Asian countries to identify the potential of "BGI sensitive" planning and policy in catalyzing urban sustainability transitions. Asia is predicted to be a hotspot of urban expansion and along with Africa will harbor 88% of all new urban inhabitants between 2018 and 2050. Just India, China, and Nigeria alone will account for over one-third of the projected increase of nearly 2.5 billion people in urban population by 2050 (United Nations 2019). Most emerging urban regions in Asia are characterized by increasing population, spatial expansion, energy and resource demands, and vulnerability to natural disasters while also harboring centers of global economy and environmentally critical areas. Although the number of countries with national policies and programs to achieve sustainable urbanization is significantly high in Asia (78% in Central and Southern Asia and 75% in Eastern and Southeastern Asia) compared to other regions, the efficacy of these policies is questionable (United Nations 2019). Asia's urban regions are under enormous social, economic, and ecological pressure that renders sustainable planning essential to impart urban ecological resilience (UN-HABITAT 2012). BGI as a planning tool therefore presents tremendous potential for devising low-cost and equitable pathways for urban transformations in Asia.

We used an extensive review of literature to understand various policy interventions for BGI integration in urban systems and to examine opportunities and challenges for BGI in urban planning. We examined different case studies from the Global South with a focus on cities from Asia to trace the gaps in both research and policy interventions that are crucial for adaptive urban infrastructure management and to identify the strategies that have worked successfully in BGI implementation. Google Scholar and ResearchGate databases were searched for literature using keywords denoting diverse categories of BGI elements such as green spaces (parks, gardens, nature reserves, trees, wooded groves, etc.), urban and peri-urban agriculture, green roofs and lanes, vertical greenery systems, lakes, streams, and drainage systems. About 65 scientific papers and six reports published post 2010, specific to cities from the Global South, were accessed for the review.

The learnings from the review are presented in Sects. 23.3 and 23.4. Section 23.3 presents interesting instances of policy measures that successfully integrate BGI in urban planning in Asia, while Sect. 23.4 charts out the way ahead in creating a pro-BGI policy environment in the Global South, by tying together the insights on policy gaps and opportunities from the literature analyzed.

23.3 BGI-Sensitive Urban Planning and Policy: Exemplary Initiatives from Asia

The review revealed a glaring lack of BGI integration in policies in the developing countries of Asia. Except for a few countries such as China, Singapore (a developed economy), and India, policy initiatives for urban BGI are either nonexistent or not well documented in Asia. Although literature that suggests comprehensive BGI-integrated planning based on research studies (Ahmed et al. 2019; Hamel and Tan 2021) and documentation of city-scale pilot projects (Prescott et al. 2021) is available, information on national- or subnational-level policies that provide an enabling environment for BGI is scarce.

This section describes a few promising documented instances of adopting effective planning and policy steps for BGI in the Asian context.

23.3.1 Sponge Cities of China

Green development being central to China's national development plan, a formal strategy of ecological civilization, was conceptualized in 2007 (Dai et al. 2018). In a stakeholder study conducted by O'Donnell et al. (2021), a respondent clearly mentioned:

> In China, national initiative from the central government is the most influential factor to drive any infrastructure built while local government has the knowledge and finances to implement it.

Fig. 23.2 Phased planning strategy of government of China to mainstream sponge city concept and harness its diverse benefits

The "sponge city" concept and implementation plan developed in China is a progressive approach for addressing several urban water and environmental issues using BGI (Fig. 23.2). The idea was conceived in 2014 to address urban flooding and waterlogging in Chinese cities by the management of urban surface water using BGI such as rain gardens, green roofs, grass swales, bioretention basins, and permeable pavements (Griffiths et al. 2020). China's recent national policy on sponge city development is an excellent example of BGI integration in urban planning to reduce flood incidences, runoff, and pollution by restoring the downstream ecosystems (Ma et al. 2020). Sponge city initiative is to be implemented by respective sub-provincial governments as well as municipalities. China aims to develop a sponge city pilot of 449 km^2 across 16 cities (selected from 130 cities), toward which the central government of China has allocated CNY 20.7 billion, while significant funding support for the project is raised from local as well as nongovernmental sectors (Xiang et al. 2019). Targets were set in a phased manner with cities expected to provide 20% land with sponge features by 2020, increasing to about 80% land by 2030 (Fig. 23.2). Though climate, geology, and socio-economic factors were considered as determinants in the implementation of national guidelines related to sponge city project, it was later observed that financial support followed by regular monitoring of targets was more impactful (Griffiths et al. 2020). The sponge city model of BGI planning has attracted global attention, and in a recent news,[1] the city officials of Kochi in the state of Kerala have showed interest in developing the city as the first sponge city of India.

23.3.2 Policy Initiatives for Sustainable Urbanization in India

In India, as a first step to recognize the unforeseen impacts of expanding urban areas and to promote greening efforts, Town and Country Planning Organisation (TCPO) published the first "Guide on Plant Materials for Landscaping in India" in 1980.

[1] https://www.thehindu.com/news/national/kerala/kochi-may-be-states-first-sponge-city/article30619126.ece.

Later in the year 2000, the Ministry of Urban Affairs and Employment published the Guidelines for Greening of Urban Areas and Landscaping. Urban Greening Guidelines in 2014 were largely a response to the rampant infrastructure buildup and concretization of India's urban areas.

Global transfer of knowledge and finances following an economic growth-driven mandate for development has significantly influenced Indian urbanism. The recent initiatives undertaken by the government of India, viz., the Smart City Project (2015) (to develop 100 cities as smart cities), the Heritage Rejuvenation and Development (HRIDAY) Scheme; the Urban Renewal Mission, and the Swachh Bharat Mission are diverse efforts to enhance sustainability and resilience of fast-expanding urban areas. However, governing authorities have mostly facilitated initiatives that focus on basic infrastructure services without giving enough consideration to achieve urban sustainability (Hackenbroch and Woiwode 2016). Smart City or Atal Mission for Rejuvenation and Urban Transformation (AMRUT) mission (2015) considers environmental sustainability as an important criterion, yet it misses on capitalizing the benefits of urban green spaces in resilience building for urban sustainability (Randhawa and Kumar 2017).

Biodiversity Management Committees (BMCs) in urban local body level stipulated in the National Biodiversity Act (2002) offer another promising avenue to leverage an existing policy to conserve and augment urban green cover, biodiversity, and ecosystem services. India's National Action Plan on Climate Change (NAPCC) of 2008 in response to the UN Framework Convention on Climate Change comprises missions dealing with sustainable habitat, water, agriculture, forestry, energy efficiency, and health, among others, all of which have the potential to boost BGI-based strategies; however systemic and process barriers—including financial constraints, interministerial coordination, lack of technical expertise, and project clearance delays—have emerged as major challenges in the efficient implementation of the missions (Mankikar and Driver 2021).

Other national policy initiatives with implications on BGI include the Prime minister's Irrigation Policy that advocates the use of treated urban sewage for irrigation and the Revised Municipal Solid Waste Management Rules (2016) that promotes composting urban solid waste to utilize in farmlands, providing a conducive policy environment to synergize the exchanges between city dwellers and peri-urban farmers and between blue and green components of urban infrastructure (Patil et al. 2018). National Disaster Management Agency (NDMA) in 2019 developed a precautionary short-term strategy for India (for urban areas as well as the states) to address heat-related risks (NDMA Heat Wave Guidelines 2019). India Cooling Action Plan (ICAP) (2019) was implemented for sustainable cooling in urban areas. But, both these plans include only short-term planning and lack long-term strategies to address the issue. Though NAPCC includes two important missions, viz., National Mission of "Enhanced Energy Efficiency" (NMEEE) and 'Green India' (GIM), less research and even lesser urban projects have considered exploring passive cooling potential of urban greenery to address many urban environmental issues (Imam and Banerjee 2016).

Complementing the national-level initiatives, several state-level programs have also been launched. Green roofs, cool pavements, and incentives for rainwater harvesting and green construction materials were undertaken as important strategies for implementing state-level Heat Action Plan by the Kerala State Disaster Management Authority (KSDMA) as a long-term strategy for climate resilience. It is important to mention that Delhi, despite its tag of the most polluted capital city, has the Delhi Preservation of Trees Act (1994) to reduce felling of trees and reduction of green cover; however, the major gap is in the enforcement of these legal measures.

City-level programs focusing on BGI through enhancing tree cover, reviving water bodies, etc. in tune with national-level mandates are also prevalent in various parts of the country. Under a recent scheme of the Minor Irrigation Department in Bengaluru, secondary-treated wastewater from the city is pumped to dried up peri-urban lakes to recharge them for farming (Vishwanath 2018). The Revised Master Plan 2031 (RMP) of Bengaluru designates the western direction of the urban agglomeration as a no-development zone considering the water catchment and reservoir services of this area—an example of urban planning that recognizes the relevance of BGI. Several Indian cities—such as Delhi, Bhopal, and Madurai—are including blue-green components in their master or action plans with the aim of enhancing existing natural green and blue systems in the city through synchronous planning to meet diverse stated objectives such as pollution mitigation, climate, and flood resilience, to improve health, resource security, and economic growth outcomes (Mankikar and Driver 2021).

23.3.3 Active, Beautiful, Clean (ABC) Waters Programme in Singapore

With a population density of over 8201 people per km^2, Singapore is one of the most populous cities in Asia (World Bank data 2021). Receiving about 2400 mm of rainfall annually, sustainable water harvesting and management are crucial for the growing city. In order to manage a pervasive network of about 8000 km of drains, canals, and rivers and 17 reservoirs, Singapore's National Water Agency with the Public Utilities Board (PUB) launched the Active, Beautiful, Clean (ABC) Waters Programme in 2006. The initiative aims to harness the full potential of the city's water bodies in a holistic manner to ensure water security while meeting recreational and aesthetic needs of the populace to make Singapore "a city of gardens and waters" by 2030 (Liao 2019). With more than 30 ABC water projects already completed as of 2018, detention and treatment of stormwater; integration of waterways and reservoirs; and, importantly, keeping up with the city's lifestyle have set an example for upcoming urban centers in planning (PUB 2018).

ABC incorporates nature-based stormwater facilities in the form of vegetated and bioretention swales, bioretention basins, sedimentation basins, constructed wetlands, and cleansing biotopes that require minimal maintenance. Flood mitigation is addressed by reducing stormwater runoff at point sources, expanding the capacities of the pathways bringing stormwater, and also identifying flood risk points (PUB 2018). The Bishan-Ang Mo Kio Park of the Kallang River section is a successful example of the ABC program where the old water channel was transformed into a 3.2 km naturalized river, integrated with surrounding green space of the park to provide for local biodiversity and creating a natural river corridor (Liao 2019).

The ABC program has been integrated in the city master plans through identification of the central, eastern, and western catchments in order to improve water quality, avoid deterioration of runoff quality, and re-harvest water. A strong 3P (people, public, private) partnership approach including governing agencies, NGOs, education institutions, and community groups is active in management. The ABC Waters Design Guidelines of 2009 to encourage partnerships to improve waterways designing, ABC Waters Certification Scheme of 2010 to recognize developers who incorporate clean water designs in their projects, and the ABC Waters Professional Programme of 2011 to build industry expertise in urban planning have contributed to increasing public-private collaborations, industry engagement, education, and outreach (PUB 2018). Further, water management is guided by the "Four National Taps policy" that links together water supply, stormwater management, and sewage treatment of Singapore. Research gaps that exist in terms of the ecological impacts of concretized canals, extent of green space inclusion, level of changes made to stormwater channels and surrounding parks, and the extent to which channels can be modified are yet to be plugged (Liao 2019).

23.4 Urban Planning and Policy for BGI: The Way Ahead

The review of literature, especially the case studies of effective BGI integration, offered crucial pointers toward leveraging urban policy and planning for BGI-based strategies of actioning urban resilience and sustainability in the Global South. Extant literature overwhelmingly points to the need of building dedicated multi-sectoral and integrated governance approaches with the participation of diverse actors at local, subnational, and national levels for devising and implementing BGI for urban resilience (Chu et al. 2016) (Fig. 23.3).

We summarize the major takeaways from the review and their implications for BGI-sensitive policies below.

23.4.1 Planning and Policy in the Global South Should Recognize High Levels of Heterogeneity and Diversity in Urban Ecology and the Continuity of BGI with Surrounding Rural Landscapes

Traditional binary representations of the urban-rural dichotomy and the hugely popular yet simplistic gradient approach to urbanity appear inadequate to capture the complexity of cities of the Global South where pockets of rurality persist in urban landscapes (Nagendra et al. 2014). Because of diverse ecological, economic, and social conditions across urban areas in Asia, customized and context-specific planning of urban green spaces is essential, and caution is required before

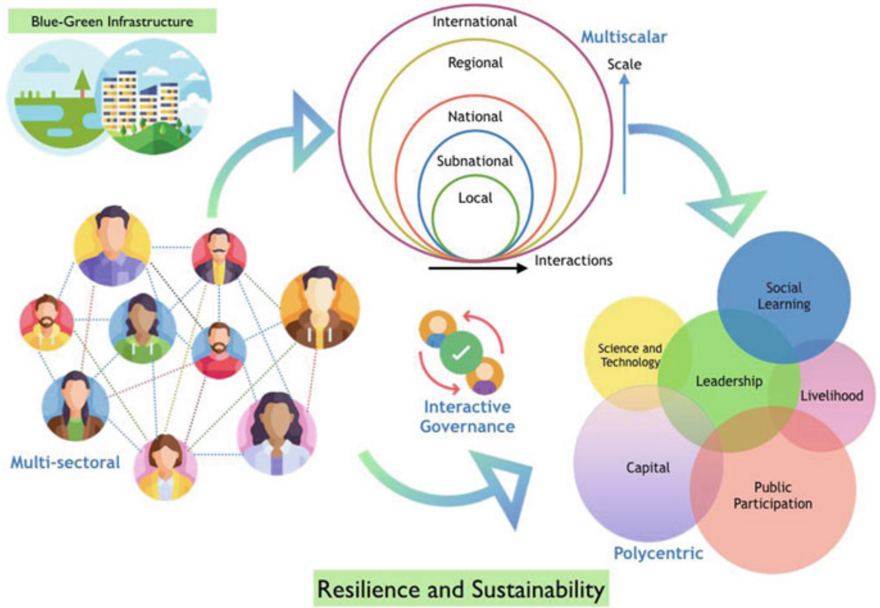


Fig. 23.3 Components and facilitative actors for multisectoral, multiscalar, polycentric, and interactive governance approaches for effective BGI mainstreaming in policy

implementing best practices imported from north in the south context (Mabon and Shih 2021).

Urban agriculture, for instance, is practiced in rooftop gardens growing vegetable and herbal produce in most cities of the developed world, while in peri-urban zones of the Global South, small farms that produce for the city are found intermingled with urban land uses (Parker and Simpson 2018). For urban farming to be viable and vibrant, sustained flow of ecosystem services such as pollination services from surrounding semi-wild as well as protected areas is critical (Mukherjee et al. 2019), which reiterates the need of promoting ecological continuity in landscapes. Landscape heterogeneity needs to be preserved, while planning for urban expansion and strict regulations that prohibit conversion of farmlands to other uses are to be formulated at the state level. For maximizing biodiversity benefits, planning of urban BGI should also be mindful of the ecological continuity of these elements into the surrounding rural landscapes, calling for consideration of regional-scale data in planning processes. Jha et al. (2019), in the context of Bengaluru, argue that design of urban plantations is to be informed by the patterns of species diversity along the rural-urban interface.

Cities of the Global South often harbor huge livestock populations. The urban district of Bengaluru, for instance, has an estimated bovine population of 89,000 heads, and the collection and use of the dung produced do not figure in the municipal waste management plans (Speier et al. 2018). Interactions between urban animal husbandry and plant production need to be better understood to exploit their economic and environmental potential in order to reduce the "waste footprint" of cities (Graefe et al. 2019). Upcycling of cow dung along with city compost for urban farming and using nutrient-rich city sewage to grow crops in the peripheries could effectively tackle the burdens of urban waste management as well as peri-urban water and soil nutrient deficiency. Enforcement of legal provisions to ensure proper treatment of city sewage before discharging into peri-urban areas can help rejuvenate farming in water-deficient peripheries. With well-functioning wastewater treatment systems, the crop and animal produce remain safe, nontoxic, and sustainable.

23.4.2 Collaborative, Multiscalar, and Adaptive Management Approaches Should Guide BGI Mainstreaming in Urban Planning and Policy in the Global South

A combined BGI- and ecosystem-based approach capturing the complexity and dynamics of urban social-ecological systems is required to support policy objectives such as sustainable development, environmental justice, social cohesion, or resilience (Lindholm 2017). Institutional structures and processes for interconnecting different knowledge systems are more serious challenges than lack of appropriate policies, as documented by Mabon and Shih (2021) in Hanoi (capital city of Vietnam), Taipei (capital of Taiwan), and Fukuoka (in Japan). In Dhaka, the capital city of Bangladesh, understanding the spatial, ecological, social, economic, and governance prospects of BGI network in urban planning emerged as an important step toward mainstreaming BGI using a comprehensive approach (Ahmed et al. 2019). Such comprehensive structural frameworks should be developed to plan and implement customized BGI network solutions as per urban morphological characters that are multiscalar and multifunctional in nature. BGI planning needs to integrate micro- and macrolevel dynamics of urban areas that include demographic changes and population density, existing buildup, and natural blue-green spaces from the very preliminary stage.

Urban protected areas and nature reserves are special cases in point for adopting social-ecological approaches distinct from "fortress models" of management prevalent in rural landscapes of the Global South. Urban protected area management must take a wider perspective and consider land uses beyond the protected area boundaries. Telecouplings with macrolevel factors such as global- and national-level socio-economic changes arising from the proximity to an urban center are to be recognized as unique pressures on urban nature reserves; for instance, Dhanya et al. (refer to Chap. 12) show how post liberalization economic changes that accelerated real estate boom, population growth, densification, and sprawl in urban peripheries created distinct stressors on a peri-urban protected area in India. Adaptive management of urban protected sites has to take into account the local context and governance mechanisms that might modify the effects of the conservation intervention (Macura et al. 2015). While areas with the highest conservation priority are to be preserved under strict protection, dynamic zoning schemes also need to be developed (Zhang et al. 2016), as in the case of designating eco-sensitive zones around nature reserves in India to provide a zone for transition between the highly protected and highly human-dominated areas.

Multiplicity of governing institutions that typically follow siloed approaches is a well-documented challenge for effective BGI implementation in developing countries. In the case of peri-urban protected areas, lakes, and wooded groves in Bengaluru (D'Souza and Nagendra 2011; Mundoli et al. 2017; Dhanya et al. in Chap. 12), a host of governance bodies including the Bengaluru Municipal Corporation; parastatal urban planning agencies that were formed in the neoliberal governance regime such as Bengaluru Development Authority and other local area planning authorities of the metropolitan region; and the state government departments including the forest department, revenue department, and the minor irrigation department have jurisdiction over the blue-green spaces. Coordination, communication, and integration are found missing even between different departments within a city corporation, as highlighted as a major institutional challenge for implementing water-sensitive urban design (WSUD) in South Africa because of the allocation of responsibilities of different water-related infrastructure to different municipal departments; e.g., stormwater management is undertaken by road departments; water supply is separated from sewage collection, treatment, disposal etc. (Armitage et al. 2014). Such disintegrated, fractured, or even competing measures that have been implemented for urban BGI management have often delayed the transformative changes essential to achieve livable, resilient, and sustainable cities (Bush 2020). This stresses on the need of leadership attributes to be displayed by city as well as local governments to enhance the capabilities and participation of multiple stakeholder groups. The growing urban environmental challenges desperately demand reinventing existing socio-economic as well as political norms with a special focus on decision-making for which legitimate and reliable leadership is crucial (Hegyi 2020). Integrated management frameworks, cognizant of the cross-sectoral nature of water cycle and other ecosystem processes, are also necessary to alleviate administrative conflicts in urban landscapes.

23.4.3 Environmental Justice and Equity Are to be Foregrounded in Urban BGI Planning and Policy Making in the Global South

Urbanization unleashes larger social-cultural transformations that often lead to a reshaping of perceptions on BGI as sources of urban recreation and aesthetics, from its traditional multifunctional provisioning roles as sources of subsistence and livelihood in the Global South (Mundoli et al. 2015; Derkzen et al. 2017). Consequently, prevalent BGI management measures such as fencing of green and blue spaces and imposition of entry fees often risk the exclusion of marginalized and poor urban communities, as demonstrated by D'Souza and Nagendra (2011) in the case of lakes and Mundoli et al. (2017) in the case of wooded groves in Bengaluru. This calls for greater emphasis on issues of social justice and equity in access to BGI in terms of quantity, quality, location, access, usage, and enjoyment.

Accessibility, not just to recreational but also to provisioning services, needs to be center staged in our imaginations and planning of BGI (Escobedo et al. 2019). Even in cases where city-level master plans designate green networks, such as in Bengaluru, the imagination of green spaces is often limited to parks and nature reserves, while urban farms are largely neglected (Patil et al. 2018). Studies reveal that there is a growing trend even in developing countries to prioritize private gardens in response to rapid urbanization (Jim and Zhang 2015); for example, rooftop gardening was reported as the most affordable green adaptation strategy in Dhaka (Zinia and McShane 2018). At the same time, informal settlements that are abundant in the Global South have traditionally incorporated BGI elements for livelihood benefits; e.g., slums in Bengaluru were found to be rich in various tree species that serve nutritional and cultural needs, and slum residents engage in distinct practices and relations with urban nature (Gopal and Nagendra 2015). Integration of such diverse land uses and livelihoods will provide a pro-poor angle to urban planning process. Urban food gardens, for instance, as socio-natural hybrids, can play a crucial role in building up the seed and food sovereignty movements and can act as sites of sociopolitical change (Classens 2014). Cities should invest in urban agriculture in collaboration with food justice–oriented organizations and disadvantaged communities (Horst et al. 2017).

Urban planners need to engage with a more systemic and situation-sensitive approach to consider questions about who benefits from BGI and how the urban system can be governed to accommodate different needs and unequal opportunities (Andersson et al. 2019). It is necessary to evolve adaptable and responsive planning strategies where preferences of all users are considered and social trade-offs analyzed in relation to greening outcomes to prevent further exclusion of the vulnerable social groups. Urban green spaces must be reimagined as resource commons including all sections of society—especially women and low-income residents, who are often excluded (Basu and Nagendra 2021).

23.4.4 Recognizing and Exploiting the Multifunctionality of BGI in Policies Can Lead to Cost-Effective and Sustainable Solutions for Urban Resilience

Investment in green space supports access to nature and promotes better understanding of ecosystem services; improves sustainable water management; and enables ecological diversity, connectivity, and multifunctionality (Mell 2017). Given their shortage of green spaces, high-density cities should strive to optimize the existing green spaces for provision of ecosystem services and to leverage cultural ecosystem services to engage citizens and gain public support (Liao 2019).

Combination of different BGI elements provides better control of an entire spectrum of storm events and helps to exploit the full range of potential ecological and social benefits (Fluhrer et al. 2021). For instance, the ABC Waters Programme in Singapore used design features that enhance the ecosystem services of the terrestrial green spaces by introducing the regulating services of water-quality treatment and flood mitigation (Liao 2019). BGI developed as floodwater management systems also supports urban and peri-urban agriculture practices by making space for cultivated land (Diep et al. 2019). A BGI network at the macroscale can guide the development of urban expansion zones and future satellite towns, by channeling the natural water system of the whole territory and by focusing on nature as the main guiding and limiting factors, respectively (Haase 2015). Policy measures should be able to maximize and take advantage of the synergies in the ecosystem benefits of BGI, and therefore reorienting and leveraging existing policies on green cover, water, waste, sanitation, public health, energy, and climate adaptation could lead to cost-effective BGI integration.

23.4.5 Greater Public Participation at All Stages of BGI Integration—From Planning to Implementation and Management Is Critical for Equitable Policy Outcomes

There is an urgency for inclusivity in urban planning in the Global South where informal settlements face a host of challenges that urban green infrastructure (UGI) can have a role in countering, such as "provision of basic needs and household materials," "mitigating hazardous or poor environmental conditions," and "meeting social needs" (Birtchnell et al. 2019). Inclusivity in terms of recognition of alternate practices, livelihood means, and knowledge systems is also crucial. In Dhaka's context, Ahmed et al. (2019) argue that the classification of BGI should open to include practices and resources in and around slum dwellers' homes so that there is potential for a greater role for citizens in decision-making on policies and practices affecting their lives.

Urban greenery development relies not only on investment and technology but also largely on the attitude and involvement of urban residents. Changes in the mindset and behavior of diverse stakeholder groups are crucial to overcome planning and implementation challenges. Research on urban green spaces in Indian cities Delhi, Gandhinagar, Chandigarh, and Bengaluru showed limited public knowledge of the connection between human well-being and ecosystem services from green spaces (Chaudhry et al. 2011); however residents in many cities of developing countries have also shown willingness to pay for developing and maintaining urban forests.

In a study from Semarang City of Indonesia, inclusiveness, appropriateness, and proactiveness were considered as prerequisites for community-centered approaches to enhance resilience using BGI (Drosou et al. 2019). Socio-economic and cultural context are key enabling conditions to promote BGI effectiveness. Adoption of appropriate policies to improve the quality of green spaces can also facilitate social interaction and thereby the social capital of urban areas (Moayedi et al. 2019), which can further contribute to social fencing of green spaces and collective action for their management. Effective implementation of GBI requires inclusive, participatory, and transparent relationships among the actors (Swyngedouw 2005.) An integrated top-down and bottom-up approach was recommended to address urban disaster risks and develop resilience against future disasters in Indonesia (Drosou et al. 2019).

23.4.6 Enhancing Public Participation in BGI Adoption Requires Site-Specific Institutional, Economic, or Legal Measures or Appropriate Combinations of These

Public participation for BGI implementation can be enhanced through multiple policy and economic incentives and institutional structures. Civil society organizations (CSOs) can act as representatives of local communities in devising local policy for BGI through their active engagement with the local governmental institutions (Mumtaz 2021). Regular community monitoring is an effective way to maintain the local engagement, bringing together new networks of communities, practitioners, and institutions (Hamel and Tan 2021). In Indonesia, Drosou et al. (2019) suggested repurposing the popular family welfare education groups to promote the adoption of BGI while harnessing the role of women in the communities for flood management. By identifying and assigning appropriate roles and responsibilities to multiple stakeholders involved, bottom-up approaches can be encouraged in urban BGI implementation.

In India, Basole et al. (2019) proposed a National Urban Employment Guarantee Scheme to revive and maintain degraded urban commons such as lakes and ponds. Engaging local labor for the management of BGI elements provides the twin benefits of livelihood support for urban poor while sustaining ecosystem service flows from BGI. Incentives in the form of subsidies and tax reductions for reducing the economic burden may be incorporated in GI programs to overcome the challenges of high construction and maintenance cost of BGI such as green roofs (Shafique et al. 2018). A study carried out in 113 urban areas of 19 countries found financial subsidies and legal obligations as the most common ways to promote green infrastructure worldwide and green roofs as the focus of most incentives (Liberalesso et al. 2020).

23.4.7 Knowledge and Information Gaps Crippling BGI Integration in Policies Need to be Urgently Addressed

There is a dearth of practical knowledge to help mainstream the implementation of BGI in urban planning in different Asian countries. Research and development in urban policy and governance for mainstreaming greenspace for disaster risk reduction and climate change adaptation is also limited (Mabon and Shih 2021). This is mostly because of lack of sufficient primary information available on hydrology and its larger impacts on society and environment. Combined impact of BGI and civil engineered structures under changing climatic conditions is also understudied, and this is a major gap hindering the integration of BGI in urban sprawls across the region (Hamel and Tan 2021). Failure to recognize diverse practices of BGI management in the Global South has also contributed to glaring knowledge gaps, as in the case of urban agriculture. Despite their multiple social-ecological roles, information about urban agriculture is fragmented and largely out of date, as was apparent in a study examining nine cities in Africa and Asia, reflecting the informal nature and non-income dimensions that do not conform to official information-gathering efforts that prioritize economic indicators (Padgham et al. 2015). Science and technology (S&T) is also fundamental for successful implementation of BGI projects as the shared economic benefits from S&T-based efforts can be substantial as has been proven from different contexts and experiences (National Research Council 2006). If layers of local knowledge and technical understanding can be combined in BGI planning processes, the co-benefits of ecological remediation, climate change adaptation, improved services, and local development opportunities could be realized (Mulligan et al. 2020).

Spatial data needs for planning processes are revealed in many studies. In addition to current methods of green space mapping, per capita green cover availability and accessibility mapping, social and environmental justice mapping, demand-supply gap analysis, ecosystem benefits mapping, heat island effect mapping, etc. are suggested (Lahoti et al. 2019). Integrating spatial data with more qualitative data can provide a holistic view of benefits of BGI (Demuzere et al. 2014). Information about the institutional settings could be added to the physical landscape with information on land ownership, user rights, and formal and informal restrictions, stakeholders, and policy targets (Andersson et al. 2019).

The popular methods of assessing green spaces including economic valuation and associated cost-benefit analyses also need to be reoriented to examine the values of green space to human health, climate change adaptation, and water management (Mell 2015). Knowledge gaps occur not only in the social, economic, and environmental attributes but also in the institutional aspects. Understanding social acceptance, in addition to economic feasibility analysis, might be useful in decision-making (Zinia and McShane 2018). There is a need to promote more research on producing and sharing the empirical data and to enhance the regional knowledge base to promote mainstreaming of BGI strategies for DRR and climate adaptation (Hamel and Tan 2021).

23.5 Conclusions

This chapter analyzed the gaps and opportunities in mainstreaming BGI in urban planning and policies for catalyzing sustainable transformations in the Global South. The review shows that scientific studies on different dimensions of BGI from Asian cities are plenty, though critical knowledge gaps are evident. However, research feeding into concrete policy prescriptions is less conspicuous, as the scant availability of information on policy measures incorporating BGI in developing Asia's context reveals. The linear view of "good science leads to good policy" appears constrained given the limited technical, financial, and political capital available for translating scientific knowledge to policy mandates. The fragmentation of urban governance regime brought in by globalisation in the Global South has eroded the social capital that has been foundational to the traditional community-based management of blue-green elements in the pre-urbanization scenario. Better policy integration of BGI-related knowledge for sustainable outcomes will therefore require addressing not only the financial, technical, and knowledge gaps but also restoring the social ownership of BGI.

In the case of a few successful documented examples like China, strong national-level policies have provided the impetus, while in India, engagement of civil society organizations and citizen groups at the city level has emerged fruitful in bringing positive policy changes for urban sustainability. Combined top-down and bottom-up approaches appear to be effective in the Global South context of Asia. Reliance on state and technology-driven BGI planning, as followed in the case of Singapore, may not be sustainable in low- and middle-income countries of Asia, given the complex social-ecological interactions and livelihood dependence on BGI. Highly engineered structures requiring extensive technical capacity and capital investment for implementation and maintenance might not be appropriate solutions, considering the prevalent knowledge gaps and economic constraints. A "commons" approach to BGI, recognizing the diversity, heterogeneity, informal practices, and local knowledge embedded in urban systems of the Global South, is the need of the hour for creating enabling policy environment for resilient and sustainable cities. Reviving the cultural attachment of communities with traditional BGI components such as lakes, streams, heritage trees, and sacred groves offers an avenue to augment social capital and ownership for BGI management. It is important to exploit the multifunctionality of BGI to create opportunities in existing climate and urban sustainability-related policies and to realign these policies to encompass an explicit focus on BGI, in cases where such thrust is missing. BGI mainstreaming in policies appreciating the dynamics and complexities of cities as social-ecological systems undoubtedly holds immense promise for creating win-wins for sustainable urban landscapes and livelihoods in the Global South.

Acknowledgement *Author Declaration*: Authors declare no conflict of interest to finalize and publish this chapter.

References

Ahmed S, Meenar M, Alam A (2019) Designing a Blue-Green Infrastructure (BGI) network: toward water-sensitive urban growth planning in Dhaka, Bangladesh. Land 8(9):138

Andersson E, Langemeyer J, Borgström S, McPhearson T, Haase D, Kronenberg J, Baró F (2019) Enabling green and blue infrastructure to improve contributions to human well-being and equity in urban systems. Bioscience 69(7):566–574

Armitage N, Fisher-Jeffes L, Carden K, Winter K, Naidoo V, Spiegel A, Mauck B, Coulson D (2014) Water Sensitive Urban Design (WSUD) for South Africa: framework and guidelines. Water Research Commission

Basole A, Idiculla M, Narayanan R, Nagendra H, Mundoli S (2019) Strengthening towns through sustainable employment: a job guarantee programme for Urban India. State of Working India, 2019, Azim Premji University Centre for Sustainable Employment

Basu S, Nagendra H (2021) Perceptions of park visitors on access to urban parks and benefits of green spaces. Urban Forest Urban Green 57:126959

Birtchnell T, Gill N, Sultana R (2019) Sleeper cells for urban green infrastructure: Harnessing latent competence in greening Dhaka's slums. Urban Forest Urban Green 40:93–104

Boland B, Charchenko E, Knupfer S, Sahdev S, Farhad N, Garg S, Huxley (2021) Focused adaptation—A strategic approach to climate adaptation in cities. Report published by C40 and McKinsey Sustainability. https://www.c40knowledgehub.org/s/article/Focused-Adaptation-A-strategic-approach-to-climate-adaptation-in-cities?language=en_US

Bush J (2020) The role of local government greening policies in the transition towards nature-based cities. Environ Innov Soc Trans 35:35–44. https://doi.org/10.1016/j.eist.2020.01.015

Chan FKS, Griffiths JA, Higgitt D, Xu S, Zhu F, Tang YT, Thorne CR (2018) "Sponge City" in China—a breakthrough of planning and flood risk management in the urban context. Land Use Policy 76:772–778

Chaudhry P, Bagra K, Singh B (2011) Urban greenery status of some Indian cities: a short communication. Int J Environ Sci Dev 2(2):98

Chu E, Anguelovski I, Carmin J (2016) Inclusive approaches to urban climate adaptation planning and implementation in the Global South. Clim Policy 16(3):372–392

Classens M (2014) The nature of urban gardens: toward a political ecology of urban agriculture. Agric Hum Values 32(2):229–239

D'Souza R, Nagendra H (2011) Changes in public commons as a consequence of urbanization: the Agara lake in Bengaluru, India. Environ Manag 47(5):840–850

Dai L, van Rijswick HF, Driessen PP, Keessen AM (2018) Governance of the Sponge City Programme in China with Wuhan as a case study. Int J Water Resources Dev 34(4):578–596. https://doi.org/10.1080/07900627.2017.1373637

Demuzere M, Orru K, Heidrich O, Olazabal E, Geneletti D, Orru H Faehnle M (2014) Mitigating and adapting to climate change: multi-functional and multi-scale assessment of green urban infrastructure. J Environ Manag 146:107-115

Derkzen, MLH, Nagendra AJA, Van Teeffelen A, Purushotham PH, Verburg (2017) Shifts in ecosystem services in deprived urban areas: understanding people's responses and consequences for well-being. Ecol Soc 22(1):51

Dhyani S, Lahoti S, Khare S, Pujari P, Verma P (2018) Ecosystem based Disaster Risk Reduction approaches (EbDRR) as a prerequisite for inclusive urban transformation of Nagpur City, India. Int J Dis Risk Reduct 32:95–105

Dhyani S, Dasgupta R, Kumar P, Pujari P, Gupta AK (2019) Exploring the current and future potential of urban agriculture in growing urban sprawls of India: strengths and challenges. Clim Change Environ Sustain 7(1):97–101

Dhyani S, Karki M, Gupta AK (2020) Opportunities and advances to mainstream nature-based solutions in disaster risk management and climate strategy. In: Dhyani S, Gupta A, Karki M (eds) Nature-based solutions for resilient ecosystems and societies. Disaster resilience and green growth. Springer, Singapore. https://doi.org/10.1007/978-981-15-4712-6_1

Dhyani S, Majumdar R, Santhanam H (2021) Scaling-up nature-based solutions for mainstreaming resilience in Indian cities. In: Mukherjee M, Shaw R (eds) Ecosystem-based disaster and climate resilience, Disaster and risk research: GADRI book series. Springer, Singapore. https://doi.org/10.1007/978-981-16-4815-1_12

Diep L, Dodman D, Parikh P (2019) Green infrastructure in informal settlements through a multiple level perspective. Water Altern 12(2):554–570

Drosou N, Soetanto R, Hermawan F, Chmutina K, Bosher L, Hatmoko JUD (2019) Key factors influencing wider adoption of blue–green infrastructure in developing cities. Water 11(6):1234. https://doi.org/10.3390/w11061234

Escobedo FJ, Giannico V, Jim CY, Sanesi G, Lafortezza R (2019) Urban forests, ecosystem services, green infrastructure and nature-based solutions: nexus or evolving metaphors? Urban Forest Urban Green 37:3–12

Fluhrer T, Chapa F, Hack J (2021) A methodology for assessing the implementation potential for retrofitted and multifunctional urban green infrastructure in public areas of the Global South. Sustainability 13(1):384
Gopal D, Nagendra H (2015) Vegetation in Bengaluru's slums: boosting livelihoods, well-being and social capital. Sustainability 6(5):2459–2473
Graefe S, Buerkert A, Schlecht E (2019) Trends and gaps in scholarly literature on urban and peri-urban agriculture. Nutr Cycl Agroecosyst 115(2):143–158
Griffiths J, Chan FKS, Shao M, Zhu F Higgitt D L (2020) Interpretation and application of Sponge City guidelines in China. Philos Trans Royal Soc A 378(2168), 20190222
Haase D (2015) Reflections about blue ecosystem services in cities. Sustain Water Qual Ecol 5:77–83
Hackenbroch K, Woiwode C (2016) Narratives of sustainable Indian Urbanism: the logics of global and local knowledge mobilities in Chennai. South Asia Multidiscip Acad J (14) Online since, connection on 01 September URL: http://journals.openedition.org/samaj/4190. https://doi.org/10.4000/samaj.4190
Hamel P, Tan L (2021) Blue–Green infrastructure for flood and water quality management in Southeast Asia: evidence and knowledge gaps. Environ Manage:1–20
Hamidi A, Ramavandi B, Sorial GA (2021) Sponge city—an emerging concept in sustainable water resource management: a scientometric analysis. Resources Environ Sustain 5:100028. https://doi.org/10.1016/j.resenv.2021.100028
Hegyi FB (2020) Leadership to address urban environmental challenges. Mark Focus 3(1):17–21
Horst M, McClintock N, Hoey L (2017) The intersection of planning, urban agriculture, and food justice: a review of the literature. J Am Plan Assoc 83(3):277–295
Imam AUK, Banerjee UK (2016) Urbanisation and greening of Indian cities: problems, practices, and policies. Ambio 45:442–457. https://doi.org/10.1007/s13280-015-0763-4
Jha RK, Nölke N, Diwakara BN, Tewari VP, Kleinn C (2019) Differences in tree species diversity along the rural-urban gradient in Bengaluru, India. Urban Forest Urban Green 46:126464
Jim CY, Zhang H (2015) Effect of habitat traits on tree structure and growth in private gardens. Landsc Ecol 30(7):1207–1223
Lahoti S, Kefi M, Lahoti A, Saito O (2019) Mapping methodology of public urban green spaces using GIS: an example of Nagpur City, India. Sustainability 11(7):2166
Liao KH (2019) The socio-ecological practice of building blue-green infrastructure in high-density cities: what does the ABC waters program in Singapore tell us? Socio-Ecol Pract Res 1(1):67–81
Liberalesso T, Cruz CO, Silva CM, Manso M (2020) Green infrastructure and public policies: an international review of green roofs and green walls incentives. Land Use Policy 96:104693
Lindholm G (2017) The implementation of green infrastructure: relating a general concept to context and site. Sustainability 9(4):610
Ma Y, Jiang Y, Swallow S (2020) China's sponge city development for urban water resilience and sustainability: a policy discussion. Sci Total Environ 729:139078. https://doi.org/10.1016/j.scitotenv.2020.139078. Epub 2020 Apr 28. PMID: 32380332
Mabon L, Shih W (2021) Urban greenspace as a climate change adaptation strategy for subtropical Asian cities: a comparative study across cities in three countries. Glob Environ Chang 68
Macura B, Secco L, Pullin AS (2015) What evidence exists on the impact of governance type on the conservation effectiveness of forest protected areas? Knowledge base and evidence gaps. Environ Evid 4(1):1–29
Mankikar US, Driver B (2021) Blue-Green infrastructure: an opportunity for Indian cities. ORF Occasional Paper No. 317, May 2021, Observer Research Foundation
Mell IC (2015) Establishing the rationale for green infrastructure investment in Indian cities: is the mainstreaming of urban greening an expanding or diminishing reality? AIMS Environ Sci 2(2):134–153
Mell IC (2017) Greening Ahmedabad—creating a resilient Indian city using a green infrastructure approach to investment. Landsc Res 43(3):289–314

Moayedi M, Kheyroddin R, Shieh I (2019) Determining the role of pedestrian-orientation, concerning the public places: improvement of urban social capital quality. Civil Eng J 5(4): 901–912

Mukherjee R, Deb R, Devy SM (2019) Diversity matters: effects of density compensation in pollination service during rainfall shift. Ecol Evol 9(17):9701–9711

Mulligan J, Bukachi V, Clause JC, Jewell R, Kirimi F, Odbert C (2020) Hybrid infrastructures, hybrid governance: new evidence from Nairobi (Kenya) on green-blue-grey infrastructure in informal settlements. Anthropocene 29:100227

Mumtaz M (2021) Role of civil society organizations for promoting green and blue infrastructure to adapting climate change: evidence from Islamabad city, Pakistan. J Clean Prod 309:127296

Mundoli S, Manjunath B, Nagendra H (2015) Effects of urbanisation on the use of lakes as commons in the peri-urban interface of Bengaluru, India. Int J Urban Sustain Dev 7(1):89–108

Mundoli S, Manjunatha B, Nagendra H (2017) Commons that provide: the importance of Bengaluru's wooded groves for urban resilience. Int J Urban Sustain Dev 9(2):184–206

Nagendra H, Unnikrishnan H, Sen S (2014) Villages in the city: spatial and temporal heterogeneity in rurality and urbanity in Bengaluru, India. Land 3(1):1–18

National Disaster Management Authority (NDMA) (2019) National guidelines for preparation of action plan- prevention and management of heat wave, Ministry of Home Affairs, Government of India

National Research Council (2006) The fundamental role of science and technology in international development: an imperative for the U.S. Agency for International Development. The National Academies Press, Washington, DC. https://doi.org/10.17226/11583

O'Donnell EC, Netusil NR, Chan FK, Dolman NJ, Gosling SN (2021) International perceptions of urban blue-green infrastructure: a comparison across four cities. Water 13(4):544. https://doi.org/10.3390/w13040544

Padgham J, Jabbour J, Dietrich K (2015) Managing change and building resilience: a multi-stressor analysis of urban and peri-urban agriculture in Africa and Asia. Urban Clim 12:183–204

Parker J, Simpson GD (2018) Public green infrastructure contributes to city livability: a systematic quantitative review. Land 7(4):161

Patil S, Dhanya B, Vanjari RS, Seema P (2018) Urbanisation and new agroecologies: the story of Bengaluru's peripheries. Econ Political Weekly 53(41):71–77

Prescott MF, Dobbie MF, Ramirez-Lovering D (2021) Green infrastructure for sanitation in settlements in the global south: a narrative review of socio-technical systems. Sustainability 13:2071. https://doi.org/10.3390/su13042071

Public Utilities Board (PUB) (2018) Singapore's National Water Agency. https://www.pub.gov.sg/

Randhawa A, Kumar A (2017) Exploring sustainability of smart development initiatives in India. Int J Sustain Built Environ 6(2):701–710. https://doi.org/10.1016/j.ijsbe.2017.08.002

Shafique M, Kim R, Rafiq M (2018) Green roof benefits, opportunities and challenges—a review. Renew Sust Energ Rev 90:757–773

Speier CJ, Mondal MM, Weichgrebe D (2018) Evaluation of compositional characteristics of organic waste shares in municipal solid waste in fast-growing metropolitan cities of India. J Mater Cycl Waste Manage 20(4):2150–2162

Swyngedouw E (2005) Governance innovation and the citizen: the Janus face of governance-beyond-the-state. Urban Stud 42(11):1991–2006

United Nations, Department of Economic and Social Affairs, Population Division (2019). World Population Prospects 2019: Highlights (ST/ESA/SER.A/423)

United Nations Human Settlements Programme, UN-HABITAT (2012) Sustainable urbanization in Asia: a sourcebook for local governments

Vishwanath S (2018) "Waste Water to the Rescue," The Hindu, 14 April. http://www.thehindu.com/to-dayspaper/tp-features/tp-propertyplus/waste-water-to-the-rescue/article23534133.ece?utm_source=tppropertyplus&utm_medium=sticky_footer

World Bank Data (2021) Population density of Singapore, Food and Agriculture Organization and World Bank population estimates. https://data.worldbank.org/
Xiang C, Liu J, Shao W, Mei C, Zhou J (2019) Sponge city construction in China: policy and implementation experiences. Water Policy 21(1):19–37
Zhang L, Luo Z, Mallon D, Li C, Jiang Z (2016) Biodiversity conservation status in China's growing protected areas. Biol Conserv 210:89–100
Zinia NJ, McShane P (2018) Ecosystem services management: an evaluation of green adaptations for urban development in Dhaka, Bangladesh. Landsc Urban Plan 173:23–32

Dhanya Bhaskar is the Chairperson, Centre for Policy Studies and Associate Professor of Ecosystem and Environment Management at the Indian Institute of Forest Management, Bhopal, India.

Samudyatha Ramananda completed Masters in Conservation Studies from Azim Premji University, Bengaluru.

Shalini Dhyani is a Senior Scientist at Critical Zone Group (CZO) of Water Technology and Management Division (WT&MD), CSIR-National Environmental Engineering Research Institute (CSIR-NEERI), Nagpur, India.