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Arnab Jana *Editors*

Advances in Urban Design and Engineering

Perspectives from India

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ISSN 2509-5986 ISSN 2509-5994 (electronic)
Design Science and Innovation
ISBN 978-981-19-0411-0 ISBN 978-981-19-0412-7 (eBook)
https://doi.org/10.1007/978-981-19-0412-7

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Preface

This book "Advances in Urban Design and Engineering—Perspectives from India" is extremely relevant in the context of rapid urbanization in almost every developing nation in the world (the so-called Global South). Various aspects—such as evolving urban fabric and the consequent effect on quality of life, disaster modeling and mapping within the urban development context and climate change, and the rapid developing relatively new field of data-driven urban governance—are addressed by researchers in the urban sphere.

The authors have actually managed to look at the rapidly evolving field of urban management from various different angles, with case studies varying across the entire spectrum of urban conglomerations in India and abroad—metropolitan cities, satellite cities and small cities, and towns. This provides a richness of experience that would be very relevant for current and future urban planners and mangers. We hope that some of the issues addressed in this book would resonate with and inform even common citizens of urban India and the Global South.

Contextualizing a book with such varied topics is a challenge. My co-editor and I have tried to group topics that have ideas associated with a particular urban context in chapter groups. Thus, the first chapter group comprising Chaps. 1 through 4 addresses issues connected with the urban fabric and economic development, its evolution and effects on quality of life, and would be relevant to urban planners and designers. The second chapter group comprising Chaps. 5 and 6 addresses issues connected with disaster modeling and estimation and managing a post-disaster scenario in the connected world of today, and would be relevant for both urban planners and managers. The final chapter group comprising Chaps. 7 through 9 addresses issues that are becoming relevant within the context of smart cities that are being developed under missions in India and across the Global South, and would be relevant for current and future urban managers.

It is impossible to satisfy everyone with a book on advances in urban design and engineering, as people may point out omission of focused topics on mobility and

ecology, areas of concern in the cities of today. To them we say, read the book and find references to these topics in many of the chapters.

Mumbai, India Pradipta Banerji

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Editors and Contributors

About the Editors

Dr. Pradipta Banerji is a Professor of Civil Engineering and the former Head, Centre for Urban Science and Engineering at IIT Bombay. He is also a former Director of IIT Roorkee. He has more than 35 years of academic and research experience. He has a B.Tech. degree from IIT Delhi, and M.S. and Ph.D. degrees from UC, Berkeley. He is a member, fellow, chair of several committees and professional societies across the world. He has developed many popular courses for working professionals in the field of structural engineering and urban sustainability. He has supervised theses of around 70 Master's and Doctoral students at IIT Bombay, and has more than 100 research publications, books, and reports. He has delivered some of the most prestigious National Lectures of professional societies in India, and several Keynote lectures in international conferences and symposia. He is the India representative on a few international academic and research networks.

Dr. Arnab Jana is an Associate Professor at the Centre for Urban Science and Engineering and associate faculty at Centre for Policy Studies, Indian Institute of Technology Bombay. He works in the area of urban infrastructure policy and planning, primarily focusing on public health policy, application of ICT in urban and regional planning, sustainability & environmental issues. He has been the visiting faculty at Hiroshima University, Japan, in 2016. Dr. Jana holds Ph.D. in Urban Engineering from the University of Tokyo, Japan. He was awarded the prestigious Monbukagusho Scholarship by the Ministry of Education, Culture, Sports, Science, and Technology (MEXT), Government of Japan. He is also an alumnus of Asian Program of lncubation of Environmental Leadership (APIEL), University of Tokyo. Dr. Jana holds a Master's degree in City Planning from IIT Kharagpur. He has guided several doctoral and post graduate students and have authored numerous peer reviewed articles in peer reviewed journals and conferences and books.

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Chapter 1
Creating a Framework to Exploring Densities in the Contemporary Post-industrial City

Pradipta Banerji and Aneerudha Paul

1 Introducing Density

Density is a much-debated issue that requires inquiry as we witness an intense urbanization process started by liberalization (Jenks 2000; Burgess 2000). For India, the phase of liberalization, which started from 1991 onwards, coincided with manufacturing industries' shifting out of the city. Along with this, most cities have relaxed their urban development policy framework to attract international capital and private investments. The authorities' call for intense development in cities is either to achieve maximum real estate potential or to create intense exclusive nodes to attract a section of its population. The reasons are varied in cities around the globe depending on their social and economic contexts (Marvin and Graham 2001, p. 308). Authorities around the globe promote these nodes as compact cities, smart cities, transit-oriented developments, urban renewal projects of a blighted area, etc. The nature of density observed in such developments is high built density that is promoted by giving higher Floor Space Index (FSI) on plots. Thus, while cities in export economies like China, Taiwan, and Korea have promoted such intensification, cities in South East Asia, South America, and Africa have grown and densified differently (Davis 2006, p. 13). In India, spurred by the desire to be an export economy, the government has promoted multiple schemes that promote intense urbanization along new infrastructure corridors.

One such scheme, the Smart City Mission of India, as one of its strategies states that

> For instance, a new layout plan of the identified area will be prepared with mixed land-use, higher FSI and high ground coverage. Two examples of the redevelopment model are the

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P. Banerji and A. Jana (eds.), *Advances in Urban Design and Engineering*, Design Science and Innovation, https://doi.org/10.1007/978-981-19-0412-7_1

Saifee Burhani Upliftment Project in Mumbai (also called the Bhendi Bazaar Project) and the redevelopment of East Kidwai Nagar in New Delhi being undertaken by the National Building Construction Corporation. (MOHUA, GOI 2016).

It is in this context that this chapter would inquiry into this process of intensification that such cities are witnessing. Is this intensification beneficial, like in compact cities that governments propagate, especially in the western world from the 1990s after the Rio Declaration? Or does it lead to the breakdown of infrastructure and overcrowding, as knowledgeable detractors indicate, in the case of Mumbai (Patel 2014)? However, in the same context of Mumbai, many have argued that intensification is necessary given the present low per capita floor space consumption and sub-optimal land utilization due to lower FSI in such cities (Bertaud 2004, p. 1). But, Betaurd's argument fails to realize that while the built density might be low in such areas, the population density remains very high in pockets he refers to as sub-optimal.

Also, as in the Global South cities, their urban fabric is often formed spontaneously and informally and exhibits high density, without seemingly any direct action from government institutions (Richardson et al. 2000). In such a case, the authors are referring to the high population density. The assumption in such cases is that informality is an outcome of lax governance. However, is this assumption correct? Moreover, is the experience of this density borne due to informality the same as those that authorities promote under schemes like compact cities, smart cities, or transit-oriented development?

Mike Davis attributes the growth of informality not due to lax governance, but to the very economic restructuring that countries have undergone in this era of liberalization, where they left the urban poor in cities vulnerable without any government support. He primarily studies this phenomenon with respect to cities in the developing world. Saskia Sassen expands this observation and notes that informality is also a part of cities in the developed world. In such cases, often it is commonly attributed to immigrants from the developing world. She disagrees and examines the role of increasing earning inequalities and extreme competition among some goods and services; that to remain profitable, some part of them stay wholly informal (Sassen 1998, p. 154). She observes that informality is not an "anomaly" but an essential part of advanced capitalism. Her argument is very different from the common belief that the urban poor in our cities produces informality, and governments fail to stop the phenomenon.

Many authors have taken Sassen's arguments further and demonstrated how governments and powerful interest groups collude in cities to produce settlements outside recognized legal processes. We should also identify them as informal as argued by Anaya Roy (2005, p. 149). Roy takes cases, like in the periphery of cities, where private interest appropriate agricultural land to build gated communities for the rich (Roy 2005). She considers informality more as an organizing logic than identifying it to a specific sector or a specific group of people. As studies show, we also realize, like in the case of Nairobi, Kenya, that even within the umbrella of the informal, a lot of the people with formal skills participate and innovate (Macharía 2007). Thus, this difference between the formal and informal cities is uncalled for,

especially in the post-industrial city, where many of its productive activities cannot remain profitable by being formal due to liberalization.

The informal can take many forms depending on the context of the city. In some cases, they can be observed as a part of vibrant historic cores of cities that have now become spaces for immigrants and small-scale economic activities that fall outside the formal framework. We observe such phenomenon in the historic part of cities in Asia like Bangkok, Jaipur, or Udaipur (Kamalipour 2016) (INTACH and NIUA 2015). In many cases, informal settlements are a part of the peripheries of cities, where land might belong to the owners, but their development is outside the framework of plans prepared by local authorities. In many cases, they are encroachments on public land or environmentally fragile pockets. Whatever may be the context, such settlements are self-organized by resident communities. A paper by Solly Benjamin explores urbanism shaped by everyday politics, material practices, and history for Indian cities. It discovers numerous ways the urban poor negotiate their right to the city and organize living and working in them (Benjamin and Raman 2011). Density in such settlements is a part of this incremental process that also leads to its diversity.

In this chapter, we want to expand the notion of density by simultaneously observing projects promoted by authorities through intensification and density that have grown incrementally and spontaneously by people-driven processes outside their purview. As Saskia Sassen has observed, informality is a part of the contemporary urbanization process and not an aberration that city governments can hope to eradicate. She calls it part and parcel of "*advanced capitalism.*" Most authorities of cities recognize them as blighted areas and call for their removal and redevelopment. However, as Keith Hart observes, such informal settlements exhibit entrepreneurship and innovation that require exploration (Hart 1985).

Thus, this chapter would like to create a framework to investigate the morphological aspect of these formal and informal fabrics resulting from either high built density or population density and explore its impact on the experience of its inhabitants. In this chapter, we will explore this phenomenon in the case of Mumbai, which might have learning for growing Indian city.

1.1 Research Questions

The critical question is how density in such urban fabrics, be it to capture land value or due to competition over scarce urban resources, or the need to evolve tightly knit social networks, is enabling or disabling for its inhabitants? Majority of density arguments concern either the environment or overcrowding. Is this the only way density is enabling or disabling in the varied typo-morphologies of our city?

Moreover, density becomes an important determinant, especially when present development institutions provide a broad framework for planning cities to attract private investments in foreign direct investments (FDI). In such cases, they allow the microplanning of neighborhoods and often wards to special planning authorities (SPA) that are private or quasi-governmental. As in the case of India, these are known

by various schemes and projects like the smart city mission, compact/sustainable cities, transit-oriented developments, cluster redevelopment of slums and historic cores, etc. In all these schemes, high density and intensification of built-form become an essential aspect that agencies propose. To exemplify, the National Transit-Oriented Development policy paper of India states that.

> TOD integrates land use and transport planning and aims to develop planned sustainable urban growth centers, having walkable and livable communes with high density mixed land-use.

Within these broad frameworks, the city authorities give the agencies complete freedom to design physical layouts as per their requirements. However, in such cases, we need to expand the notion of density to engage with the social complexity of cities. We must recognize that all four aspects, i.e., intensification, spontaneity, informality, and flexibility, are a part of contemporary urbanization processes in today's cities, especially Indian cities. As stated by Sassen, they are generated by the inherent logic of advanced capitalism. Ananya Roy, while studying Indian cities, notes that.

> Urban informality is often seen to be synonymous with poverty, this article makes a case that India's planning regime is itself an informalized entity, one that is a state of deregulation, ambiguity, and exception. (Roy 2009, p. 76).

This is a very critical and foundational aspect that this chapter accepts to carry on an exploration of urban density. Though Roy might be referring to the Indian city, as Sassen states, varying degrees of informality would be observed in any city in the developing or developed world in present-day urbanization process.

Figure 1 is an image of an urban village within Delhi. Even in Egypt, settlements growing in the periphery of larger cities like Cairo and around villages display such informal characteristics as their development is outside the regulation. However,

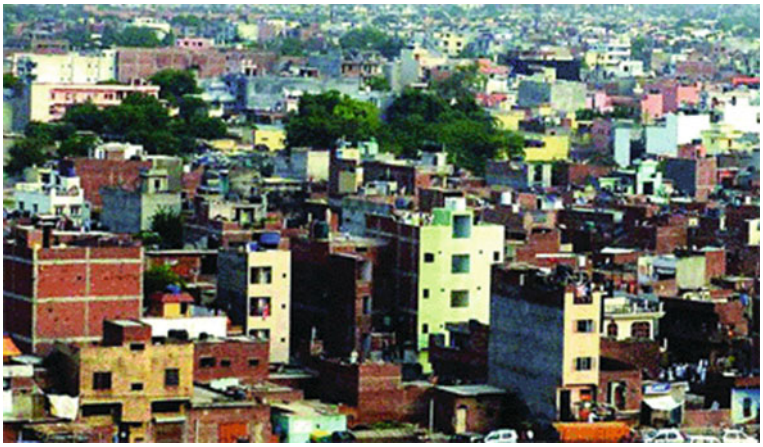


Fig. 1 Informality in Urban Villages, New Delhi (Kumar 2015)

Table 1 Summarizing the questions

Primarry questions			
1	**Under what conditions does density that emerges due to varied reasons in our contemporary cities enable or disable?**	**2**	**How do different morphologies that arise in such contexts affect the experience of density?**
	Can we observe densities for spontaneous and planned settlement without any preconceived biases?		Can we expand the notion of density that authorities conceive numerically for our cities?
	If yes, then how do we create an observational framework?		Can there be a conception of density that integrates its social and computational aspects?

lawyers, doctors, and white-collar workers inhabit these urban villages or agro-towns, both in Delhi and Cario (Bayat and Denis 2000, p. 194).

The other questions that this research would like to engage with regarding density emerges from deconstructing its notions as a numerical construct like FSI and ground coverage that city authorities presently conceive. It specifically would like to explore density within the social complexities generated out of liberalization in our cities.

Research conducted on density in Hong Kong expands the idea that it is not only a product of "absolute space" that we need to be record numerically. It explores the notion of density where inhabitants have the agency to shape their everyday lives (Tanga et al. 2018). In such a case, the authors understand density as a part of a process. They state that.

To unfold a full picture of high-density development, the context can be reexamined with the embedded dynamic of urban space, history, and society (Tanga et al. 2018).

In these cases, as shown in these informal settlements of Delhi and Cario, we realize that it is not built density but population density or maybe an amalgamation of both that is of concern. It is very different from the built density of smart cities, compact cities, transit-oriented developments, or redevelopment projects, images of which city authorities eulogize and valorize (Table 1).

1.2 Research Objectives

In this background, the research would not like to differentiate between the planned and the informal but would like to observe them as emergent out of contemporary imperatives of liberalization in our cities. With its mandate toward people, the research assumes that the city authorities have a role to play within this urbanization process. It just cannot be a silent onlooker. Thus, this research would not just observe this urbanization process but also hint at the possible intervention modes that city planning authorities can adopt. For this, it would like to refer to the work of Jennifer Robinson, *Ordinary Cities*, where she states that such cities need to imagine

alternative modes of imagination, apart from the dominant way of "*competition*" and "*developmentalism*" that our city authorities influenced by prevailing western thought replicate (Robinson 2006, p. 116). Because of this perspective, most city authorities valorize the rehabilitation and redevelopment of any form of informality, replacing a density that has formed incrementally with high built density morphologies. Even in greenfield projects, authorities promote this narrow understanding of density.

Abandoning this developmental framework of thought can allow multiple ways of intervening in "*ordinary cities*" that can be more inclusive, collaborative, and meaningful for its residents. It can lead to many homegrown solutions.

However, the present problem with the way authorities imagine density is that it is only quantitative. This approach generalizes the various contexts in which densities have evolved in our cities, both in spontaneous and planned neighborhoods. Moreover, the present quantitative aspects of measuring density are extremely limited to understanding spontaneity and informality, characteristic of the present-day urban process. In many high-density informal settlements, scholars have observed a high degree of self-organization that impacts governance (Eizenberg 2019, pp. 40–41). To comprehend this phenomenon, we need to expand the notion of density, incorporating variables that influence its performance. This paper argues that there is a need to simultaneously understand density's descriptive, quantitative, and qualitative aspects. Finally, the way residents and inhabitants perceive density individually and collectively is essential. When we simultaneously comprehend these aspects, density can achieve inclusion, sustainability, and resilience in our cities. The challenge would be to create a framework that would allow us to comprehend density, evaluate its performance, and identify variables that can inform public policy for cities. This study intends to educate architects and urban designers who shape the built environment by understanding quantitative and qualitative variables that enable density in specific contexts. For this chapter, the research would limit itself to create a possible framework for observing densities in a city like Mumbai. It assumes that this study can have a wider applicability for similar such cities that are undergoing transformation in the Global South (Fig. 2).

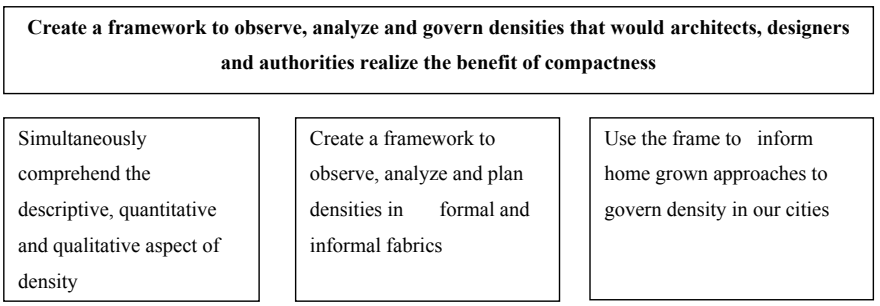


Fig. 2 Diagram summing the intent of the research

2 Literature Review

2.1 Density and Performance

In her book "*Life and death of Great American Cities*," Jane Jacobs called for the need for concentration and diversity in our cities (Jacobs 1961). The book reveals city authorities' myth on density, distinguishing between overcrowding observed within dwelling units and density witnessed in streets. In 1965, C. A. Doxiadis et al. formulated the need to study density at various scales from the room, dwelling unit, neighborhood, town, and metropolis to the ecumenopolis (Doxiadis et al. 1965).

Leslie Martin and Lionel March's work, in the early 1970s, demonstrated the qualitative aspect of density affected by the various juxtaposition of layouts and urban form. Their study of urban blocks in the Manhattan grid demonstrated that the building bulk for a low-rise perimeter block remains the same as a high-rise tower typology.

Amos Rapport, inspired by the work of environment-behavior researchers like Stokol, Desor, Esser, and Kutner, challenged the very premise of density understood quantitively and proposed that individuals perceive it collectively based on previous experience, interpersonal relationships, and social organization. (Rapport 1975).

While reviewing the notion of Density, Ernest R Alexander tries to understand the relationship between the quantitative, qualitative, and perceived aspects. He identifies standard density measures planners and city authorities use to quantify people per unit area, household per unit area, or physical bulk, also known as built density. The physical density is also affected by the scale, massing, form, and even building use (Alexander, 1993).

Through these above observations of density, for this chapter, we will assume some working definitions of density as below:

- Built Density—The density of a neighborhood refers to its physical density manifested through its urban form. City authorities manipulate the qualitative aspect of built density through the various parameters that control urban form like Floor Space Index (FSI), building height, ground coverage, setback, etc.
- Population Density—It is the density of people that occupy a certain given area, which might be a city, ward, precinct, or neighborhood. At the scale of the home, this will be referred to as the household density.
- Perceived Density—Perceived density is the experience of individual inhabitants in any neighborhood.

2.1.1 Performance of Density

Attempting to disentangle the concept of Density, Churchman explores some of the fields which use the concept of density. He notes that apart from being widely used in planning, design, transportation, and environment-behavior studies, "*economic, sociology, psychology, anthropology, and ecology*" use the concept of density

(Churchman 1999). These are more like performance factors related to density. This study proposes to use a multiple set of criteria to evaluate whether densities are enabling or disabling in various morphologies of the contemporary city. It would mean that inhabitants residing in different neighborhoods with their unique typo-morphologies might find and prioritize any one or a combination thereof of the performance aspect of density as enabling.

The chapter will explore how literature articulates the performance factors concerning density. The factor that gets maximum immediate attention is the ecological factor. Recognizing the environmental crisis in 1992, after the Rio Declaration on Environment and Development, the notion of a compact city got traction among city authorities and planners, especially in the western world. Though what it would mean for cities in the developing world was not completely understood, cities in the developing world are rapidly growing with a large migrant population, are informal, naturally dense, and have observable inequities (Jenks et al. 1996, p. 3). After 1992, William Rees and Mathis Wackernagel first coined the word "ecological footprint" to assess human beings' use of natural resources (Wackernagel and Galli 2007). The notion of ecological footprints connects closely to another concept called urban metabolism (UM). It is a notion framed by an American engineer and geographer named Abel Woolman. He used it to study the deteriorating condition of a hypothetical city due to intense resource use and waste generation (Dinarès 2014). His primary idea was to close the loop by minimum use of resources or production within city limits and simultaneous recycling of wastes. A study of urban metabolism for Mumbai demonstrates the low cost incurred in organizing public transport (Reddy 2013). Another neighborhood-based study based on the urban metabolism model for the city of Mumbai explores the ecological sustainability of high built density redevelopment projects in Mumbai. It establishes the ecologically negative impact of such projects compared to the earlier fabrics they replaced (Mandal and Byrd 2011). It demonstrates that the UM model can evaluate the ecological performance due to density for cities in India.

The other important aspect where researchers have made a lot of investigation is mobility and density. Peter Newman and Jeffrey Kenworthy attempted to relate density with car use and fuel use, and they found that high density reduces both (Newman and Kenworthy 2015, p. 589). One of their significant findings was to recognize that cities have urban fabrics based on their mobility characteristics. They called them the walking city, the transit city, and the automobile city. In these, the walking city and the transit city can accommodate high density (Newman and Kenworthy 2015, pp. 107–111).

However, we need to investigate in what conditions can transit-oriented city be effective in highly dense conditions? Research done for transit corridors along 50 neighborhoods of the San Fransisco Bay area shows that there need to be diversity and design for highly dense transit nodes to be successful. The primary finding was density, diversity, and design work simultaneously. In this case, diversity is measured by the presence of mixed-use like work and living together (Cervero and Kockleman 1997, p. 217). However, questions remain, as studies show that cities in the developing world, including Mumbai, do not have any car restrain policy like

their western counterparts. Moreover, authorities don't enable walking and cycling in cities of the developing world (Barter 2000). In such cases, high density leads to pollution and congestion as experienced in these cities. Encouragingly in Mumbai, 55% walk to work, 22% travel by train, and 15% use the bus (Rode 2009). Thus, the diversity and design of streets would play an essential role in evaluating mobility in this city.

We can evaluate the social performance of high-density environments through the quantitative and qualitative aspects of public space and social amenities. The other important factor would be to gauge how inclusive these spaces and amenities are for all residents. New York City made some moves to add to the public realm in such areas in the 1960s for the Manhattan District characterized by an increased Floor Space Index (FSI). It attempted incentivizing private developers to allow a certain percentage of space for public use within their development. It was called Privately owned Public Spaces (POPS) (Dimmer 2013, p. 8). Soon other cities, some Asain, like Hong Kong and Taipei, started adopting similar policies. Studies show that these small spaces are very effective in these high-density environments and are used most by people (Lai 2018). In the case of Mumbai, the city has not made any attempt to incentivize private agencies to demarcate public space in their projects. A study on reserved open spaces of Mumbai, supported by the MMR-EIS, shows that the city's development plan demarcates 2.48 m^2 per person open space, while only 1.91 is available. Of this, only 0.88 sqm per person is freely available to all (Adarkar Associates for MMR-EIS 2012).

The other aspect closely connected to the quantitative part is the qualitative aspect of public space. The qualitative elements engage with whether these spaces are inclusive. It is imperative, given the nature of urbanization, that cities have experienced post-liberalization. Most of the development is malls and multiplexes with residential areas that are gated and exclusive. Also, a vast network of mobility infrastructure connects these developments, but the in-between spaces are often dead and unused. It has led to the splintering and fragmentation of cities (Marvin and Graham 2001). It has led to areas that are either zealously over-managed by private interest or gated communities or undermanaged. It is within this paradigm that Mathew Caramona documents and classifies the nature of contemporary urban space. He identifies the role of management as being central to modern urban space (Caramona 2015). It is very different from a set of scholars who in earlier literature have stressed the need of governments and society to shape a genuinely inclusive public realm. The private can play no role in this. However, recognizing the shift in production of the public realm, scholars are trying to move away from this binary discourse. They are attempting to understand the public domain for the contemporary highly dense city, where the role of private players is inevitable. In a study done by researchers from the National Institute of Singapore to form a framework for evaluating urban spaces in dense contexts, they have a similar view as Caramona.

Their work recognizes the hybrid nature of the public realm that cities form by overlaps of the infrastructural, spatial, everyday requirements, ownership, etc., that various actors in such conditions constantly negotiate. Thus, they expand the notion of the public realm to include government-provided open spaces and other

spaces of everyday use like footpaths, markets, spaces created due to infrastructure, like stations, airports, skywalks, etc. After having gone through literature and being inspired by the work of Caramona, they frame a mode of a three-pronged model of analysis called the Hardware, Software, and Orgware that emerges from the play of design, function, and ownership. Thus, we realize that while density can help interaction among inhabitants in a certain neighborhood, if the public realm is not managed well in a highly dense environment, inhabitants might not perceive it as positive. It requires authorities to frame and implement policies where every actor in our cities plays a role in making and maintaining them.

Another critical criterion that requires review is the economic aspect related to density. Alfred Marshall pointed out the benefit of agglomeration in the city's economic activity (Marshall 1920). Also, Jane Jacob, in her book, *The Economies of City,* observes the importance of size, messiness, and concentration for work for innovations to grow. She notes that large cities might be inefficient, but this quality allows creation to happen. The large cities she observes are also the wealthiest. Studies done on compact cities show the positive impact on jobs and enterprise. Such cities improved business viability and also productivity. They also provided maximum property value to their owners (Hofstad 2012).

Ed Glaser has established the importance of density on non-market interactions. These interactions do not have any transactional value but are essential for "*idea flows*" to acquire "*human capital*." He takes the case of Manhattan, where he shows that residents value high density along with amenities. These spaces allow for social exchange and information flows that these inhabitants value (Glaeser et al. 2000, p. 107). He also shows how architecture plays a role in fostering such interactions.

Researchers have not made such studies in cities in the developing world due to a lack of data. However, in the case of broad-level district studies, in India, where data is available, a clear relationship is seen between agglomeration and jobs. It has significant implications as it establishes a strong connection with agglomeration and informal jobs (Mukim 2011). We need further research to see whether it holds at a more granular scale.

The other important aspect that requires investigation is governance. Does high-density lead to better governance? If so, governance is a performance factor that can benefit from increased density. However, in such a case, density is not to be understood numerically. It is more of a precondition that allows for diverse human preferences, abilities, and know-how. It fosters exchanges and helps grow tacit knowledge (Moroni 2016, p. 3). As Jane Jacob notes, it is local knowledge that people form of their environment. Essential is the support and organization that people evolve under such conditions (Jacobs 1961). However, there is a critical characteristic in such kind of density that Jacob is referring to. It is not planned; it is spontaneous, emergent, and diverse. We need to understand this aspect, especially in cities where the urban fabric is spontaneous in the developing world. It holds even for cities in India.

Thus, having reviewed some of the performance factors for density that is found in literature, this chapter will investigate the psychological aspect of density. In many cases, individuals may perceive density similarly because of shared social and cultural values. Also, age, gender, and physical abilities play an important role in forming

perceptions. It is crucial as inhabitants of different neighborhoods may perceive the benefits of density very differently.

2.1.2 The Individual Perception of Density

Mitchell researched dense neighborhoods in Hong Kong to establish that density and crowding have no direct relationship. Crowding is a perception due to loss of privacy (Mitchell 1971). Others like Stokol differentiate between density and crowding. Freedman associated the perception of crowding with other variables. He even noted that there is a difference in perception between males and females. Desor observed that crowding is dependent on visual cues from the environment (Loo 1975, p. 831). Researchers such as Schopler and Stockdale proposed that people experienced crowding when there were constraints to act freely. Stokol introduced the notion of neutral and personal thwarting based on the unavailability of space or perceived threats (Stokols 1976). Based on these, people like Amos Rapport, as mentioned earlier, have done an intense study on density, people, and the built environment. It formed the basis of the Environment-Behavior framework. After a lot of initial work, this framework did not gain much traction. One of the main reasons Rapport attributes is being a multidisciplinary field; researchers have not crystallized its basis for knowledge (Rapoport 2008).

Thus, this gave way to the Quality of Life (QOL) framework that can incorporate individual perception, social justice, and inclusivity issues. The World Health Organization definition of QOL has been the following:

> Quality of Life as an individual's perception of their position in life in the context of the culture and value systems in which they live and in relation to their goals, expectations, standards and concerns. It is a broad-ranging concept affected in a complex way by the person's physical health, psychological state, personal beliefs, social relationships and their relationship to salient features of their environment (World Health Organization 2020).

Within this framework, Elizabeth Burton conducted a critical study to understand the benefits of compactness for poor people in the UK. Her finding was that compact cities could provide more "equality" than "equity" in the UK context (Burton 2001, p. 13). A study for Bandung, Indonesia, where the authorities had adopted a policy of intensifying the inner core, concludes that the residents are unhappy with the congestion and environmental problems of the area (Arifwidodo and Perera 2011). In a similar study to understand the Quality of Life for Kolkata, densities can be as high as 25,000 people per km^2. It shows that accessibility plays a crucial role in the residents' Quality of Life (Bardhan et al. 2015). The QOL criteria are critical as individual residents can prioritize specific performance criteria as more important than others. While for some groups of inhabitants, the environment might be of prime importance, for others, it might be the possibilities of economic growth. It is imperative, especially in Indian cities where there is diversity in neighborhoods based on class, caste, ethnicity, religion, gender, etc.

2.1.3 Adopting Tools for Observing and Visualizing Density

Simultaneously, the study realizes that these settlement formation processes in the developing world lead to complex typo-morphologies that affect the perception of density. However, for this, we require the help of computational tools and models that help in its visualization. More than being a tool that can predict possibilities, what we need in such cases is a tool that can map actualities (Hillier and Hanson 1997). Also, as Micheal Batty observes, the primary metaphor of looking at cities has changed, and now we realize that cities are organisms like any other social system (Batty 2019, p. iv).

Thus, while Martin and March, as mentioned earlier, had initiated research exploring the qualitative aspect of morphology and density through the understanding of geometry, more work has been done to understand this phenomenon in the American, European, and Asian contexts. Dutch researchers Meta Berghauser Pont and Per Haut from the Delft University of Technology have done work to establish the relationship between different morphologies and density metrics. They include FSI, Ground Space Index (GSI), Open Space Ratio (OSR), and Layers or building height (Pont and Haupt 2005). Their work gives an insight into the variable that creates various typo-morphologies within the same measured densities. In all these typo-morphologies, densities are experienced differently by their inhabitants. Since their framework works in two-dimensional space, it can include a maximum of three attributes of these typo-morphologies.

However, to understand the complex self-organizing processes of urbanization that we encounter in the cities, we need new computational tools that help us analyze multi-dimensional attributes. Researchers have done more work using artificial intelligence through Self-Organizing Maps (SOM) platform to understand multi-dimensional complexities in urban morphologies. There has been work done where 9 variables like Base Area, Floor Space Index, Ground Space Index, Open Space Index, Layers, Network Density, Mesh Width, Profile Width, and Tare have been used to comprehend morphologies in relationship to density (Abarca-Alvarez et al. 2019).

There are more attempts made to conceive the study of typo-morphology within the theory of complexity. From the early works of M. R. G. Conzen, the discussion on typo-morphology varied from being descriptive, mathematical, or based on urban social theory. However, researchers recognize that cities are social systems that require a complex system perspective to comprehend them (Goh et al. 2019). There have been attempts to study city form, street networks, and their growth through fractal theory, power laws, network theory, and cellular automata theory (Jia et al. 2019). Geoff Boeing has made attempts to connect the complexity theory paradigm to urban morphology. He also relates the theory to human behavior, which can comprehend certain complexity levels in these settings. Taking clues from traditional theoretical frameworks, Boeing establishes criteria based on the temporal, visual, spatial, and structural that he incorporates within the complexity framework. He then demonstrates the possibility of measuring them mathematically, which can go a long way to contribute to resilience, accessibility, and liveability (Boeing 2018, p. 15). Such

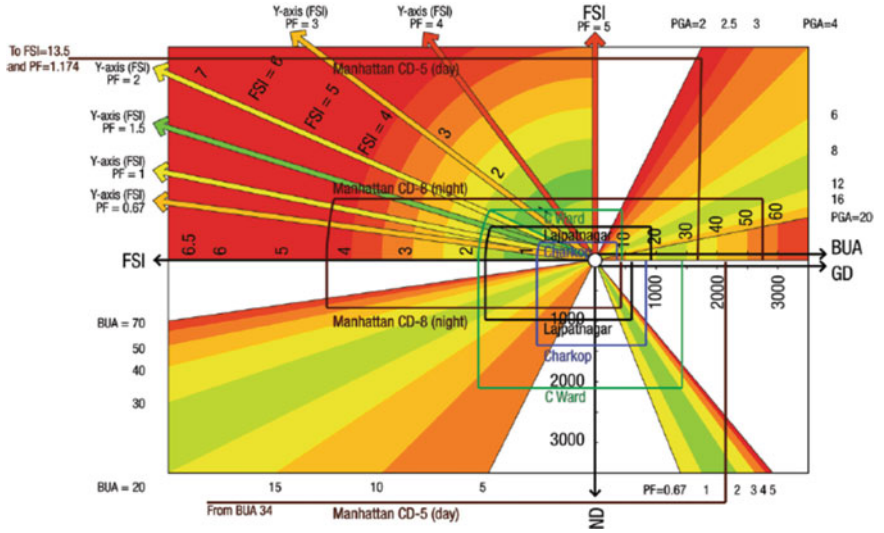


Fig. 3 Study of various morphological metrics to map liveability for different precincts in Mumbai and Delhi (Patel 2011)

studies can link urban form variables to performance in both spontaneous and planned settlements. Researchers can use this approach to understand the complex nature of form in cities with a diversity of city development processes like Mumbai.

Another study is conducted by Shirish Patel for cities in Delhi and Mumbai and comparing it to Manhattan works with morphological metrics like FSI, Built-up Space per person, Public Ground Area per person, Plot Factor, Net Density, and Gross Density. He then creates a diagram and assigns bands of colors to desirable values, as shown in Fig. 3. The neighborhoods he analyzes are more than 200 hectares in size, ranging from informal settlements in Dharavi, site and service housing projects initiated by the government in Mumbai, planned layouts from Delhi, and blocks in Manhattan. He then uses them to comprehend desirable and optimal crowding conditions in these neighborhoods (Patel 2011).

However, the model evolved by Shirish Patel to comprehend densities primarily considers outdoor crowding as the main criteria for desirable living. It requires questioning as outdoor crowding, which is a matter of perception and differs in various cultures, might not be undesirable in many conditions. We cannot establish any numerical threshold can for such a phenomenon.

2.2 Research Methodology

The research proposes to comprehend the historical context of density in Mumbai to understand it as a process. It will also locate it within the contemporary processes

of urban transformation that the city is witnessing. Further, it will choose a few formal and informal precincts that are undergoing such transformation to document neighborhoods with varied inhabitants and differing typo-morphologies. The initial part of the analysis will concentrate on comprehending the complexities presented by neighborhood morphologies based on various formal metrics. This research proposes to use formal metrics based on the built-form, street network, and fractal nature of morphology of each of these high-density neighborhoods. It helps in giving a computational perspective that can provide insight to city authorities and designers. The literature review and the findings of the next part will help create a framework of the performance aspect that we can use to decide whether density is enabling or disabling in these varied morphologies. Further research can help determine the relationship between morphologies, performance aspects, and inhabitants' experience.

3 Observing Densities in Mumbai

3.1 The Evolution of Density

In this research, we take the case of Mumbai city to study the density of neighborhoods inhabited by various communities with differing typo-morphological conditions. For this, we will investigate the history of Mumbai city to understand the process of urbanization and aspects of densities associated with various periods. The study observes density through the following phases of urbanization, where there were transformations.

3.1.1 Bombay as a Trading Port

As Mariam Dossal states, under colonial rule, Bombay witnessed important urban design and planning interventions from 1845 to 1847. It was a time when the city saw the evolution of civic consciousness. We have to know the incident in the background of two events, one the end of the monopoly of the East India Company in 1813, after which many business houses started their enterprises in Mumbai. The other was the defeat of the Marathas by the British in 1818 (Dossal 1991, p. 15). It would be a significant period where the Fort and the Native Town of Bombay were the two primary centers inhabited by the British and the Indian population. However, within the walled town of Fort toward the northern part, the authorities allowed the Parsi and Bhori population to settle. As per the first minute and accurate survey census of Mumbai in 1849, there were six urban subdivisions in the Native Town which exhibited the highest densities. The population recorded in this area of 6659 acres was 337,169. It was nearly 9.5 sq. yards per person, which was 1/13 times that of cities in England (Conybeare 1855, p. 21). As per the report prepared by Conybeare, Khara

Taloa had 20.5 sq yard per person, Market—16 sq. yard per person, Bhooleshwar—10.5 sq. yard per person, Mandavee—8.5 sq. yard per person, Oomerkharee—8.5 sq. yard per person, and Dhobee Tulao—8 sq. yard person (Conybeare 1855, p. 20).

The 1863 census recorded the population of Bombay to be around 816,352. In the Market, Dongri, Dhobi Talao, and Girgaum section, the census observed family size in 2–3 storey houses to be about 3.71.to 9.42. Each house had approximately 39 to 83 people (The Gazetteer, Vol. 1, 1909, p. 164). It was this very high household density that led to overcrowding. Along with the density and presence of open drains, the conditions in the Native town were recognized as unclean by the British sanitary engineers (Conybeare 1855, p. 13).

As per the 1864 census, the authorities divided the city into wards. Wards B and C that were the core of the native town and contained the bazaars had the highest densities. It shows some sections like Market, Chukla, Dongree, and Dhobeetulao have very high densities. Interestingly, the census documents all types of work activities that were present in the city. Most of the work present was in these dense B and C wards.

From accounts, it is evident that informality was historically a part of Indian cities. A lot of the urban fabric of such towns was spontaneous, and the densities associated with these fabrics were due to people's instinct to agglomerate. As seen through the census, these densities helped people create networks that assured entrepreneurship and occupation. People established these networks through religion, caste, ethnicity, livelihood, place of migration, etc. These affinities allowed the people to agglomerate with ease. As Pattrick Geddes noted, congestion was an issue more for the British planners and engineers than the Indian inhabitants of historical cities (GoodFriend 1979, p. 349).

3.1.2 Growth of an Industrial City During the Colonial Rule

With the advent of the mills, there was a shift in the city's growth. While the old city continued to be one of the densest, the census observed some demographic changes due to the plague that started in 1896 (Census of Bombay, Government, 1901, p. 10). The areas that started showing growth were Mahalakshmi, Byculla, Tarwadi, Parel, Sewri, Sion, Mahim, and Varli. We can attribute this shift to Parel's transformation into the mill district, the heartland for industries in the city from 1881 onwards (The Gazetteer, Vol. 1, 1909, p. 201). A new pattern of density started emerging with the housing required for industrial workers. The chawls, a building typology unique to the city, provided early housing to the mill workers. Each room in a chawl would measure around $12' \times 8' \times 8'$ with a $3'$ long public corridor in the front. There would have a partition in the room, and the inner portion would be for women with a sink for cooking. These rooms would house two families with around 10 to 15 people, excluding children, thus experiencing crowding. As per the 1901 census, industrial workers in mills and factories formed nearly 41% of the population. People involved in commerce or other professions were around 14%. Thus, while many workers lived in these chawls, the mill areas of Byculla, Parel, Tarwadi, Sewri, and Warli did not

have densities comparable to the B and C wards. It would be less than 100 people per acre (Census of Bombay, Government, 1901, p. 12).

3.1.3 The Post-independent Industrial City

From 1930 onwards, Bombay implemented town-planning schemes in Bandra, Juhu, Vile Parle, Borivali, and Chembur (Maharashtra State Gazetteer 1986). After 1950, with the incorporation of suburbs into the municipality, planning schemes were implemented by the Municipal Corporation of Greater Bombay.

Due to migration resulting out of the partition, the housing problem increased in the city with independence. The government formed the Bombay Housing Board to address this problem. Also, the government introduced the Bombay Rent Control Act, 1947, to freeze the rents to safeguard the interest of the poor tenants. It affected the dense historic inner city most and led to owners not maintaining their buildings. It led to the dilapidation of such structures, some of which would collapse during monsoons. Nineteen thousand such buildings were affected by this regulation. To address this issue, the government formed the Bombay Repair and Reconstruction Board in 1969. Under this scheme, the board would repair the buildings and charge a cess from the tenants. However, the quality of repairs was always under question, and the problem remained. In 1984, the authorities had introduced a policy of redevelopment of these buildings with an increased Floor Space Index (FSI) of 2. However, there were not many projects initiated as most of the existing buildings in the inner city had more FSI.

The Municipal Corporation prepared the first Development Plan for the city in 1966. The first time the plan included the concept of FSI in the development plan to control the city's built density. The FSI ranged from 1.33 to 2.45 to as high as 3.5–4.5 for the Backbay Reclamation Area and Cuff Parade Reclamation. The other aspect that Merhotra and Dwivedi note, a characteristic of the city during this period, is formality and informality closely interlocking. It was not so during the colonial period when there was a clear division between the Fort and the Native Town (Merhotra and Dwivedi 1995, p. 320).

To address slums, the government formed the Bombay Slum Improvement Board under the Bombay Housing Board. It provided water taps, drainage, pathway, street lights, and public toilet within these settlements. In the 1980s, it even tried to implement site and service schemes with assistance from the World Bank to address the housing for the urban poor. Though some of these schemes were successful, they could not handle the massive challenges of providing houses to half of the city population living in slums.

3.1.4 Mumbai and Liberalization

The year 1991 was very critical to the country as it embarked on liberalization of the economy. It was the same year that the second Development Plan of Mumbai

was adopted. This development plan was vital as it introduced Transferable Development Right (TDR). Also, Regulation 33 of the DCR authorities allowed incentive FSI to enable builders and developers to redevelop slums and dilapidated tenanted properties.

Meanwhile, the Government of Maharashtra had formulated the urban renewal scheme under Regulation 33(9) in 1991 (GOM 1991). Later, it allowed for redeveloping larger areas in the historic city above an acre, stating that such projects would provide better amenities and infrastructure. It was called the cluster redevelopment scheme. Such redevelopment schemes were also allowed for old housing schemes planned and constructed by the Bombay Housing Board, now known as Maharashtra Housing and Area Development Authority (MHADA), at a higher FSI. The government has recently, in 2019, allowed all cooperative housing societies that are more than 30 years old to be redeveloped.

Simultaneously, in 1991, the government had also allowed the redevelopment of slums under Regulation 33(10) (GOM 1991). In 1995, the government announced free housing for slum dwellers, with increased FSI for builders. It also formed a new authority called the Slum Rehabilitation Authority (SRA) to facilitate the redevelopment of slums. As in the case of dilapidated buildings, the government had allowed the relaxation of development control regulation. Subsequently, the authorities have further increased the FSI of such projects to make them more attractive for builders. In addition, the government conceived larger slum projects like the Dharavi Redevelopment Project that a Special Planning Authority (SPA) would execute.

Thus, with liberalization, these redevelopment projects initiated the intensification of the city's urban growth. Presently, most of the city is allowed higher FSI under the pretext of a redevelopment regulation. Most of this intensification was without commensurate public amenities like open spaces, public schools, and hospitals. There have been questions raised on this process of intensification. Shirish Patel argues that though the FSI of Mumbai might be lesser than Manhattan, the average family size is much larger. He notes that while the per capita indoor space of Mumbai is around five m^2., it is fifty-five m^2. for Manhattan. It leads to nearly the same amount of crowding on the streets (Patel 2014). A study supported by the Mumbai Metropolitan Region Environment Improvement Society (MMR-EIS) and conducted by the Indian Institute for Technology, Bombay (IITB) and Doctor for You (DFY), conclude that there is a strong correlation between the buildings of redeveloped slums and tuberculosis (Doctor for You 2018).

Others argue that the present FSI regime leads to sub-optimal land use, and FSI needs to be further increased (Nallathiga 2007). Alan Bertaurd shares a similar sentiment that FSI in Mumbai is the lowest among cities globally, leading to a low per capita space utilization (Bertaud 2004). Another study of ten neighborhoods of Mumbai shows that authorities can achieve compact neighborhoods in Mumbai if there are ample amenities (Dave 2010, p. 25). While the debate around intensification and density continues, it is evident that the government is no more interested in playing an active role in developing mass housing that forms the bulk of the city's development in the last three decades. They are only interested in facilitating the private sector toward the provision of housing requirements of the city.

Thus, while the government regulations have entirely enabled private builders and developers in the city's development process, density as a tool is now used by them only to achieve real estate objectives. Whether this has reduced informality that is an integral part of our cities, formed due to lack of formal policies to address the legitimate needs of working and living in our society?

A study on India's economy for three cities, New Delhi, Mumbai, and Bangalore, has an entirely different finding. The author notes that for the Mumbai region, informal employment has been on the rise from 1991 onwards to the mid-2000s. It also questions the assumption that the city's manufacturing has shifted with the closure of textile mills in the 1980s. Instead, the author's findings show that manufacturing still happens in the city in informal enterprises employing informal labor (Barnes 2017). It is also able to establish that most of this manufacturing is home-based, own account establishments.

Thus, Mumbai has witnessed a rise in informality in these three decades of globalization, where the notion of density is very different. It is a density that allows for enterprises not provided for by the formal sector to flourish. Thus, any study on density should explore the varied urban processes that have led to Mumbai being a dense and compact city.

In this background, this research looks at three locations in Mumbai—one is the old historic city where 19,000 tenanted properties face dilapidation, some of which builders have redeveloped under 33(7). These are in the C ward of the city. The other is the informal settlement of Dharavi near the central business district of Bandra Kurla Complex. In 2004, the government proposed redeveloping this slum, spread over 525 acres, and formed a Special Planning Authority for its development (SPARC and KRVIA 2010). The third is the rapidly growing P ward characterized by greenfield projects, comprising back processing offices, residential complexes, malls, and multiplexes. In the 1980s, this ward had gaothans, old government housing colonies, cooperative housing societies, site and service schemes, and slums. Most of this old fabric that is more than 30 years is undergoing rapid redevelopment. Figure 4 demarcates the three precincts.

4 Analyzing Density

4.1 Introducing the Site Observation

4.1.1 Density in the Historic City

C ward has many communities and neighborhoods formed based on commercial activity, religion, ethnicity, and evolution in distinct periods. These neighborhoods often display different typo-morphological characteristics. This research will investigate some of these neighborhoods for further analysis.

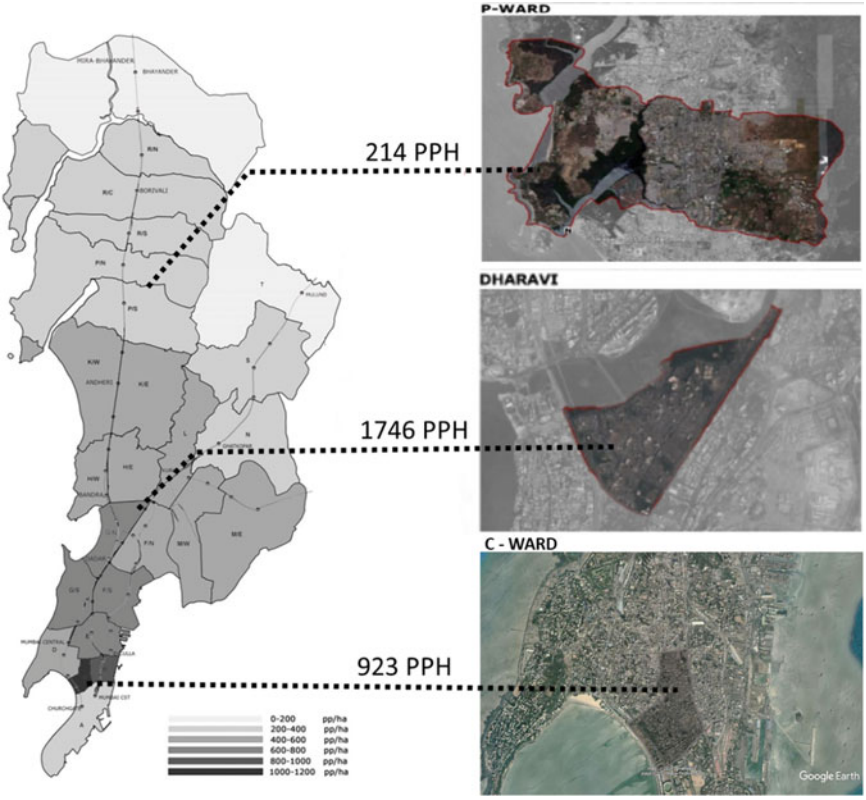


Fig. 4 The three precincts with varying densities and processes of urbanization

As mentioned earlier, the C ward was a part of the native town. It developed as the indigenous trading hub closely connected to the port on the eastern side. In the evolution of this ward in 1784, it had markets, agricultural fields, and low-lying areas that authorities had reclaimed to expand the town (Dossal 1991, p. 23).

Through the decades, C Ward has shown a decrease in population. One of the reasons can be attributed to outmigration to newly developing northern suburbs in the city. Also, over time, the district with a mixed-use character changes its nature to a commercial neighborhood with residences converted to workshops and storage. Also, some of the spaces landlords give rent to migrants employed in workshops involved with gold jewellery, metal fabrication, pottery, bazaar, sabzi mandis, textile markets, etc. The district had a substantial residential population in history; presently, a floating and transient population inhabits this place like any other bazaar area in India. Table 2 shows the change in the resident population from 1961 onwards till 2011 (Census of India 2011). It shows how the residential density has halved in the last fifty years. However, it remains one of the densest wards of the city.

Table 2 Decadal change of population and density in the C ward (Census of India 2014)

Ward Area—1.8 km^2	Population	Density (people/ha)
1961	339,452	1886
1971	312,472	1736
1981	270,705	1504
1991	199,260	1107
2001	202,922	1127
2011	166,161	923

4.1.2 Densities of the Informal

The next district for observation is Dharavi, one of the largest slums in Mumbai. *The* settlement started in 1887 with the leather industries, which attracted many migrants. The leather industries flourished close to the abattoir of Bandra. The Gazetteer of 1909 mentions Dharavi as one of the eight villages of Bombay in the year 1727 (The Gazetteer 1909, Vol. 1, p. 30). However, by 1897, the Gazetteer notes that missionaries built a church for Tamil migrants employed in the tanneries (The Gazetteer 1909, Vol. 1, p. 219). The next was a group of potters from Saurashtra whom the authorities relocated to Dharavi at the end 1800s (Slum Rehabilitation Authority, GOM 2021).

Because of the 1896 plague in Bombay, the authorities shifted the polluting activities to the periphery. Even the independent government that evicted slums from the city through the 1960s resettled them in Dharavi. Thus, the morphology of Dharavi exhibits characteristics of being self-organized to being planned wherever authorities relocated people. Inhabitants in self-organized settlements have built their settlements around industrial compounds or clusters that provide employment. Also, slumlords were influential in settling people here, especially in private properties. The slum extended through the 1970s when the government implemented the Maharashtra Slum Areas Improvement, Clearance, and Redevelopment Act of 1971. In 1972, authorities attempted to improve Dharavi by providing civic amenities like water, drainage, and toilets. However, the scheme did not achieve the intended results as the authorities had done no comprehensive survey (Chatterji 2005). The census of 1976 was only limited to slums on state government land. In the early 1980s, the government implemented the Slum Upgradation program as supported by World Bank. The precondition was that communities organize themselves as cooperative societies to upgrade the infrastructure of a complete area. While provisions were made for the incremental up-gradation of houses by increasing heights, area-level water, sanitation, and electricity infrastructure were implemented in the societies. However, only some societies implemented these schemes, and thus, the government stopped the program in the early 1990s. Till this scheme, density was an outcome of poor inhabitants of Dharavi clustering themselves to find work opportunities within nearby industrial compounds.

Through time, these tightly knit communities had to negotiate with city authorities, trying to evict or relocate them, constantly establishing their claim over space.

Through this process, they would form a strong sense of collective that one immediately sees through the formation of Nagars or neighborhoods. A recent study done by the Society for the Promotion of Area Resource Centers (SPARC) of Dharavi shows the existence of around 123 such Nagar.

With the Slum Redevelopment Scheme introduced in 1991, the government allowed a larger FSI for Dharavi, recognizing it was a difficult area. Also, the private builder in such cases was allowed TDR for the sale component. Such redevelopment projects were higher in population density and built density, often leading to poor light and ventilation. In 2004, the government proposed the Dharavi Redevelopment Project and formed a Special Planning Authority (SPA) for its implementation. The attempt was a complete area redevelopment of Dharavi that the SPA had divided into five sectors. They invited private developers to redevelop each sector. They would rehabilitate the existing slum population and then develop the sale component within that sector. The approach would attract more population density within the current settlement and generate a high built density. Questions about the quality of life, especially within the rehabilitated buildings, became a dominant concern within this approach. Moreover, many experts and activists felt that the small enterprises that the earlier incremental densification allowed would be lost. Many activists thought that the scheme did not take care of the interests of the rehabilitated population.

4.1.3 New Landscapes of Intensification

The P ward is one of Mumbai's most crowded wards in the Western Suburbs of Mumbai, with a high intensity of growth. Table 3 shows the decadal evolution of the population for this ward (Census of India 2014). The overall density of this ward is not so high as it contains a lot of forests, mangroves, intertidal areas, coasts, and no development zones. However, many greenfield projects and redevelopment projects in this ward have a very high built density. Because of its high population, the ward has been divided into two wards P/N and P/S. During the colonial period, this place had goathans, koliwadas, and a few bungalows. Also, due to the easy availability of land, earlier film studios were located here. In 1949, the Aarey Colony in Goregoan East was conceived and handed over to the Department of Dairy Development Board for cattle rearing and milk production. In the 1960s and 1970s, MHADA started to build low-income housing like Motilal Nagar, Siddhartha Nagar, Unnat Nagar,

Table 3 The decadal growth of population in the P Ward (Census of India 2011)

	1961	1971	1981	1991	2001	2011	Density_p/ha
P (64.3 km^2)	1,67,625	3,72,335	6,63,716	9,54,825	12,36,624	14,04,873	219.51
P/S	–	–	2,96,075	3,50,948	4,37,849	4,63,507	
P/N	–	–	3,67,641	6,03,877	7,98,775	9,41,366	

etc., in Goregoan. These Nagars were low-rise plotted development that had 200 sq. ft. houses. The MHADA also built low-rise walk-up apartment housing in these colonies.

In the 1970s and 1980s, developers built private cooperative housing societies constructed as walk-up apartments. They planned and executed Bangur Nagar, Sunder Nagar, and Evershine Nagar during this time. Most of these developments had an FSI of one. In the late 1980s, the government planned the site and service scheme in Malwani with assistance from the World Bank in this ward. As development grew in this ward, many low-lying lands or parts of the forest were encroached by slum settlements.

In the late 1990s, with the construction of the Link Road and shifting of the city dumping ground from Malad, intensification started in this ward. The city dumping ground gave way to a Back Processing Offices (BPOs), malls, theaters, gardens, and high-rise complexes. Transfer of Development Right (TDR) generated from other locations was loaded on greenfield projects in this ward. The Link road, the widening and construction of flyovers on the Western Express Highway, and improved east–west connectivity led to rapid residential development of land earlier used for agriculture or as cowsheds. Most of these projects had an FSI of 2.66.

The process of infrastructural growth spurred many projects in the ward. It led to redevelopment projects of slums settlements, MHADA colonies, and cooperative housing societies. The new metro line along the Link Road and the Western Express Highway will transform this ward further.

The present research would explore the notion of density in greenfield projects or redevelopment projects developed in the last decade for neighborhoods in this precinct. Here, the impact of high density that results due to maximizing of real estate potentials would be studied.

4.2 Compiling the Data

This section will analyze the various density metrics of the neighborhood identified in the three precincts. Here, it would quantitatively analyze various formal aspects of a high-density environment. The attempt would be to group neighborhoods as per the formal attributes of their morphologies in a precinct. The formal characteristics at this scale will analyze the figure-ground of the urban fabric. The research will study the following aspect of morphology in detail (Table 4).

4.2.1 Analyzing the Data

The research used the QGIS platform to perform the preliminary analysis to establish some of the critical metrics of the built-form for each neighborhood. The platform was used to generate metrics on crucial aspects of the urban form of each neighborhoods from all the three precincts like the following:

Table 4 Various aspects of formal analysis of neighborhoods

	Metrics	Intents
Built and unbuilt analysis	Floor Space Index, Ground Coverage, Open Space Ratio, and Layer	Qualitative aspects of the form of the neighborhood like scale, nature of open space, and urban form (high-rise, low-rise developments)
Street network analysis	Road length per unit area, No. of Nodes per unit area, and Average Street Length	Street versus building relationship, permeability, interactivity in various streets, and presence of active nodes
Fractal analysis	Fractal dimension	Process of growth and diversity

- Global FSI—As stated earlier, it is the total built area in a neighborhood divided by the total area inclusive of roads and open spaces.
- Ground Coverage % (Ground_Cov)—It is the percentage of footprint area of the total area for a given neighborhood.
- Intersection per hectare (INT_HA)—It is the number of intersections in a given hectare for a neighborhood.
- Road Density per hectare (RDL_HA)—It is the road length in a given hectare for a neighborhood.
- Average Road Length (AVG_RDL)—It is the average segment of road length in an area.
- Fractal Dimension (FRAC_D)—It determines the fractal nature of the urban form.

These metrics are calculated for the neighborhood in all three precincts. Figures 5, 6, and 7 show all the Nagars and neighborhoods of Dharavi, C Ward, and P Ward considered for analysis in its five sectors.

Table 5 shows the statistical measures of the formal attributes of the neighborhoods for the three precincts. It shows the average mean, standard deviation, and coefficient of variance for all the attributes. There are some patterns that become evident in these measures. We can notice that the neighborhood sizes have a high coefficient of variance in the case of Dharavi. This is because in Dharavi, small compounds to big Nagar's exhibit neighborhood characteristics. It was evident during the process of documentation. In Dharavi and the C Ward, the Global FSI shows minor variance as compared to P Ward. In P Ward, the global FSIs are increasing drastically in the case of redevelopment projects and greenfield projects.

Interestingly, Dharavi has a low global FSI compared to all the other precincts. However, the population density is the highest, while neighborhoods in the P ward have a low population but have high global FSI. It is due to the large number of high-rise gated communities that have been built in this ward in the last decade. The ground coverage and intersection density of Dharavi far exceed any of the precincts. It is an important aspect of the precinct. It would be interesting to observe whether it correlates with Dharavi's large amount of entrepreneurship activity. Dharavi also has a high variance as compounds with larger industrial sheds have lesser intersections

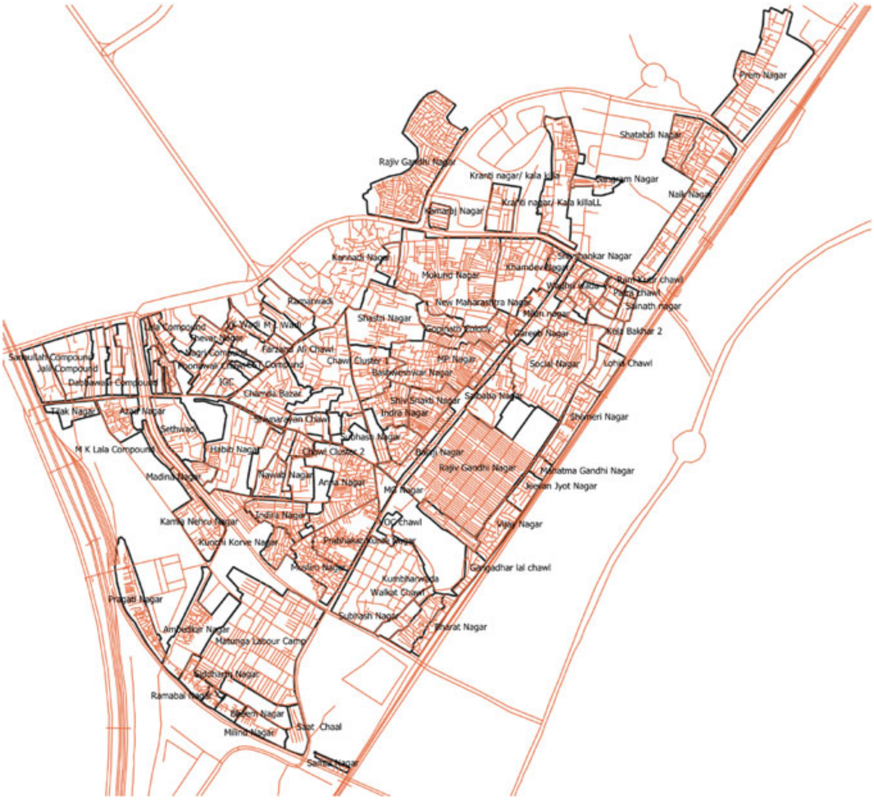


Fig. 5 Map showing the Nagar Locations, Street Networks, Sectors, and Graduated Densities as per Global FSI of Dharavi

than mixed residential neighborhoods. The road length per hectare is much higher in Dharavi as compared to other precincts. However, the average road length is smaller.

These are clear indicators of the spontaneous and self-organizing nature of the fabric. C ward also has high ground coverage, moderate road length per hectare, and average road length, though much less than Dharavi. In contrast, P ward has low road density, with the average road length being larger. It indicates that the state or builders have attempted to introduce some form of planning in these neighborhoods. The granularity of the C ward and Dharavi indicated by the fractal dimension is much higher than the dimensions observed in the P ward.

These formal measures, as summarized in Fig. 8, that the research establishes in this section indicates are very important as they clearly show the diversity of urban forms that are there in such cities that have evolved post-liberalization. Though there is a similarity in some of the metrics, the form that the figure-ground represents can be completely different. This research attempts to understand these differences within the wide range of metrics proposed for these cities. As stated earlier, the relationship

Fig. 6 Diagram showing the neighborhood of C Ward along with its street network

of these metrics to various performance aspects of density in the further research stage will give valuable insights.

However, before this, we would have to analyze the neighborhood data to understand whether we can identify clusters with similar properties. It can help us categorize the urban form as per the generated metrics. We could also compare the finding with the visual observation made on-site and through typologies that have evolved through history. The next section of this chapter would analyze this aspect further.

4.3 Visualizing Typologies Within the Precincts

This section extensively uses the Self-Organizing Maps platform to identify the clusters based on the six metrics we have generated for the neighborhoods. The clustering was done based on the hits shown in violet that were generated by the SOM platform. The first precinct or analysis is Dharavi. Figure 9 shows the outcome of analyzing the data giving equal weightage to all the attributes in the SOM platform. The next precinct for analysis is the C ward. This ward has fewer neighborhoods as

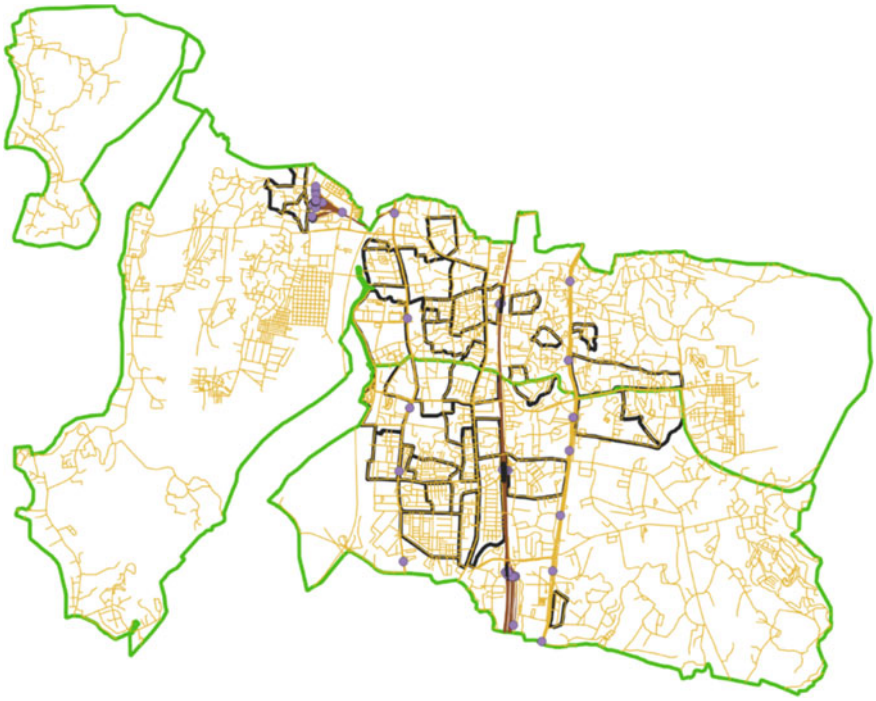


Fig. 7 Neighborhood in P Ward that are undergoing rapid transformation

compared to the other precincts. Figure 11 shows the results of the analysis. After observing the clustering, we can make the following observations. The final precinct for analysis is the P Ward. The study identified 38 neighborhoods in this precinct. In this case, as with the earlier precincts, the SOM platform analyzes the data. The results of this analysis are shown in Fig. 13. The study of the figure-grounds of neighborhoods in this precinct can reveal some critical patterns. We can summarize the findings as follows:

- In the case of Dharavi, neighborhoods with industrial, manufacturing, and large storage units with large building footprints form Cluster 4. Thus, important Nagar like the 13th Compound, Kumbharwada, and Prem Nagar are under this cluster. Cluster 2 is formed out of morphologies with highly granular residential fabrics. In this case, they might be gridded or organics or have manufacturing units within them. For Clusters 1 and 3, there is a difference in granularity but they are undergoing a transformation with new slum rehabilitation buildings. Some of the representative neighborhoods and their morphologies are shown in Fig. 10 (Fig. 11).
- For C Ward, Cluster 2 comprises the oldest bazaars like the Chira Bazaar and Bhuleshwar. The next layer of the dense bazaar is represented by Cluster 1, comprising of Kalbadevi, Cavel, Panjrapole, and Zaveri Bazaar. The bazaars that

Table 5 Table showing the statistical measures as well as normalization of averages for all the precincts

C ward statistics							
	Area_sqm	Global_FSI	Ground_Cov	Int_ha	RDL_ha	Average_RL	Frac_D
Average mean	98,798.86	1.68	46.71	6.06	274.99	88.50	1.71
Standard Deviation	47,849.80	0.53	7.88	1.89	45.18	22.60	0.09
Coeff of variance	0.48	0.32	0.17	0.31	0.16	0.26	0.05
Dharavi statistics							
	Area_sqm	Global_FSI	Ground_Cov	Int_ha	RDL_ha	Average_RL	Frac_D
Average mean	13,391.51	1.60	64.00	29.68	874.21	38.14	1.66
Standard deviations	16,281.33	0.33	13.18	19.28	319.17	31.73	0.19
Coeff of variance	1.22	0.21	0.21	0.65	0.37	0.83	0.12
P ward statistics							
	Area_sqm	Global_FSI	Ground_Cov	Int_Ha	RDL_Ha	Average_RL	Frac_D
Average mean	248,181.03	1.84	26.66	2.59	165.27	151.54	1.54
Standard deviation	206,165.50	1.01	8.65	1.26	43.91	41.65	0.11
Coeff of variance	0.83	0.55	0.32	0.48	0.27	0.27	0.07
	AREA	G_FSI	G_C	INT_A	RDL_A	AVG_RL	FRAC_D
C Ward	0.40	0.91	0.73	0.20	0.31	0.58	1.00
Dharavi	0.05	0.87	1.00	1.00	1.00	0.25	0.97
P Ward	1.00	1.00	0.42	0.09	0.19	1.00	0.90

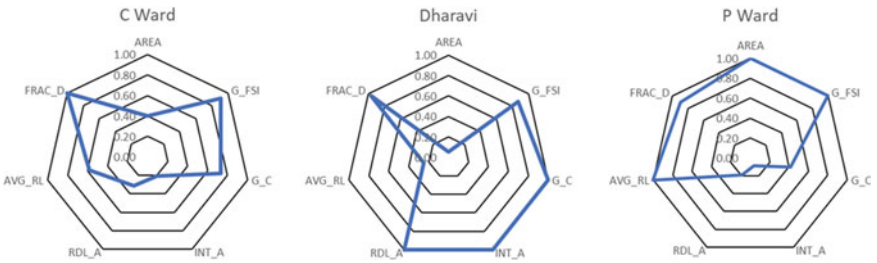
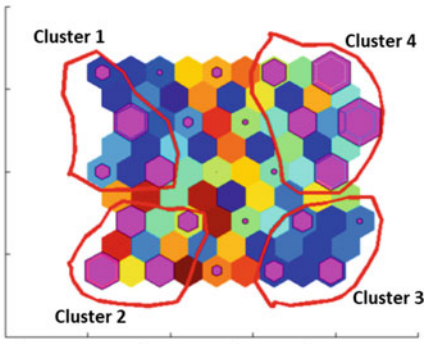


Fig. 8 Comparative Radar diagram showing normalized average value for various aspects in the three precincts

The SOM U Matrix for the data set showing the various hits and clusters



Clustering area of maximum hit together

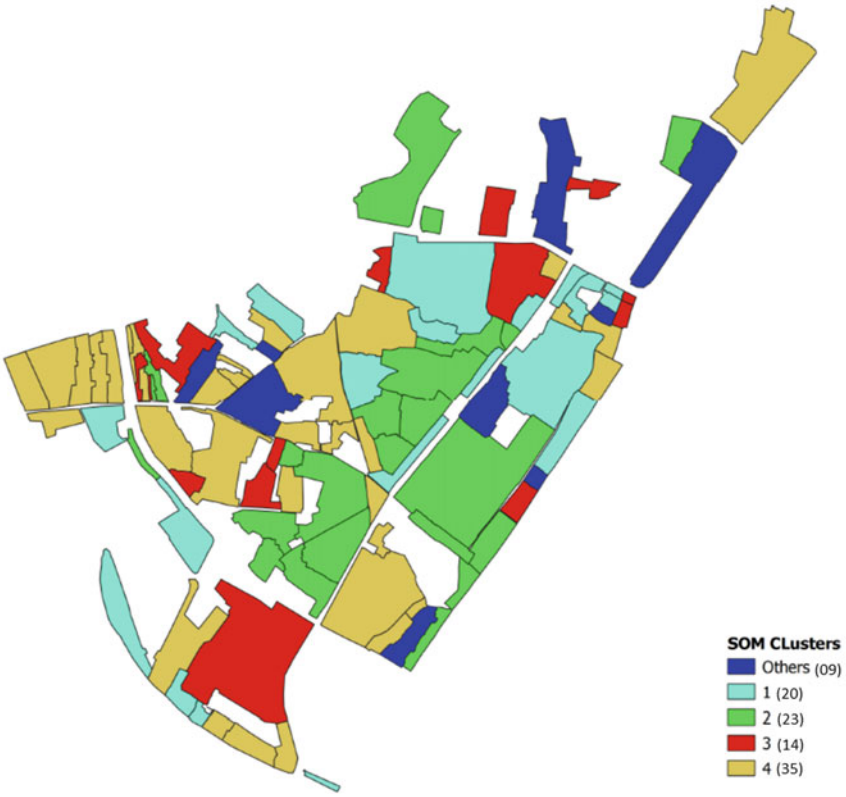


Fig. 9 The SOM analysis, the identified cluster, and the corresponding Nagar in each cluster

Kumbharwada

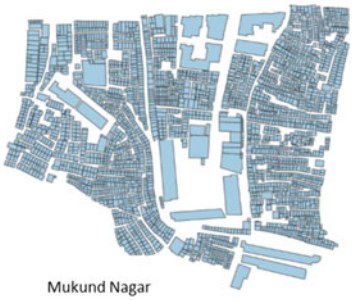
13th Compound comprising of Navarang Compound, Sanaullah Compound, Shakkir compound

Typo – morphologies in Cluster 4 that are industrial and have livelihood activities

Anna Nagar

MP Nagar

Typo – morphologies in Cluster 2 that are primarily residential in nature

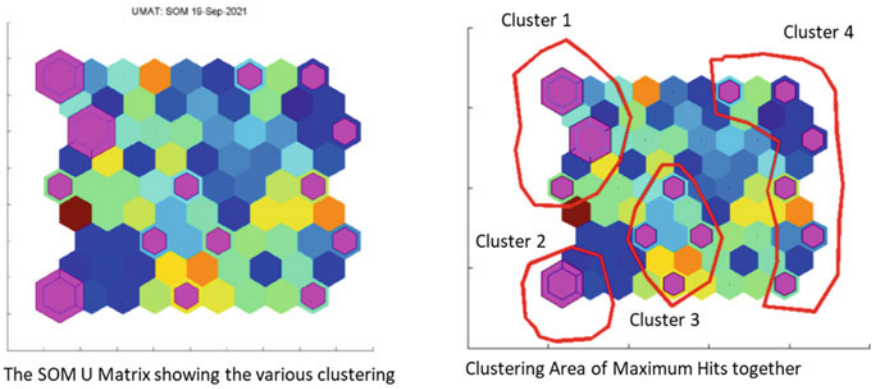


Mukund Nagar

Kamla Nehru Nagar

Typo – morphologies in Cluster 1 that have new redevelopment projects

Fig. 10 Some examples of typologies identified through the clustering process on the SOM platform for Dharavi



The SOM U Matrix showing the various clustering of hits

Clustering Area of Maximum Hits together

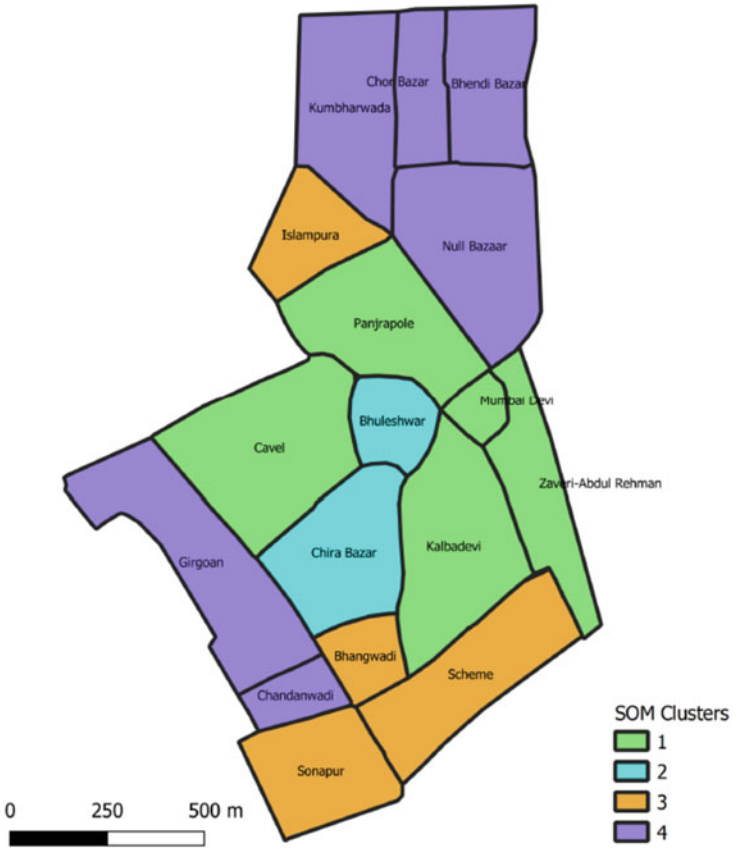


Fig. 11 It shows the result of clustering of the data in the SOM platform and the identified typologies in the precinct

have been redeveloped under the town-planning scheme by the Bombay Improvement Trust form Cluster 4 like Chor Bazaar, Bhendi Bazaar, and Null Bazaar. Girgoan, though shown in the same cluster, should be separate as it lies on the edge of the cluster boundary. Some representative clusters are shown in Fig. 12 (Fig. 13).

- For P Ward, the newly formed neighborhood in greenfield sites comprises high-rise towers, with large open spaces forming Cluster1, like Yashodham and Gokul Dham. Cluster 2 contains neighborhoods that are low-rise plotted developments or walk-ups that MHADA had built. Cluster 3 contains slum redevelopment projects like Omkar Almote and Gautam Nagar, high-rise, with high ground coverage and high population density. Figure 14 shows some of the representative clusters.

5 Creating the Framework for Evaluation

This section of the study will suggest a framework researchers could use to study density for cities like Mumbai witnessing the process of intensification post-liberalization. The attempt is to create this framework based on findings reviewed through literature and the varied typo-morphologies identified in the earlier part of the chapter.

In all the above morphologies observed, density has differing objectives. The study recognizes this aspect of density, as a process, stated in the literature review (Tanga et al. 2018). The paper argues that this is a characteristic of urbanization processes in such cities where various urban fabrics have formed out of differing impulses. Some of it might be historical and presently functional, some are spontaneous and self-organized by people, some planned, and some speculative. In many cases, researchers might find overlaps between these various processes. Figure 15 identifies the multiple processes of urbanization for which researchers can explore densities with differing implications for cities like Mumbai.

5.1 Performance Indicators

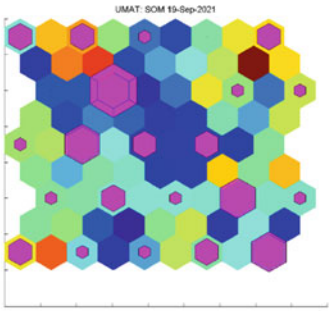
The next aspect of density would be to evolve a set of multi-criteria indicators relevant for cities like Mumbai. In such a case, density should not be solely equated to crowding and other environmental factors but is tested against other aspects where it might be enabling for its residents. In literature, as we have seen, there are already many parameters established for cities in the developed world. These need to be examined for their relevance to form the framework for Mumbai that may be representative of cities in India, as well as in the global south. The indicators found in the literature relate to mobility, ecological/environmental, public spaces, economic, and governance performance that we can attribute to density. The final objective of

Typo – morphologies of traditional bazaar like Chira Bazaar

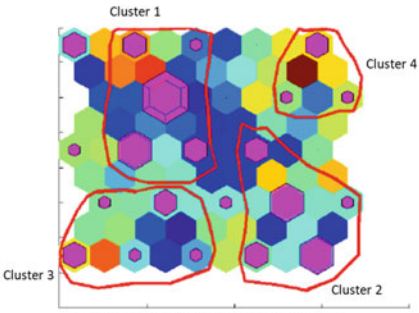
Typo – morphologies of historic residential neighborhood, Girgoan that had wadis, a traditional housing type

Typo – morphologies in of bazaar with small scale manufacturing units like in Null Bazaar

Fig. 12 Examples of typologies identified through the SOM platform for C Ward, Source for Chira Baazar Image, MCGM



The SOM U Matrix showing the various clustering of hits



Clustering Area of Maximum Hits together

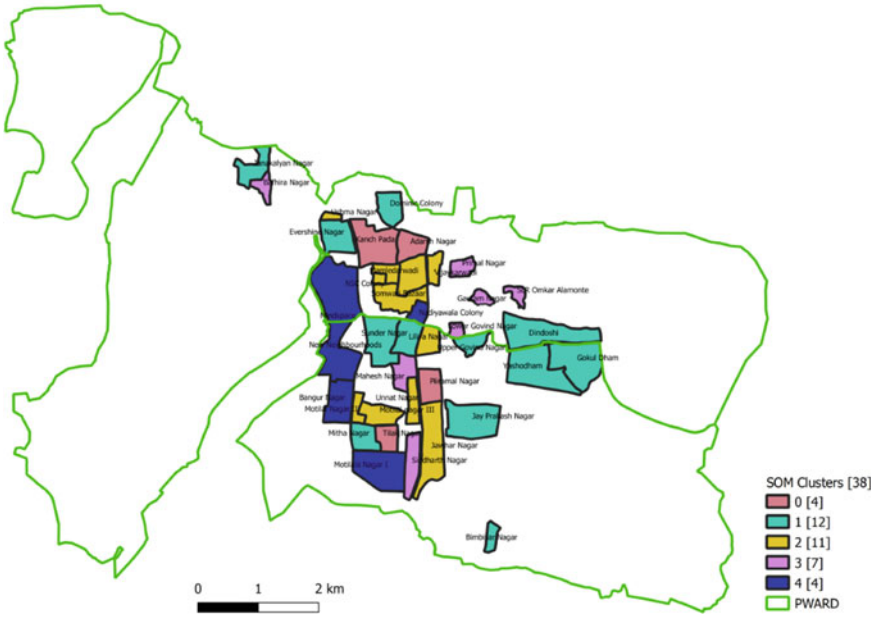


Fig. 13 The clustering of various typologies of a neighborhood in the P Ward as analyzed in the SOM platform

these criteria would be to judge sustainability, resilience, inclusiveness, and social liveability as prioritized by inhabitants.

5.1.1 Mobility Performance

Mumbai we have observed is a city that walk to work, as well as uses the public transport system. Thus, any evaluation criteria should be able to judge the quality and adequacy of walking infrastructure. Nearness to public transit points would be

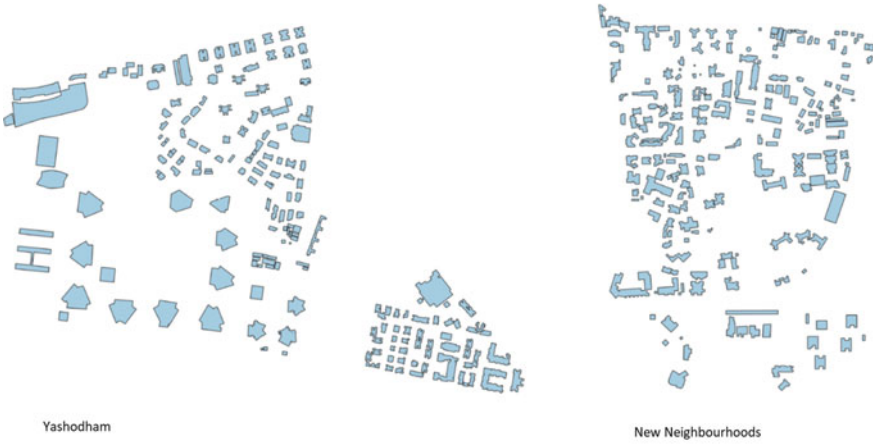


Fig. 14 Some examples of typologies identified through the SOM platform for the P Ward

	Planned City	**Informal City**	**Historical City**	**Speculative Cities**
	Governments authorities, and even companies	Inhabitants and Residents. It might have the involvement of non - state actors.	Authorities like kings/ rulers, etc., and their noblemen, inviting people involved in various crafts and livelihoods.	Private agencies like builders/developers
Motive	Supply housing to all classes of citizens.	Establishing basic shelter near jobs, starting small -scale entrepreneurial activities.	Encourage trade and commerce	Profit
Nature of urban fabric	Inclusive and Mixed, Often sparse to medium dense	A lot of small-scale livelihood activity though there might be deficiencies in infrastructure. High Density	High Density, Bazaar, and craft -based manufacturing activities	Demand driven housing that are often gated, with exclusive amenities. Often high density to maximize real estate potentials

Fig. 15 Studying density resultant of varied processes of urbanization

considered very important. Also, affordability of such systems especially where the urban poor inhabits would also form important criteria. Thus, these will form very important criteria for neighborhoods of Dharavi that have a high labor population. Vehicle ownership and the presence of parking would also have to be quantified in the chosen precinct under consideration. High vehicle ownership with no parking might lead to an experience of congestion. Also, existing policies regarding vehicle restraint if any have to be studied.

5.1.2 Ecological/Environmental Performance

As stated earlier, we might evaluate this aspect for neighborhood in Mumbai through the urban metabolism framework. We will quantify their use of resources as well as the ability to handle waste generated within their neighborhood. In many cases, especially with cities in the developing world, we might observe that they would use fewer resources per capita, but most residents live in environmentally hazardous conditions with a high pollution level (Satterthwaite 1997). Most of these residents who live in settlements with high density might exhibit less ecological footprint. However, the quality of life in such settlements is often highly compromised (Sanyal et al. 2009). The urban metabolism model, in such cases, can understand the production, source, and use of various resources and the generation of wastes and pollutants. However, some neighborhoods in Mumbai might have implemented water-harvesting, solid-waste, and waste water recycling infrastructure as mandated by MCGM for new projects. These might perform better environmentally.

5.1.3 Public Spaces and Amenities Performance

Cities like Mumbai have very low open spaces that are provided by MCGM. Thus, apart from public open made available by the government, freely accessible footpaths, skywalks, and private spaces if made available to people should be included in the evaluation. Kim Annette, who documents the sidewalks of Ho Chi Minh City, calls these spaces the "*most over-looked spaces*" as compared to city parks and gardens. She observes that these spaces that are more than the planned spaces are the "*democratizing spaces"* in such cities (Kim 2015). In the informal settlement, and as seen in the case of Dharavi where the road length per acre is more, roads that are predominantly pedestrian should also be considered in the public realm. Accessibility should be the primary criteria to judge these spaces.

A paper on India's newly empowered middle class examines how they claim their localities and re-imagine the public realm according to their values. While they have no problem with cars being a part of streets, they resist cows and cycle-rickshaw that have always been a part of Delhi's streets. The paper terms the phenomenon as "*bourgeois environmentalism*" (Bavaskar 2011). Thus, qualitative criteria to establish diversity and inclusiveness have to be a part of any performance indicator for such cities.

Also, spaces that underused spaces in and around infrastructure corridors, and private spaces that claim to be public should also be evaluated. There are attempts to evaluate such a public realm in high-density cities within the Urban Space Framework (Cho et al. 2015). The framework recognizes three aspects of urban space called Hardware, Software, and Orgware. The application of such a framework might be relevant for cities in the developing world as such a study incorporates government-recognized public spaces and emergent spaces like streets, sidewalks, and spaces resulting out of infrastructure, and even privatized spaces like malls.

5.1.4 Economic Performance

In her book *Economies of Cities*, Jane Jacobs documents how cities are economic innovation and diversity centers. She attributes this phenomenon to the aggregation that such cities provide. She notes that entrepreneurship is possible because of the division of labor available in big cities (Jacob 1970). For cities like Mumbai and especially for informal settlements and low-income neighborhoods, where there is a lot of entrepreneurship activity, this might be very important criteria. In every neighborhood, we should document the number, diversity, and quality of such activities. We should also map the human skills that are available in these neighborhoods.

5.1.5 Governance Performance

The criteria capture the degree of self-organization that is available with settlements and neighborhoods. Self-organization might not have direct links to density. Still,

it might be one of the characteristics of an assemblage created out of the process of urbanization, institutions involved, people practices and the urban environment, etc. (Eizenberg 2019). The question would be can density play a role in supporting self-organization? Here, the notion of density might not be numerical but connected with being spontaneous, evolutionary, and an integral part of the cultural milieu. The notion of self-organization is about people playing a role in the planning process and having a sense of agency. It is a qualitative criterion that we can observe in settlements through the nature of collective action that they undertake. It plays a significant role in making settlements resilient.

As seen in Table 6, these are critical density performance indicators that can have relevance for cities like Mumbai. While this is an initial suggestive framework, researchers might modify it during actual use to make it more sensitive to the context. This allows researchers to evaluate density through a multiple set of criteria apart from congestion and overcrowding with which it is normally associated. This chapter argues that this is very important for cities like Mumbai that have varied morphologies, as shown in the earlier part of this chapter. These morphologies allow for different sets of criteria to be enabling for inhabitants depending on their class and unique social practices.

5.2 The Perception of Density

Understanding the perception of the community toward density will require interaction with lived stakeholders. It is more a spatial-ethnographic mode of documentation that will indicate the quality of life that residents have. The residents in such cases might differ because of gender, age, class, and ethnic/religious groups. It would be critical to understand whether density has been enabling for all. Some groups might perceive it as unfavorable. Though some of the quantitative indicators might highlight high density's positive or negative aspects, the inhabitant's perceptions may vary. In different neighborhoods, residents might give priority to different aspects of density. It is where understanding the Quality of Life (QOL) and perception of residents is essential. We can judge whether high density has been inclusive, provide equal access to amenities, engender a feeling of safety and security among residents, provide economic opportunities, help them build human capital, and generate participation. The primary question to observe is whether concentration in the urban environment, an integral cultural part of such cities, plays an essential role in empowering inhabitants and creating positive perceptions? (Fig. 16).

Table 6 Creating a set of cross-performance criteria to evaluate the density

Performance	Possible criteria	Source of data	Scale
Mobility	Proximity to Public Transport Systems and Nodes	OSM and ground observation	Ward
	Affordability	Interviews	
	Diversity of land use near transport nodes	Development plan	
	Design near transport nodes for walkability	Ground observation	
	Car Restraint Policy		
Ecological	Water Consumption versus harvesting	Ground observation	Ward and Neighborhood
	Sewage production versus recycling		
	Waste production versus recycling		
	Energy consumption versus production		
Public space and amenities	Open Space per Person	Ground observation	Neighborhood
	Privately owned Public Space		
	Accessibility		
	Diversity of Usage		
	Inclusivity of different classes		
Economic	Human Capital among inhabitants	Interview and ground observation	Neighborhood
	No. of Work and Small Establishments		
	Diversity of Establishments		
Governance	Existence of self-organizing institutions	Interview	Neighborhood
	Level of Participation	Interview	

5.2.1 Determining Variables that Affect Density Performance and Perception

The culmination of this framework could be to understand and locate variables that affect the performance and perception of density. These variables can be the physical environment, social-cultural aspects, situational characteristics, and individual aspects (Churchman 1999, p. 404). In most cases, these variables overlap with each

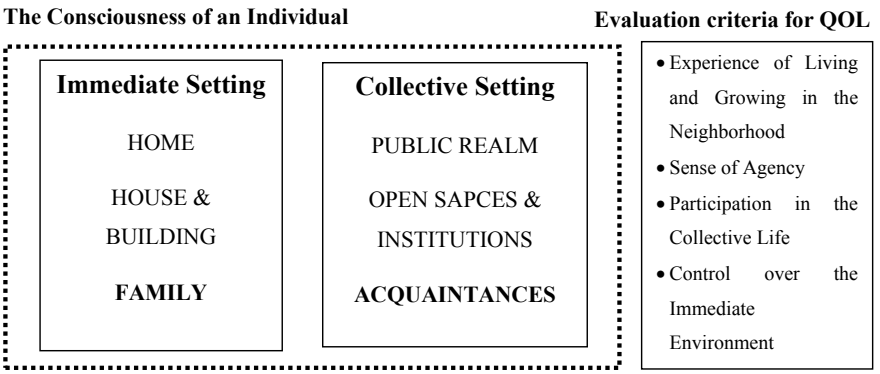


Fig. 16 Documenting the perception of density through the perception of the individual

other in complex ways. These are essential variables to planners and urban designers as they might affect performance and perception by modulating them.

5.3 Discussion and Conclusion

While the framework is broad and indicative, it indicates a process researchers can use for such studies in their contexts. However, the final aim of the framework should be to realize that varied community groups in our cities might prioritize differing performance aspects of density. These might have a close relationship to the typo-morphologies that they inhabit. Promoting a narrow understanding of the compact city by the authorities might not help achieve sustainability, inclusiveness, and resilience for all groups.

The complexity framework that this study suggests can be conducive to creating an expanded set of metrics required to understand a complex set of social practices that contemporary cities house within their differing neighborhoods. They can help develop planning standards and methods that make them more relevant to social practices resulting from differing cultural milieu within communities in our cities. Like in our cities, pedestrian streets and sidewalks play an essential role as public space, but present planning regulations hardly recognize their importance.

Researchers should consider the manifestation of densities as assemblages that come from a complex interaction between human and non-human components. As suggested in this study, the variable captures elements that result from the built environment, people, and processes. These combine in various ways to enable density for inhabitants in a particular context. They might not be easily replicable as designers and planners want by controlling only one set of variables like the physical environment.

The other aspect this framework recognizes is the varied notion of densities that might help an empathetic formulation of different modes of urbanization, both legal

and extralegal, within cities of the developing world. Generally, the extralegal is considered illegal by city authorities, and the resultant solution they propose is demolition, rehabilitation, and redevelopment. Through this framework, there is a possibility of recognizing varied enabling aspects that density allows for different city residents, both rich and poor. It might result in more careful and conservative approaches that might be possible instead of widely accepted redevelopment models that our city authorities propose. Such models imagine private developers to be the key players and communities to be passive receivers. This framework can hint at a combination of physical conditions, processes, and agents that can play an important role in conceiving alternatives.

References

Abarca-Alvarez FJ, Campos-Sánchez FS, Osuna-Pérez F (2019) Urban shape and built density metrics through the analysis of European urban fabrics using artificial intelligence. Sustainability

Adarkar Associates for MMR-EIS (2012) Inventorisation of open spaces & water bodies in greater Mumbai. MMRDA, MMR-EIS, Mumbai

Alexander ER (1993) Density measures: a review and analysis. J Archit Plan Res 181–202

Arifwidodo SD, Perera R (2011) Quality of life and compact development policies in Bandung, Indonesia. Appl Res Qual Life 6:159–179

Barter AP (2000) Transport dilemmas in dense urban areas: examples from Eastern Asia. Compact cities: sustainable urban forms for developing countries. Spon Press, London and New York, pp 271–284

Bardhan R, Kurisu K, Hanaki K (2015) Does compact urban forms relate to good quality of life in high density cities of India? case of Kolkata. Cities 48:55–65

Barnes T (2017) Informal labour in urban, three cities, three journeys. Routledge, Oxon and New York

Batty M (2019) Foreword: the morphology of cities. In: The mathematics of urban morphology. Springer Nature, Cham, Switzerland, pp v–ix

Bavaskar A (2011) Cows, cars and cyclerickshaws: burgeois envirenmntalism and the battle for Delhi streets. Elite and Everyman. Routledge, London; New York; New Delhi, pp 317–419

Bayat A, Denis E (2000) Who is afraid of ashwaiyyat? Urban change and politics in Egypt. Environ Urban 12(185):185–199

Benjamin S, Raman B (2011) Claiming land: rights, contestations and the urban poor in globalized times. In: Urban policies and the right to the city in India: rights, responsibilities and citizenship. United Nations Educational, Scientific and Cultural Organization, New Delhi, pp 63–75

Bertaud A (2004) Mumbai FSI conundrum: the perfect storm: the four factors restricting the construction of new floor space in Mumbai. s.l.:s.n

Boeing G (2018) Measuring the complexity of urban form and design. Urban Des Int

Burgess R (2000) The compact city debate: a global perspective. Compact cities: sustainable urban form for developing countries. Spon Press, London and New York, pp 9–24

Burton E (2001) The compact city and social justice. s.l., s.n.

Caramona M (2015) Re-theorising contemporary public space: a new narrative and a new normative narrative and a new normative. J Urban: Int Res Placemaking Urban Sustain 8(4):373–405

Census of Bombay, Government (1901) Census of India, 1901, vol XI. Bombay Town and Island. The TImes of India Press, Bombay

Census of India (2011) District census handbook: Mumbai, s.l.: Government of India

Census of India (2014) District census handbook: Mumbai Suburban 2011, s.l.: Government of India

Cervero R, Kockleman K (1997) Travel demand and the 3Ds: density, diversity, and design. Transpn Res.-D, 2(3):199–219
Chatterji R (2005) Plans, habitation and slum redevelopment: the production of community in Dharavi, Mumbai. Contrib Indian Sociol 39(2)
Cho IS, Trivic Z, Nasution I (2015) Towards an integrated urban space framework for emerging urban conditions in a high-density context. J Urban Des 20(2):147–168
Churchman A (1999) Disentangling the concept of density. J Plan Lit 389–414
Conybeare H (1855) Report on the sanitary state and sanitary requirements of Bombay. Bombay Education Society's Press, Bombay
Dave S (2010) High urban densities in developing countries: a sustainable solution? Built Environ (1978-)36(1)
Davis M (2006) Planet of slums. Verso, London
Dimmer C (2013) Privately owned public space: the international perspective. The University of Tokyo, s.l.
Dinarès M (2014) Urban metabolism: a review of recent literature. Doc d'Anàlisi Geogràfica 60/3:551–571
Doctor for You (2018) Studying the association between structural factors and tuberculosis in the resettlement colonies in M-East ward, Mumbai. MMREIS, Mumbai
Dossal M (1991) Imperial design and Indian realities: the planning of Bombay City, 1845–1875. Oxford University Press, Bombay
Doxiadis CA, Waddington CH, Johnson-Marshall P, Hall ET (1965) Techniques of studying density. Ekistics 20(119):199–207
Eizenberg E (2019) Patterns of self-organization in the context of urban planning: reconsidering venues of participation. Plan Theory 18(1):40–57
Glaeser EL, Henderson V, Inman RP (2000) The future of urban research: nonmarket interactions. In: Brookings-wharton papers on urban affairs, pp 101–149
Goh S, Lee K, Choi M (2019) Emergence of complexity in urban morphology. In: The mathematics of urban morphology. Birkhäuser, Cham, Switzerland, pp 291–314
GOM (1991) Development contorl regualation for Greater Mumbai 1991. GOM, Mumbai
GoodFriend DE (1979) Nagar Yoga: the culturally informed town planning of patrick geddes in India 1914–1924. Hum Organ Winter 38(4):343–355
Hart K (1985) The informal economy. Camb J Anthropol 10(2):54–58
Hillier PB, Hanson DJ (1997) The reasoning art: or. London, University College London, The need for an analytical theory of architecture
Hofstad H (2012) Compact city development: high ideals and emerging practices. Refereed article No. 49. Eur J Spat Dev
INTACH & NIUA (2015) Urban heritage in Indian Cities. National Institute of Urban Affairs, New Delhi
Jacob J (1970) The economy of cities (EPUB). Vintage Book House, New York
Jacobs J (1961) The life and death of great American cities. Vintage Books, New York
Jenks M (2000) sustainable urban form in developing countries? Compact cities: sustainable urban forms for developing countries. SPON PRESS, London and New York, pp 1–6
Jenks M, Burton E, Williams K (1996) The compact city: a sustainable urban form? Spon Press, Oxford
Jia M, Liu Y, Lieske SN, Chen T (2019) A fractal approach to explore australian urban form and its impacting factors at neighbourhood scale. In: The mathematics of urban morphology. Birkhäuser, Cham, Switzerland, pp 123–146
Kamalipour H (2016) Forms of informality and adaptations in informal settlements. Int J Archit Res 10(3):60–75
Kim AM (2015) Sidewalk city: remapping public spaces in Ho Chi Minh city. The University of Chicago Press, Chicago and London
Kovalenko, V., n.d. s.l.:s.n.
Kumar R (2015) 39 villages under SDMC to be made 'urban villages'. The Pioneer, New Delhi

Lai C (2018) Open space opinion survey. Civic Exchange, Hong Kong
Loo C (1975) The psychological study of crowding. Am Behav Sci 18(6):826–843
Macharía K (2007) Tensions created by the formal and informal use of urban space: the case of Nairobi,. Kenya. J Third World Stud 24(2):145–162
Maharashtra State Gazetteer (1986) Greater Bombay district, vol III. Government of Maharashtra, Bombay
Mandal A, Byrd H (2011) Intensification and urban metabolism—analyzing current trends for Mumbai. s.l., s.n
Marshall A (1920) Principles of economics, 8th edn. Palgrave Macmillan, London
Marvin S, Graham S (2001) Splintering Urbanism; network infrastructures, technological mobilities and the urban condition. Routledge, London and New York
Merhotra R, Dwivedi S (1995) Bombay: the cities within. Eminence Design Pvt. Ltd. Mumbai
Mitchell RE (1971) Some social implications of high density housing. Am Sociol Rev 36(1):18–29
MOHUA GOI (2016) Smart cities mission. http://164.100.161.224/content/
Moroni S (2016) Urban density after Jane Jacobs: the crucial role of diversity and emergence. City, Territ Archit 3(13):1–8
Mukim M (2011) Industry and the urge to cluster: a study of the informal sector in India.London School of Economics: Spatial Economic Research Center
Nallathiga R (2007) Compact city and smart growth as policy guiding models for achieving sustainable city development: the case for Mumbai metropolis. ICFAI J Urban Policy 42–59
Newman P, Kenworthy J (2015) The end of automobile dependence. Island Press, Washinton; Covelo; London
Patel SB (2011) Analysing Urban layouts—can high density be achieved with good living conditions? Environ Urban 23(2):583–597
Patel SB (2014) Housing, FSI, crowding and densities. PRAJA, Mumbai
Pont MB, Haupt P (2005) The spacemate: density and the typomorphology of the urban fabric. Nordisk Arkitekturforskning 4:55–68
Rapoport A (2008) Environment-behavior studies: past, present, and future. J Architect Plan Res 276–281
Rapport A (1975) Towards a redefinition of density. Environ Behav 7(2):133–159
Reddy B (2013) Metabolism of Mumbai-expectations, impasse and the need for a new beginning. s.l.:Indira Gandhi Institute of Development Research, Mumbai
Robinson J (2006) Ordinary cities. Routledge, Oxon and New York
Rode P (2009) Mumbai: the compact mega-city. Urban India: understanding the maximum city. London School of Economics and Political Science, London, pp 45–46
Roy A (2005) Urban informality. J Am Plann Assoc 71(2):147–158
Roy A (2009) Why India cannot plan its Cities: Informality, Insurgence and the idom of urbanization. Plan Theory 8(1):76–87
Richardson WH, Bae C.-H.C, Baxamusa MH (2000) Compact cities in developing countries: assessment and implications. Compact cities: sustainable urban forms for developing countries. SPON PRESS, London; New York, pp 25–36
Sanyal S, Nagrath S, Singla G (2009) The alternative urban futures report, s.l.: Mirabilis Advisory Private Limited for the World Wildlife Foundation
Sassen S (1998) Globalization and its discontent. The New Press, New York
Satterthwaite D (1997) Sustainable cities or cities that contribute to sustainable development? Urban Stud 34(10):1667–1691
Slum Rehabilitation Authority, GOM (2021) History of growth of slum in Dharavi. https://sra.gov.in/page/innerpage/growth-history.php
SPARC and KRVIA (2010) Re-Dharavi. KRVIA and SPARC, Mumbai
Stokols D (1976) The experience of crowding in the primary and secondary environment. Environ Behav 8(1):49–86
Tanga WS, Lee JY, Huia TW, Yip MK-C (2018) The "Urban density" question in Hong Kong: from absolute space to social processes. Cult Soc City 1–22

The Gazetteer (1909) The Gazetteer of Bombay City and Island. The Times Press, Bombay
Wackernagel M, Galli A (2007) An overview on ecological footprint and sustainable development: a chat with Mathis Wackernagel. Int J Ecodyn 2(1)
World Health Organization (2020) Health statistics and information systems, WHOQOL: measuring quality of life. https://www.who.int/healthinfo/survey/whoqol-qualityoflife/en/. Accessed 15 September 2020

Chapter 2
Livelihoods, Mobility, and Housing: In Search of Missing Links in Indian Towns

Sheuli Mitra

1 Introduction

Everywhere in the global south, housing choice is a harsh battle of confusing trade-offs. Way back in the 1960s, John Turner had proposed the novel concept that "housing is a verb" and future studies on urban housing have gone on to accept this as the fundamental dictum. In Turner's very original model, based on his work in Peru in the 1960s, rural migrants first try to move from the province to central locations in the city, paying any price, to find jobs. Then, with security of employment, they move to the periphery, where land or housing ownership is attainable. He coined the terminologies of "bridgeheader" to "consolidator" to show this progression in the life of the migrants (Turner and Fichter 1972). Thus, the urban poor have to juggle many factors as they try to optimize housing cost, tenure security, quality of shelter, journey to work, and sometimes, personal safety. For many people, including many pavement-dwellers, a location near a job is even more important than a roof. For others, free or nearly free land is worth long and expensive commutes from the periphery to the center. And for everyone the worst situation is a bad, expensive location without municipal services or security of tenure (Davis 2006). These new migrants, many of whom become slum dwellers, score far lower on human development indicators than other urban residents, they have more health problems, less access to education, social services, and employment.

Many past responses to the problem of urban slums have focused on mere slum upgradation through the provision of improved housing and related services. The thrust on the physical eradication of slums was considered as the solution to the problem of the homeless and the slum dwellers. Solutions based on this premise have failed to address the main underlying causes of slums, of which poverty is the most significant. The Challenge of Slums report by the United Nations Human

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P. Banerji and A. Jana (eds.), *Advances in Urban Design and Engineering*, Design Science and Innovation, https://doi.org/10.1007/978-981-19-0412-7_2

settlements Programme (2003) was one of the first to emphasize the need for future policies to support the livelihoods of the urban poor by enabling urban informal-sector activities to flourish and develop, by linking low-income housing development to income generation, and by ensuring easy geographical access to jobs through pro-poor transport and more appropriate location of low income settlements. It asserted that slum policies should in fact be integrated within broader, people-focused urban poverty reduction policies that address the various dimensions of poverty (United Nations Human Settlements Programme 2003).

In India, the problem of linking the urban poor with livelihoods and housing is still a growing one, spilling over from the mega-cities to the large and medium towns too. The predominant issues yet to be tackled in this regard are an equitable access to infrastructure and services, access to livelihoods (physical and economical), and the access to serviced land for housing. The provision of urban infrastructure in Indian cities is more reactive rather than proactive (Knight Frank Research 2020), as in most developing countries, and has resulted in urban sprawl and low-density suburbanisation that substantially increases the cost of delivering infrastructure to a dispersed population. This has a negative impact on the environment being energy intensive and consequently contributes significantly to climate change. It also creates social and spatial inequalities which are characterized by housing of the rich and the poor juxtaposed in close proximity with cities perpetually facing difficulties in ensuring an equitable sharing of their social and cultural assets. This reactive nature of urban infrastructure provision is unsustainable from an economic perspective as the costs incurred to fill in the gaps in the capacities not developed in the early stages of growing cities, far outweigh the perceived savings at the time of omitting to install them in the first place (Knight Frank Research 2020). Most urban infrastructure inserts are burdened under the pressure of the ever growing urban population and ULBs are not in a position to effectively improve service levels. While current infrastructure development focuses on the resource mobilization and public–private partnership for creation of better urban infrastructure and services, it is often criticised for failing to ensure that the infrastructure and services remain accessible and affordable to the urban poor. Often the enthusiasm of creating high-end infrastructure and services undermines the concerns of urban poverty thus creating a progressive social imbalance (YASHADA 2009). Poor or biased policies with regard to land are also an enormous obstacle for the poor in their search of a place to live, as the legal and regulatory frameworks on the supply side, particularly with regard to land markets and land acquisition, are often ineffective. Furthermore, on the demand side, the poor often do not have access to the financial resources including housing finance, needed to buy houses, and often subsidies for housing are not properly targeted or not properly implemented (Knight Frank Research 2020). In light of the increasing numbers of urban slum dwellers, governments across the world had adopted a specific target on slums, i.e. Millennium Development Goal 7, Target 11, which aimed to significantly improve the lives of at least 100 million slum dwellers by the year 2020. Given the enormous scale of the problem, much more would have to be done if ‘cities without slums’ are to become a reality.

According to UN estimates, the proportion of urban population living in slums in India in 2009 was 29.4% while the Census of India figures for 2011 peg the slum population to roughly 65 million or 17% of urban India. Indian Housing policy has been influenced by changing global housing thought. Three major interventions have been emphasized which could help improve spatially concentrated urban poverty within cities, namely access to land through security of tenure and functioning of land markets; access to basic services; and citizen engagement ensuring better governance (Revi and Rosenzweig 2013). The focus of the New Urban Agenda (NUA) of Habitat III is also on the progressive realisation of the right to adequate housing as a component of the right to an adequate standard of living (UN Habitat 2018).

In India, national housing policies have over time replaced the rhetoric of 'removal' and 'clearance' and instead started talking about 'improvement' and 'upgradation' of informal housing (Batra 2009). However, in recent policy frames, with the involvement of the private sector in housing provision, the role of housing as an economic good seems to outweigh its presence as a component of welfare and social security (Bhan et al. 2014). Urban Local Bodies and households are the two pivotal participants who can together address housing poverty effectively and hence need to be empowered adequately through technical and financial assistance from the Centre and the State governments, through appropriately designed schemes and programmes (Mitra 2021).

This research brings case based evidence from the city of Bhopal, to illustrate the missing links in livelihoods, housing and mobility that poor urban households have to negotiate to survive in the city. While the case studies highlight the pro-active role of households in finding jobs, housing and amenities, they also bring to light the inadequacies of the interventions by different levels of Governments in catering to their needs. Some cases of successful implementation of government programmes across housing and infrastructure are also seen in Bhopal which are discussed to explore possibilities of upscaling them in similar contexts. In conclusion, the research argues that the present thrust of ambitious centrally sponsored programmes for housing need to be judiciously implemented by ULBs in local contexts, to truly benefit the urban poor. The implementation of several programmes on livelihoods, transport, water and sewerage, housing, health and education need to be looked at in tandem and not in silos as is the current practice, to address the larger dimension of urban poverty. For effective implementation, there is a need to conduct extensive household surveys to understand the multi-dimensional nature of the problems of the urban poor to help provide more targeted interventions. Thus a clear assessment of the work-home relations and the nature of trips (both quantitative and qualitative) made by the urban poor can help develop strategies of urban development both at the core and the periphery, which will ultimately lead to a more equitable spatial structure, cause less damage to the environment and ensure better livability for all residents of the city.

2 Where Do the Urban Poor Live?

Contemporary research on urban housing assert that while urban areas provide better access to employment and the promise of an improved lifestyle, growing cities are hard pressed to accommodate the influx of prospective workers. Prohibitive housing costs in the city force most of this workforce, especially with mid to lower income levels to settle in far off suburbs with long commute times to workplaces or settle in slums near the city core (Neuwirth 2005). However, in the last four decades, it has been seen that urban population growth has occurred at the periphery of most cities of developing countries, with India being no exception. The "horizontalization" of poor cities is often as astonishing as their population growth. In the sprawling cities of developing countries, the concept of the "periphery" is highly relative, and time-specific, with today's urban edge, abutting fields, forest, or desert, becoming part of a dense metropolitan core in future (Davis 2006). The cycle of slow conversion of a previous periphery to a core, with the definition of a new periphery determines the spatial structure and dictates the land markets of cities, which in turn impacts the location choice of the urban poor as a factor of their affordability. This gives rise to wider socio-economic divides in the city, which become more and more difficult to be rectified as legacy burdens.

2.1 The Research Question and Process

This research started with a fundamental research question "Where do the urban poor live?". In the Indian context, while a large body of existing research exists on mapping urban sprawl (Indian Institute of Human Settlements 2012) and classifying the typology of low income housing relating to different locations (Joshi 2009) (Hingorani 2012), lesser research is available on ground studies looking through the lens of the urban poor households to analyse their location choices and the factors which dictate them. The broad methodology used for the study has two main stages. The first stage consists of understanding the urban structure of Bhopal by correlating spatial patterns of population density, transport linkages, government land banks, land values with slum, and squatter locations. A broad understanding of factors governing the choice of housing locations of the urban poor can be identified by relating the different maps. The second stage consists of evidence based work including visual surveys, physical documentation, and semi structured interviews of sample slum households from selected slums, squatters, and other informal settlements. It consists of an ananlysis of the relationship between livelihoods and housing choices. Documentation of the occupations of households along with their housing location and typology, mode, time, and cost of transport was conducted to arrive at conclusions. It also analyses housing aspirations and possible solutions for upgrading their conditions. The locations and typologies of various government affordable housing schemes are evaluated to test their success as appropriate housing for low

income households. The study attempts to evaluate the linkages and gaps in access to livelihoods, access to mobility and access to housing as the three realms influencing household wellbeing in the large lower income segment of urban population.

Thus demand and supply side dynamics are attempted to be analysed through empirical data analysis. The results are interpreted to identify the missing links in the urban planning interventions which propel the formation of slums. In conclusion, the assertions of the state on successful integration of livelihoods with housing and transport through various schemes are tested for successful implementation on ground, suggesting alternative ways ahead to achieve a more equitable cityscape.

2.2 Understanding Bhopal as a Case Study City

The city of Bhopal with a population of 19 lakhs, according to the Census, 2011, spread over a total area of 41,784.42 ha and consisting of 85 wards, is taken as the case study city. The gross population density of the Bhopal Municipal Corporation (BMC) area is 62 persons per hectare (pph). As there are large water bodies and reserved forest land within the city limits, the population density translates to 104 pph considering the developed area of the city (School of Planning and Architecture Bhopal 2021). There are 21 wards having densities between 300 and 975 pph, while all the remaining have moderate to low densities. Bhopal is a prototype of the modern planned Indian cities which have old historic cores and large planned city areas, forming different layers of development over time. The metropolitan (I) cities of 10 lakh to 50 lakh population have a different pattern of urbanization as compared to the Metropolitan (II) cities, which have populations greater than 50 lakhs. The largest cities house the majority of the slum populations, and have received much greater technical and financial support for their upliftment (Khan 2014). Cities where land values are rising but still low, and pressure from real estate lobbies is yet to gain momentum have almost no medium to long term strategies for housing, nor see it as a pressing need to put these in place (Bhan et al. 2014). In recent years with the implementation of various large scale Central Programmes targeted for urban development, such as the PMAY, Swatch Bharat, AMRUT, many cities of this category have started relooking at their city planning initiatives in a proactive manner. Bhopal serves as a good case study for this category of cities. The Bhopal Development Plan-2031 as a draft document had identified sustainability and liveability as its two main conceptual thrusts (Directorate of Town and Country Planning, Madhya Pradesh, 2019). The Plan includes several GIS based maps on various focus areas, following the AMRUT guidelines of Development Plan preparation, which help in analyzing the spatial growth pattern of the city in a more comprehensive manner (Fig. 1).

While 21 of the wards in and around the old city have densities higher than 300 pph, the rest of the planned city has densities lower than 200 pph. Two third of the total land under the Bhopal Municipal Corporation comprising of the peripheral wards have densities lower than 100 pph, which clearly points toward the inefficient

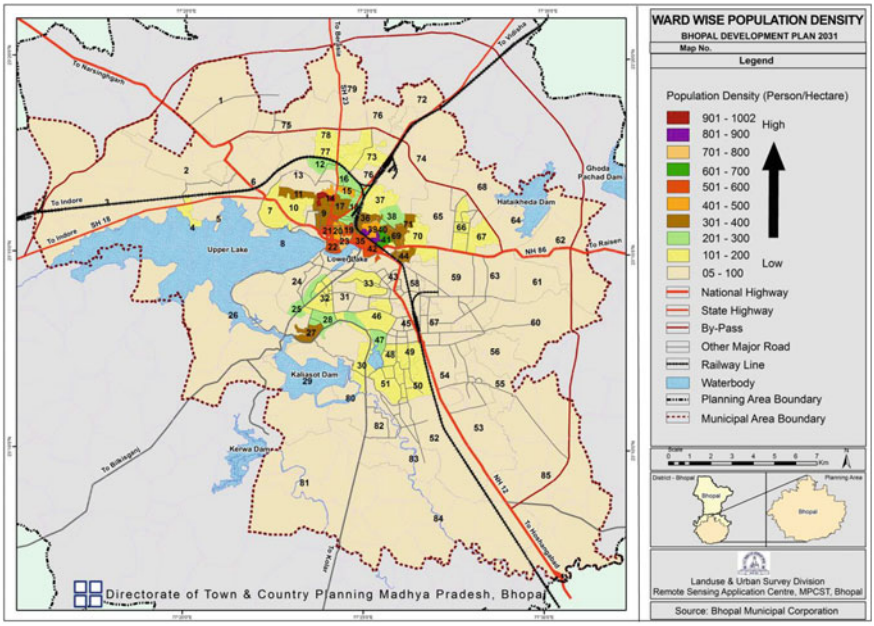


Fig. 1 Population density map of Bhopal (ward wise). *Source* BDP 2031 (Draft, unpublished)

and sprawling nature of development in the city since the last 20 years. Older developments such as the huge BHEL township with large vacant land banks and large institute campuses are the other cause of the low densities developed. It is interesting to note that certain areas in the city centre also have significantly low densities, owing to the state developed Capital Complex residences in bungalow pattern developed in the 1960s occupying large tracts of land in what is the heart of the city now. The Area Based Development under the Smart City Mission has chosen to redevelop and redensify some of the Capital Complex area. The sudden availability of land and an increase of FAR have released a large quantum of potential built up development in the core. However it is to be seen how the lower income households benefit from this development as the Smart City model is based on the concept of land value capture and is criticized to be exclusionary in nature.

The urban sprawl map (Fig. 2) shows the chronological development of the city in various directions. The growth pattern of Bhopal during 1999–2005 indicates a shift in preference for areas south and southeast, as large land banks were opened up for private development in these corridors, but at much closer distance to the city core during this period. During the 1994–2005 period, the growth was concentrated around the transportation corridors, along railway lines and major road networks, largely undertaken by the state in PPP model on government land unlocked, along with private developments which continued from the previous decade (Fig. 3).

An analysis of the land value map of Bhopal as an overlay to the density and sprawl map provides insights into the land markets prevailing in the city and their

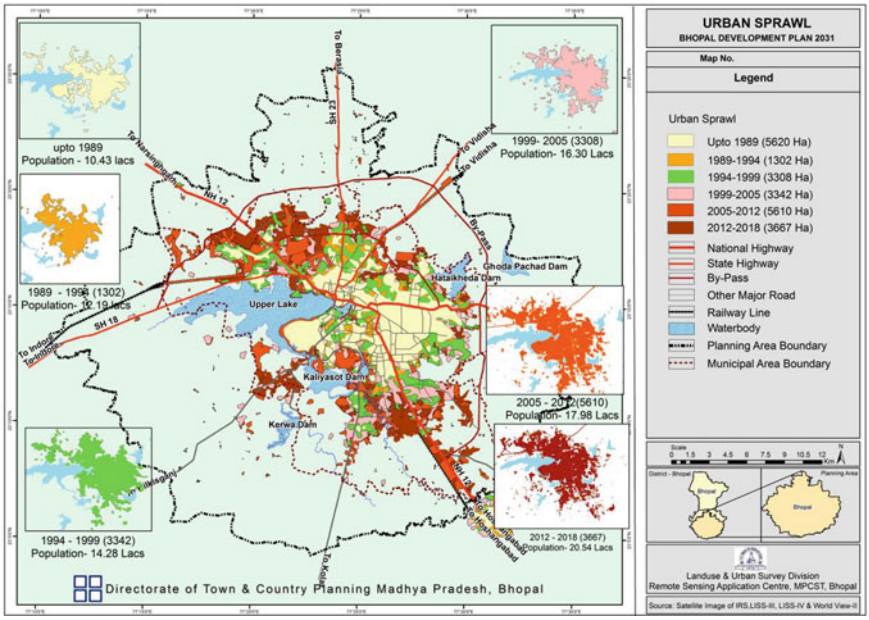


Fig. 2 Urban sprawl map of Bhopal (planning area). *Source* BDP 2031 (Draft, unpublished)

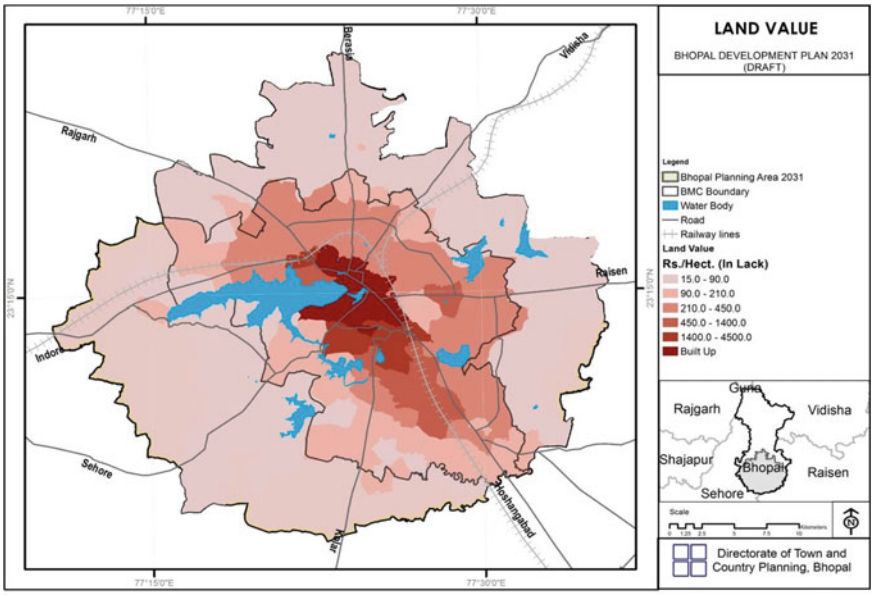


Fig. 3 Land value map of Bhopal (planning area). *Source* BDP 2031 (Draft, unpublished)

impact on distribution of housing in different socio-economic groups. While the population densities are not significant to be mapped beyond the BMC limits, both urban sprawl and land values are significant enough to be mapped for the Planning Area, even beyond the Municipal Corporation boundary. It is noticed that the growth in the south and south eastern direction, demonstrates the classical price gradient curve. However, densities do not match with the relatively high land values, pointing to a skew in the housing market towards more affluent, low density housing formats in most parts of the city. The BDP 2031 states that the preferred plot sizes are 2400 sqft–1500 sqft for independent units for 80% of the population (Directorate of Town and Country Planning, Madhya Pradesh 2019), thereby corroborating this finding. The peripheral wards within the BMC limits are no exception. The lowest land prices are prevalent in the concentric zone beyond the 15 km radius with the core as centre, where no urban development exists. The concentric zone between the 10 and 15 km radius is the most heterogeneous in its development pattern as well as land price, as it consists of various land uses including agricultural land, converted agricultural land, high end residential communities, low income squatters and urban villages, government institutes, and public semi public facilities. Depending on the radial growth directions of the city, land use and prices fluctuate the most in this belt. These land values, though lower as compared to the Metropolitan (II) cities, are not low enough to facilitate market led formal housing projects for low incomes households, at reasonable distances to work places. Thus the parallel market of informal housing proliferates across the city, irrespective of land values, guided by proximity to workplaces and accessibility to major transport corridors. The state led affordable housing projects do intervene into this process, but the quantity and quality of housing supplied along with inappropriate locations, are often unable to attract the target households resulting in creation of vacant stock and wastage of precious funds (Fig. 4).

3 Where Do the Poor Live in Bhopal?

From an analysis of several recent maps sourced from the Bhopal Development Plan 2031 (Draft) it is evident that the case of Bhopal is very similar to that of most Indian cities, from the perspective of housing the urban poor. The slum households constitute around 27% of the urban households. Spatially, slums and illegal colonies are dispersed in most wards of the city and are located along major arterial roads and on environmentally vulnerable sites such as hill slopes, along the lake and *nallahs* and on reserved land under high tension lines. However, in Bhopal, efforts towards slum regularization was initiated in the 1980*s* with the enactment of the '*Patta* Act of 1984' which gave extension of land tenure rights over government land, locally known as '*patta*', to slum dwellers, legalised through the Tenure Regularisation Scheme (Bhatnagar 1996). The provisions of the *Patta* Act supersede city zoning and sub-division regulations and have been used in combination with other schemes of land reservation and municipal infrastructure programmes resulting in allocation of land to

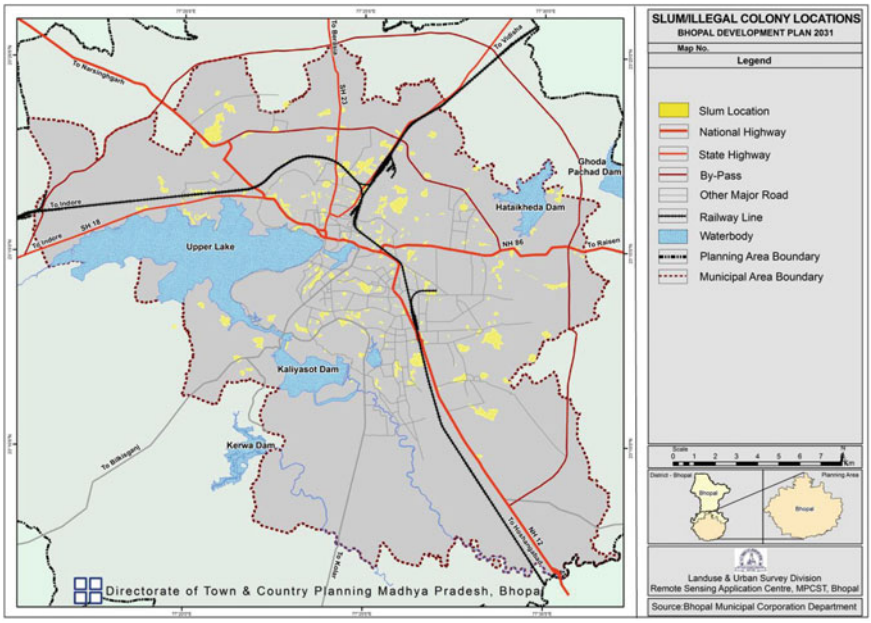


Fig. 4 Slum and illegal colony map of Bhopal (BMC area). *Source* BDP 2031 (Draft, unpublished)

thousands of households since the 1980s (Bannerjee 2002). A large government land bank in the new capital city of Madhya Pradesh helped in proving land tenure to the urban poor through enactment of this enabling legislation making Madhya Pradesh a forerunner in this domain. It is ironical however that when the State became proactive in using the *Patta* Act 1984 again as a major enabling tool for legalising tenure by giving '*patta*' or land title to landless households and thereby catapulting the construction of self assisted low income housing under the BLC component of the PMAY (Mitra 2021), it excluded the two major cities of Indore and Bhopal from its ambit, as land in these two cities was now considered too precious to be given away to the urban poor to build their own low density-low rise housing formats. Bhopal has seen significant number of state constructed housing stock developed in-situ on previously slum occupied land at prime locations since the implementation of the BSUP component of JNNURM. Under the PMAY, the AHP component is being constructed on government land banks, but many are in remote locations. Under the PMAY, in situ slum redevelopment is facilitated through the ISSR component only where most tenable slums are treated as prospective sources of revenue by leveraging on the value of the land they occupy. As location preferences dictate the success of the ISSR component, slums in non-prime locations are chosen in the first phase. Underlying tendencies of the ULBs to selectively keep informal settlements vulnerable prevail, by denying access to water supply or sewerage, thereby slowing down the process of housing consolidation in such settlements. These settlements form easy targets to 'reserve' for ISSR projects in later phases when the land is lucrative

enough (Mitra 2021). As the success of the ISSR depends on the higher income 'for sale' component, very few such projects are being implemented in Bhopal, as there is a surplus supply in the higher income segment through several government redensification projects and private developer driven projects, when compared to the demand, based on the overall economy of the city.

Thus it is evident that a variety of housing options are available to the urban poor in Bhopal, in both the formal and informal sectors, as analysed from the study of various secondary sources of data and maps. The question of how the urban poor exercise their choice of formats and location preferences from among these available formats can however not be answered from these data sources and needs to be derived from evidence based ground research.

3.1 The Case of the 'Shifting Boundary'

This section summarises the responses of households living in various formats and locations and also mapping locations of informal settlements versus formal housing supplied by the state. The near absence of private sector developed housing projects for this segment was also noted. The section discusses not only quantifiable data retrieved from the semi-structured questionnaires but also aspirations and opinions of households and more significantly, households' compulsions and lack of choice when choosing housing formats and locations. The priority of accessing livelihoods, incomes and minimize housing and transport costs were the main factors seen to influence their choices. On the supply side, the ever spiraling land prices made the chances of poor households entering the formal market without compromising on the locational advantages a distant dream. The financial and physical boundaries of the ever growing city keep shifting beyond the bounds of the urban poor. The results of empirical studies proving this assertion are included in this section.

The study was conducted in three types of settlements: illegal slums, *patta* colonies, and government housing in the southern part of the city, where development and land prices have both shown higher rates of growth. The zone with the selected wards is marked on a thematic map (Fig. 5) showing the comparative grading of land prices within the BMC boundaries. Government projects under construction are also identified and analysed in this part of the city to understand the demand supply dynamics in the affordable housing segment.

3.2 Documenting Responses

A series of primary studies of low income housing settlements form the basis of this section, with interactions with households being the major source of information. While this is a pilot survey, conducted in only a few locations, it gives a clear view of the demand side perspective on low income housing and their location choices,

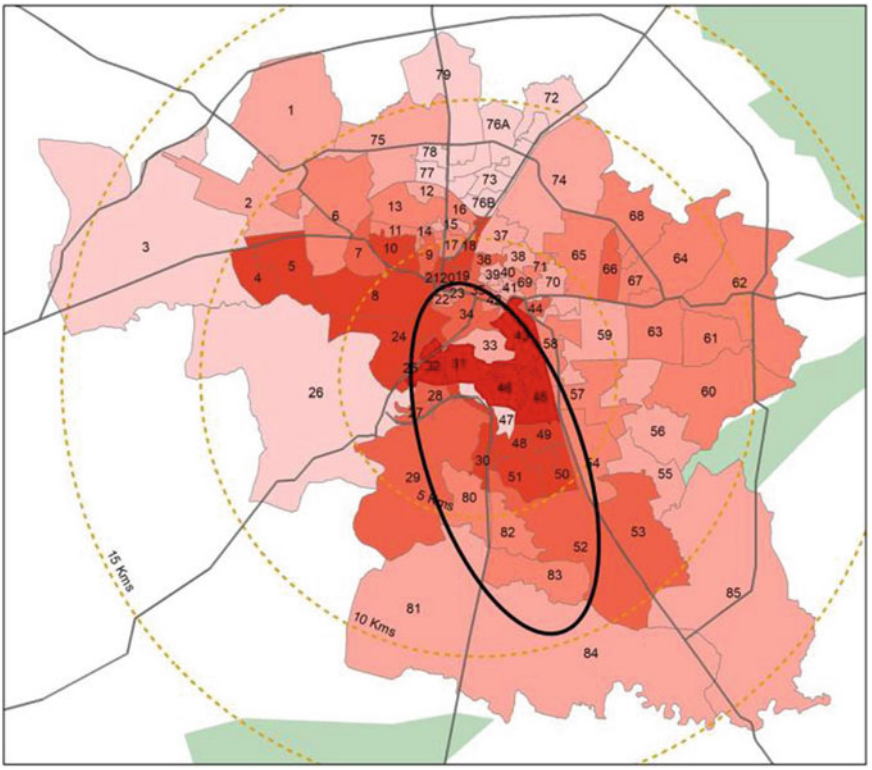


Fig. 5 Ward map of Bhopal with thematic land value gradient and study area marked (BMC area). *Source* MURP studio study, SPA Bhopal 2020–21 (Unpublished) with author inputs for study area delineation

which are often overlooked in the bigger planning exercises which prioritise land markets and infrastructure funding over vulnerable people's aspirations.

The household surveys consisted of semi structured questionnaires targeted to collect information on (i) the reasons behind occupying their present housing, (ii) the aspirations of moving up the urban ladder through housing consolidation, and (iii) preferred residential format and location choices. The responses to these questions were mapped spatially on satellite images of the zone of the city being discussed and also tabulated to understand the implication on time and cost considerations related to location choices. The responses to the questionnaire are thematically represented under the categories of (i) negotiating the livelihood and housing dynamics, (ii) negotiating housing versus mobility conflict, and (iii) moving up the liveability ladder: myth or reality.?

4 Negotiating Livelihood and Housing Dynamics

The surveys validated several concepts discussed in theoretical housing research. The constant refrain that permeated all responses was the inflow of migrants to urban areas in search of livelihoods and a better life. While the search for a livelihood began immediately after landing in the city, the dream of a better life was almost as immediately shattered to be redefined over many years and often not realized. The salient observations, when generalized from surveys across different informal settlements revealed differences between first generation new migrants and consolidated migrants living for a longer period of time.

The observations by new migrants revealed the following key findings:

i. Access to jobs at the minimum or zero cost of commute was the first priority for the first generation migrants and dictated residential location choices.
ii. Minimum or zero cost of housing was the second priority dictating residential choice, making informal settlements the only choice.
iii. Housing quality was of least importance and even temporary setups under unused bus shelters, in construction sites, on the vending cart are options as long as they are near the workplace.
iv. Environmental quality and access to basic services of water supply, drainage, sewerage, electricity, was totally compromised, with many living on environmentally vulnerable sites and accessing public toilets or opting for open defecation and managing with water from stand posts far from their living area.
v. Health and education are the last priority, and no expenses are incurred for them. If free government schools are available in the vicinity, children are sent, but such occurrences are few. Health is impacted the most but healthcare is of the least concern.
vi. These migrants do not have any form of identity proof such as voter cards or driving licenses, nor work place identities as they work in the informal sector. Thus government schemes on health, education or finance are not accessible to them, leaving them to their own resources only to survive and upgrade their lifestyle in the competitive environment of the city.

The fate of these make shift housing arrangements made by new migrants varies from case to case.

i. Many such settlements have slowly consolidated over time from a cluster of shanties and transformed to large squatter slums, with consolidated housing of better quality, but still lacking in most urban services. Electricity is usually made available, but other amenities such as water supply and sewerage are often missing for years.
ii. Some sites, if considered less vulnerable and on encumbrance free land, are converted to notified slums and are then eligible for provision of basic urban services. These slums see massive building construction, with housing consolidation happening at a very fast pace, and households expand their premises to

not only have more space for themselves, but to use the house as an asset and rent out parts of it to tenants. With a good location and access to basic services, these slums become the most sought after.

iii. Some settlements develop on well located sites considered environmentally vulnerable or on litigated land. These form targets of eviction and relocation, sometimes years after the initial migrants settled there. The resettlement sites provided are often at far flung locations, with no access to livelihoods, or on transport corridors, taking the households to the bottom rung of their journey again. Thus a formal housing unit is of little value to the migrants if it is far away from their livelihood locations. The search for a new site to squat on begins afresh, starting a new cycle of slum formation.

In case of older migrants, the interactions revealed a different set of observations. Their life trajectory changes after 10–12 years of residence in any of the above conditions, if they have not been evicted from their original site of residence.

i. Households living on *patta* land even without basic services slowly upgrade their houses both in size and quality of building materials. Many have upper floors added and keep tenants, if they are in prime locations.
ii. They usually provide education to their children who over time start working too and contribute to the family income.
iii. In a period of 10–15 years these families move socio-economically from the EWs to the LIG segment and own various assets such as multiple motorcycles, televisions, washing machines, coolers, LPG connections and cooking gadgets, etc.
iv. Some households also have bank accounts and have some formal system of accumulating savings.
v. In *patta* settlements two scenarios are prevalent. Those settlements which were formed about two decades back and were subsequently serviced with water supply and sewerage services, are the most coveted, with households choosing to consolidate and expand their houses over time, as the location has changed from a far flung periphery to a comparatively well connected and dense area over time, which gives access to city level education, healthcare, and entertainment facilities. In *patta* settlements not serviced with water supply, sewerage and drainage, the dilemma of households to remain or relocate is higher. While the pull of a good city network and access to city level amenities is strong, the push factors of the daily struggle for water and squalid environmental quality of the slum often outweigh the pull, forcing households to think of alternative housing options. Many households aspire to purchase houses in the formal housing market which provides a better quality of physical and socio-cultural environment.

4.1 Negotiating Livelihood and Transport Conflicts

On the basis of the surveys conducted, the major conclusions reveal that the nature of occupation and earnings is the single most significant influence on the location and typology of the housing urban poor. The diversity of occupations calls for a more nuanced response with respect to housing provision. While the occupations vary, the common thread of informality manifested in the form of meager earnings, lack of a stable income, lack of permanent job locations, access to support vending infrastructure, remain constant in all contexts. The hope of maximizing the earnings leads vendors to select the most prime locations with large footfall and minimizing travel costs leads to choice of residential locations in the vicinity, with the shelter being in various stages of permanence and consolidation depending on the socio-economic level of the household. Transport requirements not only include manpower transport but also goods transport of different sizes, shapes, and weights. A photo essay illustrates the relation between the nature of occupation, mobility, and the location and type of residence.

4.1.1 Recognising the Diversity in Livelihoods

Figures 6 and 7 depict that the nature of produce determines location of fabrication and sales. Products such as cane furniture and accessories, seasonal products like effigies of *Ravan* for *Dussera* are voluminous and difficult to transport. Artisans engaged in these trades form 'workshops' along main roads, near bus stands to get the locational advantage of production and sales at prime locations along arteries. Residences remain 'on-site' from security concerns and convenience of work.

Figure 8 depicts the fabrication of quilts stuffed with cotton being manufactured along a main residential road, where customers stop by and place orders and also collect the bulky finished product. Cost of transportation is reduced to zero, with workplace and selling point being 'on road' with a rudimentary residence, alongside. This 'temporary' setup has been in this neighbourhood changing spots since the last 5 years. Evidently surviving from the earnings of an occupation such as this does not permit the luxury of having a house.

Figures 9 and 10 depict vending along the roadside or as a wandering vendor displaying wares. In both cases minimum distance to house from work zone reduces the burden and time of travel. These occupations become impossible to be undertaken from relocation projects at the periphery of cities.

Figure 11 displays an ingenious informal solution for goods movement. Weekly and bi-weekly temporary markets occur at different designated spots of the city approved by the Municipal Corporation, selling perishable, and non-perishable goods. However setting up and winding up the stalls is the responsibility of the vendors, with no permanent storage space in the vicinity. Innovating solutions of a 'modular' caravan of vending carts strung together to one tractor engine are regular sights on the city's streets. They demonstrate an efficient and affordable

Fig. 6 Cane product makers on sidewalks

cooperative mechanism of goods transport using minimum technology. Each such vehicle consists of around twenty carts of vendors living in proximity pooling their carts together. Relocation projects disturb such transportation dynamics, affecting livelihoods.

4.2 Assessing Appropriate Interventions

The preceding section demonstrates the mobility needs of the urban poor through a quick pilot study. Apart from the ones documented, several other types of mobility types were present in the city. It may be noted that in most of the cases documented, the standard intervention of inserting BRTS routes throughout the city based on demand surveys, would not solve the problem of mobility. The need for inventorising the types of informal trade and their supporting infrastructure is as essential as assessing the demand for logistic hubs, dry ports and other infrastructure for the formal freight movement sector. Integration of work spaces for the informal sector in the new Smart City Mission is conspicuous in its absence. The ABD of Bhopal has created wide boulevards in the core of the city but is silent on the fate of the large weekly market held on Sundays on roads abutting its boundary. Many open spaces and derelict government quarters were earlier used by artisans for making terracotta idols of

Fig. 7 Large scale effigy making and sales on roads

Fig. 8 Living space, storage, and work space of a quilt maker on the edge of the street

Fig. 9 Potters' wares along a main arterial road

varying scales during the festive season from *Ganesh Chaturthi* to *Ram Navami*, every year. With the demolition of these buildings for the construction of the Smart City ABD, these artisans have been evicted and are absent in the new planned area. There is a need to revisit the large scale of city building activity occurring under the various urban missions and attempt to mainstream the informal workplaces, to prevent such activities encroaching on roads, reducing their level of service and inconveniencing pedestrians and drivers on one hand, and also leading to sub-optimal living and working places for the informal sector.

5 Moving up the Liveability Ladder: Myth or Reality?

A sub-set of the household survey included a separate survey on housing aspirations and housing relocation plans. The respondents were asked their present occupations and their locations, the modes of transport and time and cost of transport from their present residence. They were then asked about their relocation plans and only those who responded in favour of relocating or aspiring to relocate were considered for

Fig. 10 Vending on foot carrying wares

Fig. 11 An innovative modular caravan of vending carts stringed to a single engine

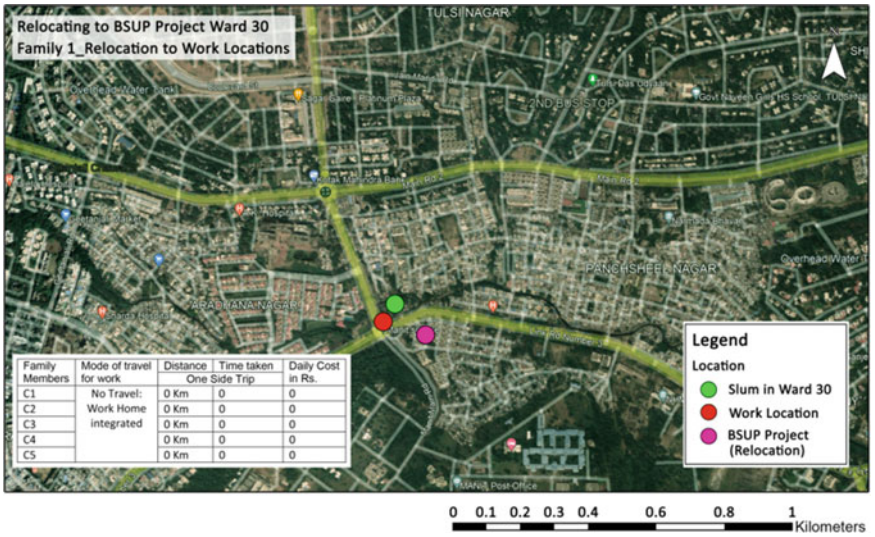
this segment of the study. A set of two maps were created for each family mapping the transportation routes of work to home, on satellite images, once from the current residence and once from the prospective relocated residence. A comparative table was made of travel costs in terms of money and time in both cases to evaluate the change in travel cost incurred due to change in location. Would relocating to the new house really change their lives for the better? A few cases are presented here.

5.1 Case of In-situ Rehabilitation

This family of 5 (Family 1) lives in a slum of potters in ward 30, within 5 km from the heart of the new town area. The entire family is engaged in the traditional occupation of clay and ceramic pottery. In this site, a large number of BSUP houses were constructed in-situ in place of a large slum which existed here. Inspite of being in the immediate vicinity of an in-situ redevelopment site, the potters continue to live in a slum along the steep banks of a '*nallah*' adjacent to a main road. As the relocation is in-situ, there are no changes in the cost of commute. However these potters work in their traditional houses and courtyards and sell their wares along the road. The new walk-up apartment housing typology has no provision for workspaces and thus is not suitable for the potters. While the in-situ location is acceptable, the apartment format is not acceptable as it is not conducive for their work. Relocating would mean either incurring extra costs to hire a work space or shift occupations. Thus the family continues to live in the shanty slum as it is 'designed' with their workspaces, and compromises on housing quality, hygiene and infrastructure (Figs. 12, 13).

5.2 Case of a Patta *Colony and Relocation Options*

The families 2, 3, and 4 surveyed are from a colony named Naya Gehukhera, on Kolar Road in Ward no. 81 in the southern periphery of the city. In this colony, *patta* land (500–600 plots of 15' × 30' dimension each) was given to relocated slum dwellers in 2002. Beneficiaries had the option of either choosing a vacant plot, or a plot with house consisting of a single room and toilet. The colony was provided electricity under the subsidized '*ek batti* scheme' but it was not serviced with water supply or sewerage lines. Concrete roads were made in 2017. Underground water supply and sewerage lines are presently being laid, but house connections are yet to be provided, even after 20 *years* from the formation of the *patta* colony. There is a severe water shortage with erratic supply of water by Municipal tankers while house septic tanks are the mode of sewerage disposal, which are rarely serviced, contributing to putrid overflows at times. The Municipal Corporation has mandated that all residents are required to pay a property tax of around Rs. 350 per annum from 2017 onwards, in order to get house connections of water supply and sewerage. The colony today is on prime land with a large Departmental Store abutting it and high



Family Members	Mode of travel for work	Distance One Side Trip	Time taken One Side Trip	Daily Cost in Rs.
C1	No Travel: Work Home integrated	0 Km	0	0
C2		0 Km	0	0
C3		0 Km	0	0
C4		0 Km	0	0
C5		0 Km	0	0

Fig. 12 In situ rehabilitation in a prime location. *Source* Google Earth Pro 7.3.3.7786 (64 bit). (October 19, 2020). Bhopal, Madhya Pradesh, India. 23°13′22.52″ N, 77°24′22.02″ E, Eye alt 2.37 km. http://google.com/earth/index.html . (Accessed Oct 26, 2021)

Fig. 13 Large scale pottery selling encroaching on roads at the edge of a relocation colony

end residential colonies in its vicinity. The houses have changed hands many times in the past 20 years and only 30% of original residents remain. Many are tenants while others have bought houses on resale.

Pilot Survey of Family 2: This is a family of 5 adult members residing in this colony since the past 15 years. The family has only one female, a mother of two adult working boys, living with her husband and father-in-law. She works as a domestic help and aspires to have a house primarily to escape the daily fights for water. With

the tankers coming at any time of the day, and all able bodied members going out to work, collecting and storing water is the biggest challenge. To fetch water, they travel 10 km to a main pumping station with bore wells and collect water in cans strapped to a bike or cycle every other day. Even after paying all dues of property tax since 2017, they are yet to get house connections of water and sewerage, as it is subject to all residents paying the dues. The '*ek batti* scheme' of subsidized electricity has been discontinued and electric bills in summer are often as high as two thousand rupees. With an average monthly household income of around thirty thousand rupees, commuting expenses itself are as high as five thousand rupees, but savings are done as much as possible in the hope of having a home better than their present one. The family was fortunate to be selected in the lottery for housing in an under construction project under the PMAY, even though the new apartment of 60 m^2 would not be adequate for the whole family. In their current house, the lack of built space is compensated with semi-covered outdoor spaces and an open yard with plants. The family is also apprehensive of increased recurring costs, as repayment of the housing loan through monthly installments would commence and the 7 storied building with stilted parking and two lifts, would have significant maintenance charges. In spite of these barriers, the family considered itself fortunate to have been selected for an apartment in a PMAY project within 5 km. of their current residence, within a fairly developed peripheral zone, as social networks would not be disrupted and transport costs would not change significantly. The family has paid the deposit of rupees fifty thousand from their savings, but their ordeal began when they tried accessing financial support through housing loans from banks. In spite of having a monthly family income of thirty thousand, which makes them eligible for the five lakh rupees loan they require, no banks are willing to lend, as they all work in the informal sector as a housemaid, a construction daily labour, a mobile repair shop assistant and a car driver. Agents are offering to help avail the loan charging anywhere between twenty thousand to forty thousand rupees. The family has no more savings to pay these agents and is considering surrendering their booked house in absence of access to credit facilities.

Some of their neighbours (family 4) had relocation options to government projects in much more remote locations, with sparse development at the edge of the city. Others (family 3) have bought plots subdivided from farmland at the periphery. Though these peripheral options are cheaper, the locations are beyond public transit routes increasing commuting time and cost significantly. Also in case of agricultural land transactions, risks are high of illegal subdivisions on non-developable land or low density lands.

The mapping of all three cases of possible relocation from this *patta* colony is done on satellite images showing the variation in travel distance to work locations in each case and the consequent implications on travel cost.

Family 2: Mapping and Travel Time and Cost Comparison table

The mapping of travel routes to work place from existing location and the new formal housing reveal the increase in transit costs. In this case, for a family with an income of Rs 30,000 an increase of Rs.250 can be borne. However reduced access to public transport impacts the mobility choice and subsequently the independence

of the woman in the family. In conclusion, this relocation would help the family in moving up the liveability ladder as the advantages of good quality housing, better environment and access to physical and social infrastructure outweigh the costs of loan repayment and increase in transit costs. The severe problem of water scarcity faced in their current location which was a major hindrance to the well being of the family, will also be addressed. But all this would be possible after crossing the hurdle of access to financial assistance (Figs. 14, 15 and Table 1).

Family 3: Mapping of Travel Time and Cost Comparison table

A similar mapping was conducted, and the comparison of transit distance and costs of Family 3 reveals that the relocation would cost the family Rs. 120 per day, translating to Rs. 3000 per month. With a family of two working members earning around Rs. 25,000 per month, this increase in cost would not be viable, with no access to buses for 8 km. Also as the family has bought a land and not a house, the cost of construction of the house would be a major burden, with home loans difficult to obtain in such privately developed layouts due to lack of credibility of the project. The access to drinking water and sewerage would be dependent on the collective contribution of all

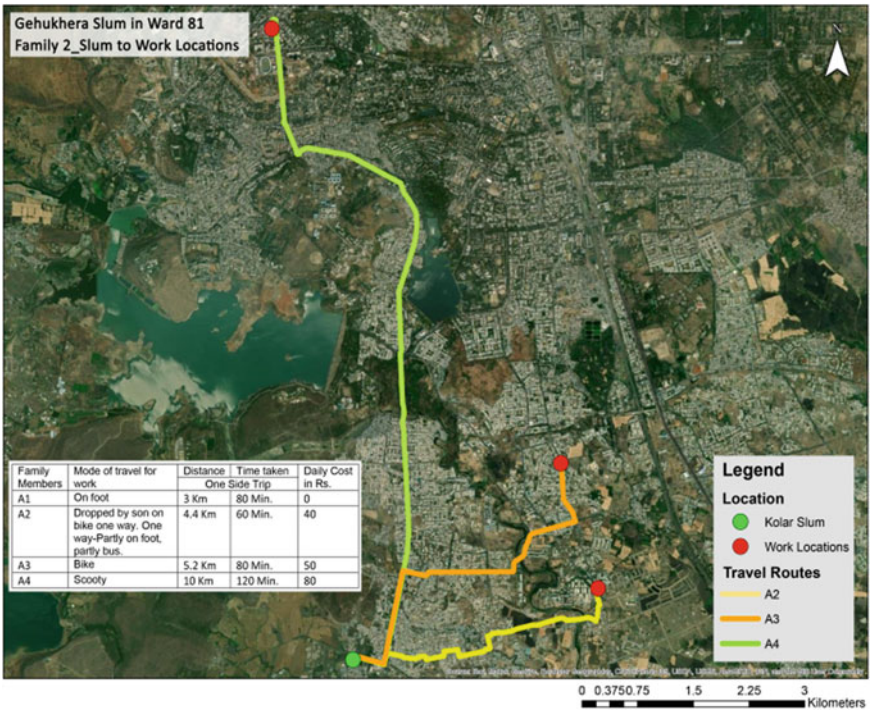


Fig. 14 Location map of current location of Family 2; *Source* Google Earth Pro 7.3.3.7786 (64 bit). (October 13, 2020). Bhopal, Madhya Pradesh, India. 23°09′41.57″ N, 77°24′36.96″ E, Eye alt 5.25 km. http://google.com/earth/index.html (Accessed July 30, 2021)

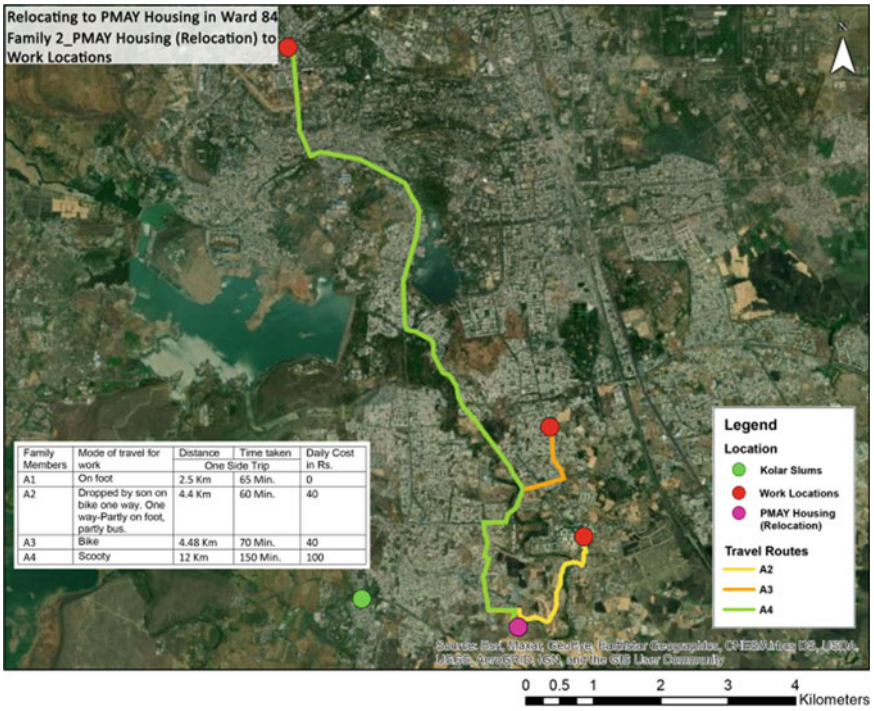


Fig. 15 Location map of relocation of Family 2; source: Google Earth Pro 7.3.3.7786 (64 bit). (October 13, 2020). Bhopal, Madhya Pradesh, India. 23°09′26.06″N, 77°25′56.82″E, Eye alt 15.09 km. http://google.com/earth/index.html (Accessed July 30, 2021)

Table 1 Comparison of travel characteristics of current and relocation sites of Family 2

Family members	Distance to workplace (one side trip)		Time taken (one side trip)		Daily cost in Rs	
	Original	Relocation	Original	Relocation	Original	Relocation
A1	3 km	2.5 km	80 Min	65 Min	0	0
A2	4.4 km	4.4 km	60 Min	60 Min	40	40
A3	5.2 km	4.48 km	80 Min	70 Min	50	40
A4	10 km	12 km	120 Min	150 Min	80	100
			Total Daily cost (Rs)		170	180

source: author generated

the residents in the layout and remain uncertain. Thus although the cost of purchasing plot is comparatively lesser, in the long run, it is unlikely that this relocation would result in uplifting their financial condition or improve their quality of life (Table 2).

Table 2 Comparison of travel characteristics of current and relocation sites of Family 3

Family members	Distance to workplace (one side trip)		Time taken (one side trip)		Daily cost in Rs	
	Original	Relocation	Original	Relocation	Original	Relocation
B1	0 km	0 km	0	0	0	0
B2	4.5 km	12 km	25 Min	65 Min	40	100
B3	4 km	12.5 km	25 Min	80 Min	30	90
B4	0 km	0 km	0	0	0	0
B5	0 km	0 km	0	0	0	0
			Total daily travel cost (Rs)		70	190

source: author generated

Family 4: Mapping and Comparison of travel Time and Cost

The Mapping of Family 4 revealed that Family 4 consisting of four working members had booked a government walk-up apartment housing of 4 floors in the periphery, built by Bhopal Development Authority in 2016. The relocation would have meant a daily increase of Rs. 90 in commuting costs which translates to an amount of Rs. 2,250 per month. With a family income of around Rs. 45,000 per month the expense would be possible to be borne. But the relocation posed other problems. One of the members is a school van driver and does shuttle trips at other times for local passengers in the busy catchment of his current location, while another earner is an electrician going across town and travelling upto 100 km in a day. Thus a remote location takes these earning members away from a dense catchment, reducing their work opportunities. Also one of the members is a child who goes to a government school near their current residence. In the new area there are no government primary schools so the child would have to give up studying. The BDA housing faces water shortage in summer and residents on upper floors struggle to carry water up to their residences and store it in the small dwelling units. Thus this relocation to a formal housing would impact the family's financial and social well being negatively. Hence the family chose to surrender their housing, get a refund of the booking amount, and continue to remain in the *patta* colony (Table 3).

6 The 'Shifting Boundaries' Revisited

The pilot study analysed several sites and the relocation options in the Southern part of the city, some of which are marked in the map shown in Fig. 15. It was seen that in most cases the residents of the slums and informal settlements chose these locations from compulsion but aspire for better housing and living conditions, serviced by physical infrastructure and accessible to social amenities. However on

Table 3 Comparison of travel characteristics of current and relocation sites of Family 4

Family members	Distance to workplace (one side trip)		Time taken (One Side Trip)		Daily Cost in Rs	
	Original	Relocation	Original	Relocation	Original	Relocation
D1	4.5 km	12 km	25 Min	50 Min	40	100
D2	100 km	100 km	300 Min	300 Min	750	750
D3	20 km	25 km	120 Min	150 Min	110	140
D4	0 km	0 km	0	0	0	0
D5	0 km	0 km	0	0	0	0
D6	1 km	1 km	15 Min	15 Min	0	0

source: author generated

the supply side, most of the mass housing projects are built progressively further away in the periphery, where cheap land banks are available, with limited amenities in the vicinity and unserviced by public transport connecting to the core of the city. The PMAY programme has advocated the solutions of rehousing slum households though in-situ or ex-situ rehabilitation, in tenable and non-tenable slum locations respectively, through the two components of In Situ slum Rehabilitation (ISSR) and Affordable housing in Partnership (AHP). The ISSR has drawn strong criticism from early days, as it is seen as a surrogate opportunity to benefit the private builders and make well located land available for occupation by higher income groups, under the garb of slum rehabilitation (Patel 2016). Only those slums are taken up for redevelopment under the ISSR, which are in prime locations, on tenable land and have the possibility of constructing a sizeable amount of 'for sale' component beyond the rehabilitated 'not for profit' slum housing. In case of slums not fulfilling any one of the criteria, they are left undeveloped. As location preferences dictate the success of the ISSR component, not all slums are found to be viable at the same time. Thus slums on non-prime emerging locations remain undeveloped for long periods, serving the underlying agenda of 'reserving' them for ISSR projects in later years, when land values reach the required threshold (Mitra 2021). One of the pilot surveys validates this tendency. On the other hand, AHP projects are built on government land banks, which are usually on the urban periphery with lower land prices as correlated from maps in Figs. 5 and 16. The land banks within the city are reserved for higher priced residential or commercial uses to leverage on the value of land. Post liberalisation of India's economy, the inordinate focus on profits has propelled urban governments to act as brokers rather than providers, with an imperative to monetise on public and urban land rather than regulate against market failure and exclusions (Bhan et al. 2014). The price of land is the single factor determining location of housing typologies for different income groups, and by the laws governing land markets, the urban poor are supplied housing on cheapest land, which is obviously at the periphery and only semi-serviced. While the buildings constituting formal housing may be serviced with physical infrastructure, they stand tall as islands amid vacant agricultural lands, with no amenities for miles around, and no public transport

Fig. 16 Location map of 3 pilot slums and possible relocation sites; *Source*: Google Earth Pro 7.3.3.7786 (64 bit). (October 19, 2020). Bhopal, Madhya Pradesh, India. 23°11′06.12″N, 77°26′04.09″E, Eye alt 18.21 km. http://google.com/earth/index.html (Accessed Oct 26, 2021)

connecting them to the city. Thus the urban poor households are perpetually left negotiating the 'shifting boundary'—sometimes physical, pushing them out of the liveable limits of the city and sometimes financial, pushing them out of the affordable limits of formal liveable housing. This process continues over time and the housing needs of the urban poor are met through the slums and un-serviced colonies from which they can seldom move out.

7 Addressing the Missing Links

All the past and present programmes on 'housing for all' have progressively contributed more to the stock in the bottom segment, but the methodology of determining the spatial distribution of these projects have always followed the supply side dynamics of land and infrastructure. The demand side dynamics of access to livelihoods, access to social amenities external to the projects, access to entertainment facilities have never been considered or planned while implementation of these housing projects. The first step towards this would require extensive surveys similar to the ones carried out in this pilot study to survey and spatially map the households' travel patterns and modes and compute travel costs in time and money as a ratio of their total income. The type job and the support needed to transport not only the people but also goods of varying weights, sizes, material also needs to be documented. Household trip surveys are an essential starting point in understanding

the complexities of catering to the transport needs of the urban poor in different contexts. The housing project locations, type of mass transit units and the typology of housing supply need to address these concerns if the city authorities would seriously want to realize the vision of a 'slum free city'. This study asserts that the need for detailed inventorisation of the city's informal sector and the types of jobs they undertake is a priority which should precede any vending or housing policy or other spatial intervention made for them so that the intended beneficiaries are truly benefitted. This type of study is context-specific and will differ not only with size and scale of city but also with specific geo-climatic and geographical settings. Thus this has to be integrated with city development initiatives and implemented by the ULBs. Only through building large data bases of the informal sector can patterns emerge which will lead towards appropriate solutions. The recently released recommendations of the 15th Finance Commission, increased the Central grants to urban and rural local bodies by 52%, and a gradual increase in the allocation of urban local bodies from 33 to 35% by the target year of 2025–26. As a fall out of the pandemic, a significant allocation has also been made to improve healthcare facilities at the local level (Lahiri 2021). As a follow up of this, the mission AMRUT 2.0 has been launched covering all statutory towns in India, unlike the limited reach in the previous version. The new programme of *e-shram*, facilitating the registration of all occupations- formal and informal, of urban residents, with the ULB's is a step in the right direction. There is a need to leverage on such central programmes with large financial allocations, by developing correct implementation strategies and mechanisms on ground to ensure a more equitable distribution of land and resources for all sections of society. As the problems of livelihood, mobility and housing are inter-related for all urban residents, but disproportionately more so for the urban poor, missions and schemes need to address all three links comprehensively and not in silos, administered by different Ministries, as is the present case. It is time that social inclusion is considered and accepted as a non-negotiable layer in the planning process, and all interventions from policy level to implementation are structured accordingly.

References

Bannerjee B (2002) Security of tenure in Indian cities. In: Durand-Lasserve AR, Royston L (eds) Holding their ground. Earthscan, London, pp 37–58

Batra L (2009) A review of urbanisation and urban policy in post independent India. Centre for the Study of Law and Governance Jawaharlal Nehru Univeristy, New Delhi

Bhan G, Anand G, Arakali A, Deb A, Harish S (2014) Urban housing and exclusion. In: C. F. Studies (eds) India exclusion report 2013–14. Books for Change, pp 77–108

Bhatnagar K (1996). Extension of security of tenure to urban slum population in India: status and trends. *Shelter* 22–28

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

Directorate of Town and Country Planning, Madhya Pradesh (2019) Bhopal development plan 2031 (volume 1 Draft). Directorate of Town and Country Planning, Madhya Pradesh, Bhopal

Dwivedi RM (2007) Urban development and housing in India:1947–2007. New Century Publications, New Delhi

UN Habitat (2018) Prosperity for all. UN Habitat, Nairobi
Hingorani P (2012) Revisiting low income housing: a review of policies and perspectives. Indian Institute of Human Settlements, Bangalore
Indian Institute of Human Settlements (2012) Urban India 2011. Indian Institute of Human Settlements, Bangalore
Joshi R (2009) Integrated townships as a policy response to changing supply and demand dynamics of urban growth. India Infrastructure Report, India
Khan S (2014) The other JNNURM: what does it mean for Small Towns. Centre for Policy Research
Knight Frank Research (2020) India infrastructure report 2020. Knight Frank India Pvt. Ltd., Mumbai
Lahiri AK (2021) Building from below. The Indian Express
Ministry of Housing and Urban Affairs (2019) Urban transformation through housing for all—1 crore and more. Ministry of Housing and Urban Affairs, Government of India, New Delhi
Mitra S (2021) Policy-implementation dynamics of national housing programmes in India—evidence from Madhya Pradesh. Int J Housing Policy
Neuwirth R (2005) Shadow cities: a billion suatters, a new urban world. Routledge, New York
Office of the Registrar General and Census Commissioner, India (2011) Primary census abstract data tables—Madhya Pradesh. Retrieved April 7, 2019, from censusindia.gov.in: https://censusindia.gov.in/pca/pcadata/Houselisting-housing-MP.html
Patel SB (2016) Housing for All by 2022: Assignment Delivered, Accountability Nil. Econ Polit Wkly LI(10):38–42
Revi A, Rosenzweig C (2013) The urban opportunity: enabling transformative and sustainable development. SDSN, New York
School of Planning and Architecture Bhopal (2021) Assessment of BDP 2031 (Draft) using city scale PAT. UN Habitat, New Delhi
Turner JF, Fichter R (ed) (1972) Freedom to build: dwelling control of the housing process. MacMillan Publishing Company, New York
United Nations Human Settlements Programme (2003) The challenges of slums—global report on human settlements 2003. Earthscan Publications Ltd., London
YASHADA (2009) Best practices in the financial management of urban local bodies of India. The Ministry of Housing & Urban Poverty Alleviation, Government of India, New Delhi

Chapter 3
The Pattern of Gentrification in a Knowledge Economy: The Case of Bengaluru, India

Arindam Biswas, Sukanya Koner, and Jayant Singh

1 Introduction

Changing global order towards knowledge driven development has direct impact on the geographical connotations of cities (Cappellin 2007; Penco 2013). Today's knowledge clusters, example, "Silicon Valley" in San Jose, California (Saxenian 1983) and "BioRN" in Heidelberg, Germany (Krauss and Stahlecker 2001) draw attention to the sprawling urban formations and processes that transform intermediate settlement space (Isaksen 2006). Post Fordism, the neoliberal agendas facilitated economic transition towards knowledge economies based on technological innovations (Asian Development Bank 2007). Many scholars consider regional economy as geographical and economic base for production and, as a result, act as new gateways to generate new economic activities, commodities and services, jobs, and revenue streams (Den Hertog et al. 2001; Feldman et al. 2005; Florida 2003). In fact, geographic concentration of knowledge industries and associated institutions with strong government's strategic policy choices (Hariharan and Biswas 2020a, b) reinforces knowledge cities to become global magnets for foreign investments and human capital (Porter 2000).

Transition from traditional industrial district to innovative milieu, mainly due to technological advantages, is responsible for the changing spatial and social configurations of the region (Maillat 1998). Innovative milieu is a spatial set identified by

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P. Banerji and A. Jana (eds.), *Advances in Urban Design and Engineering*, Design Science and Innovation, https://doi.org/10.1007/978-981-19-0412-7_3

a technical culture with innovative process and optimum location factors (skilled labour, research centres, airport, pleasant climate etc.) (Maillat 1995) Knowledge cities are hubs of such innovative milieus where interactions between interdependent firms and institutions promotes spatial proximity and high-level competitiveness (Trippl and Bergman 2014; Tallmann et al. 2004). They assimilate large pool of skilled labour, local entrepreneurship and globalised markets creating industry-institution-human capital nexus (Florida 2002; Ergazakis et al. 2006). The notion of these socio-economic networks mainly explains the stimulated flow of diversity and cross-fertilised ideas to build new business opportunities deteriorating the old dynamics of a society, termed as "creative destruction" (Schumpeter 1947).

Therefore, knowledge-based economy is highly criticised for creating spatial segregation and socio-economic polarisation in the urban milieu (Autor et al. 2003; Edlund et al. 2015; Stehlin 2015). The influx of inhabitants to the low-income neighbourhoods due to the employment opportunities (Kennedy and Leonard 2001), post-secondary institutions (Moos et al. 2018), government's investments supporting middle and upper class (Morisson and Bevilacqua 2019) accelerates gentrification processes. Movement of knowledge workers into the city transforms the urban neighbourhoods by communities' and accelerates cultural displacement with skyrocketing economic heft in housing and mobility costs (Richardson et al. 2019).

Bengaluru has been recognised as a knowledge city (Hariharan and Biswas 2020a, b), global outsourcing city (Sengupta 2010) and global hub of tech start-ups (Subrahmanya 2017). The decennial data of migration reveals a 141% increment in in-migration due to work or employment in Bengaluru (Census of India 2011). Moreover, the upsurge of 117% in knowledge workers during the same period (2001–2011) to the present count of over a million workers in the city (Hariharan and Biswas 2020a, b), acknowledges the inflow of diverse human capital transforming socio-economic structure of city's neighbourhoods.

The chapter aims to explore how the rapid urban growth in Bengaluru has influenced the pattern of gentrification. The study is based on a hypothesis that the emergence of knowledge-based industries in Bengaluru is the prime reason behind its accelerated urban growth. The objectives of this research are

i. To assess the temporal growth of Bengaluru urban district;
ii. To understand the dynamics of knowledge economy in Bengaluru; and
iii. To identify the patterns of gentrification in Bengaluru.

This book chapter consists of eight sections. Following the 'Introduction', Sect. 2 focuses on "knowledge economy, urban transformation and gentrification" by reviewing the contextual literature that offers the formation of a knowledge city and examines the relationship between the knowledge economy and different facets of urbanism. It also elucidates the concept of gentrification and its different forms to understand the shift in the demographic, socio-economic, and cultural fabric of neighbourhoods. Section 3 discusses "Urban growth in Bengaluru" by reviewing the Bengaluru Urban District (BUD) and emphasises the decadal spatial analysis of urban growth in BUD. Section 4 comprehends the "Industrial restructuring and Urban Transformation in Bengaluru" through regional socio-economic profile for a deep

understanding of the conducive ecosystem of the knowledge economy in Bengaluru. Section 5 details out the research methodology. Both qualitative and quantitative methods are applied in this research. Section 6 analyses the patterns of gentrification within the neighbourhoods of BUD using the patch-based Landscape Expansion Index. The section discusses the findings by explaining the extent of different types of gentrifications based on the classification of three urban growth patterns. The "Conclusion" in Sect. 7 elucidates the conceptualisation of the research. It reflects various insights gained by the novel pattern identification process for gentrification in a knowledge city.

2 Knowledge Economy, Urban Transformation, and Gentrification

The paradigm shift from "agriculture to knowledge" (Drucker 1992), the process of deindustrialisation (Penco 2013) and technology based information density (Raspe and Oort 2006) has developed the production processes creating "knowledge cities" (Carrillo 2011). The decline in natural resource driven economy, represented as global agriculture raw material exports in Fig. 1, with an upsurge in the knowledge-intensive economic activities reveals the transition in global pattern of economic growth. Figure 2 demonstrates the upscale production in "Information Technology" (IT) service in four major economies of the world. Thus, wealth creation through application of human knowledge and creativity is steadily outpacing wealth creation through extraction and processing of natural resources.

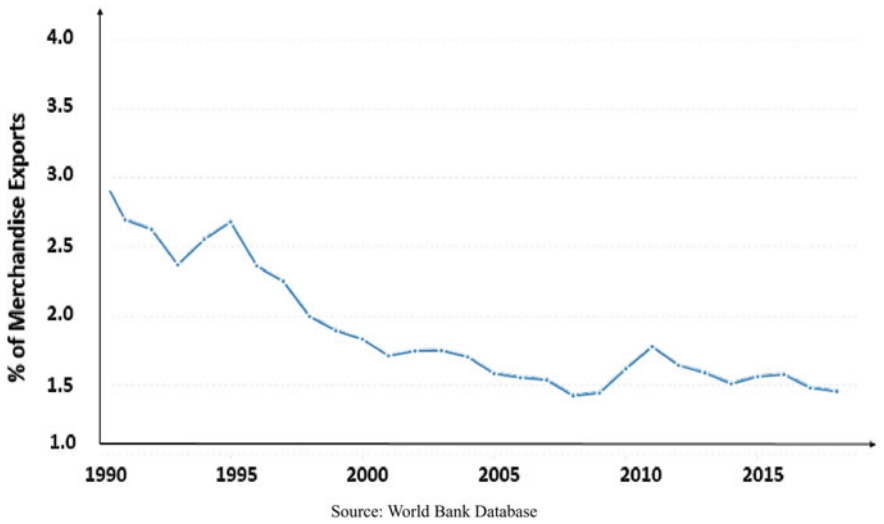
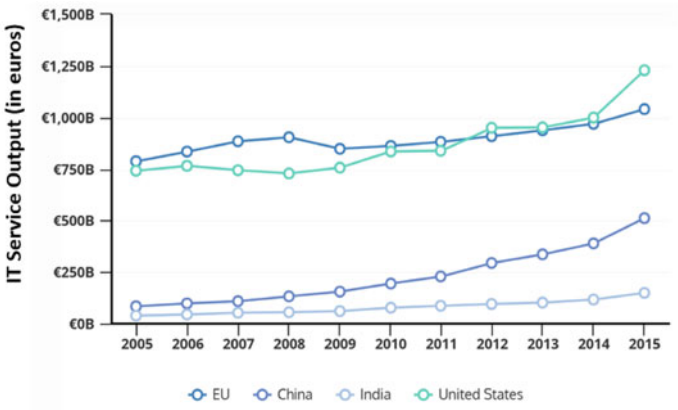


Fig. 1 Timeline for global agricultural raw materials exports



Source: Brookings Institutions, Joint Research Center and European Commission and Communications Networks, Content and Technology.

Fig. 2 IT sector production in 4 economies

The knowledge based economic development model was first introduced by Machlup and Drucker but surfaced in late 1990s as a "new growth theory" with knowledge as the key driver of productivity (OECD 1996). Four pillars of knowledge economy have been identified (Asian Development Bank 2007; World Bank 2007; ODI 2009). Firstly, an institutional regime that incentivises the knowledge creation and dissemination with policy based regulatory environment. Secondly, thriving educated and skilled workforce as human capital for effective knowledge creation. Thirdly, a vibrant innovation system of government, academia, private sector and civil society, which can channelize the global knowledge into products valued by local needs as well as the markets. Lastly, a dynamic information infrastructure that facilitates efficient flow and access to information and technology.

The contemporary research discussion raises fundamental concerns about conceptualisation and interpretation of functional urban hierarchy (Luthi et al. 2012). There is a need to examine at the interconnection of knowledge-intensive economic activities at various geographic scales, particularly, due to morphing of cities into networks of clusters, characterised by a new functional division of labour providing immense economic strength (Hall and Pain 2006; Hoyler 2011). Formation of knowledge clusters is the result of a spatial upscaling of agglomeration economies and a spatial concentration of global network of knowledge-based economies (Raspe and Oort 2006; Davoudi 2003). These are primarily driven by continual innovation enhancing productivity due to competitive advantages and fuelled by the supply and demand for high-quality urban attributes (Porter 1998; Oort 2003). On the supply side, advancements in transportation and telecommunication technology are propelling the growth of urban environments. On the demand side, spatial requirements of knowledge-intensive industries drive the concentration of global network economies in large-scale metropolitan environments. High-quality infrastructures, such as academic

institutions, large settlements of leading global companies, proximity to international gateway infrastructures like airports or high-speed train nodes, as well as the availability of specialised knowledge, the presence of competitors, business partners, and customers, are all important to knowledge-intensive firms (Porter 1990). The interaction of these forces produces a highly strategic location-based Knowledge city-region, reinforcing socio-economic transformations on a new spatial scale.

The concept of a "knowledge city" is still in its nascent stage but there are several complementary perspectives to explain the formation of a knowledge city, such as urban capital systems (Carrillo 2004), regional intellectual capital (Bounfour and Edivinsson 2006), and Information Technology (IT) (Komninos 2002). Another interesting concept of integrating people, places, processes and purposes determined by "knowledge moments" that triggers, and enables the formation of a knowledge city (Dvir 2005). A "knowledge moment" is a planned or spontaneous human interaction in which knowledge is discovered, created, nourished, exchanged, and transformed into an intellectual material that any institution can use to create value (Dvir 2005). Multitude of escalated "knowledge moments" spurs the city-region into a "space of flows" highlighting the paramount role of knowledge intensive industries in shaping the urban growth of the city (Castells 1989). Such growth with high economic performance that concentrate wealth germinates social inequality (Glaeser et al. 2009) and stimulates urban transformations, both structural and spatial (Mattar et al. 2014). The structural transformations are propelled by the pool of specialised human capital, easy flow of technological externalities or knowledge spill-overs, increased access to global markets and conducive policy based regulatory environment (Krugman 1991; Spencer et al. 2010). However, spatial transformations intricate multi-scalar changes in urban morphologies due to reasonable urban services and high quality of living standards escalating cosmopolitan urbanism (Penco 2013; Moos et al. 2018). Figures 3 and 4 explain the formation of a knowledge city and associated urban transformations in the knowledge city, respectively.

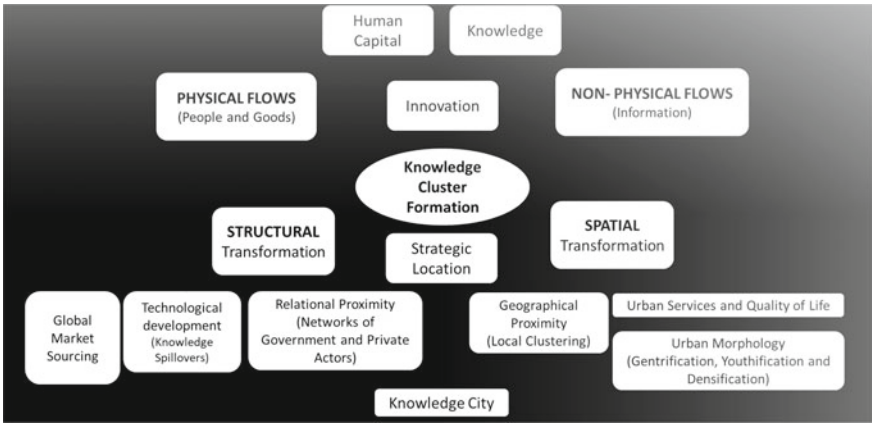


Fig. 3 Formation of a knowledge city

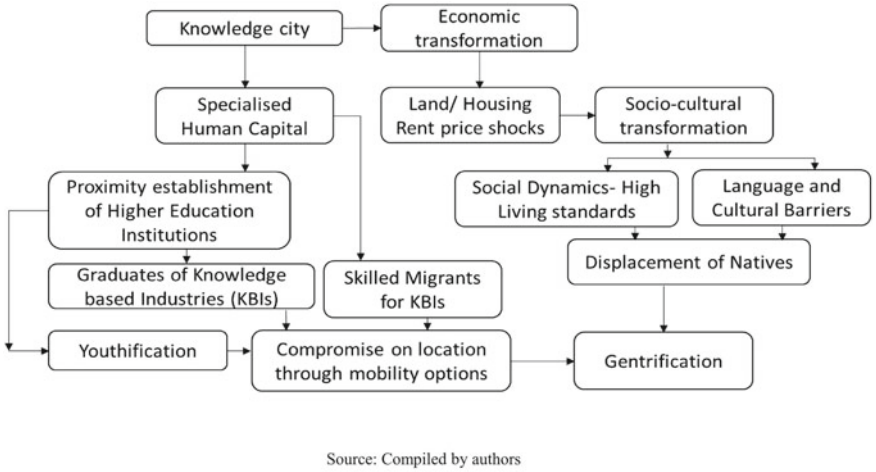


Fig. 4 Economic and socio-cultural transformations in a knowledge city

Cities also highlight the importance of real estate development enterprises in meeting the high demand for urban transformations as a place-based strategy to promote the knowledge economy (Bevilacqua et al. 2017). Knowledge based industries price out city's neighbourhood character due to shocks of rising rent and cost of living. This leads to compromise on location through mobility options, social character transition of natives and conflict in social dynamics for living conditions. The incoming of the knowledgeable workforce and skilled migrants to accommodate as urban milieu automatically creates pressure on the well-functioning neighbourhoods through socio-economic restructuring of its character. The problem exacerbates with influx of new educational institutions that leads to "youthification" and further distorting the housing and rental markets (Moos et al. 2018). The knowledge-based development strategies accelerate the cognitive distances between different socio-economic groups in city regions, leaving negative externalities of gentrification as the outcome of development process. The negative impact of gentrifications assorts from 'displacement' to destruction of community due to the increased sparseness on housing availability and higher rents (Morisson and Bevilacqua 2019).

The concept of gentrification was first identified by Ruth Glass in 1964, as the transformation in housing pattern and ownership, changing the physical and socio-economic urban environments (Glass 1964; Seo 2002; McKinnish et al. 2010; Meltzar and Ghorbani 2017; Atuesta and Hewings 2019; Cho et al. 2020). This is a "classical gentrification" where middle class rehabilitates in city's neighbourhood displacing working class or indigenous communities (Lees 1994; Kosta 2019). Many researchers have focussed on the cause of this phenomenon in cities like New York City, San Francisco, Baltimore, Chicago, Washington D.C. etc. (London and Palen 1984; Cohen 1983; Smith 1996; Richardson et al. 2019). The rent-gap theory, which is based on the principles of the potential land value and capitalised land value, was

used by Smith to describe the cause of gentrification (Smith 1996). The term "potential land value" refers to the value of land that can be realised when it is used to its full potential. The capitalised land value is the value of the land's present use (Smith 1996). Smith claimed that, while the capitalised land value is low in older neighbourhoods, the potential land value increases with the prospect of redevelopment for profit maximisation. Thus, gentrification occurs because of the disparity between the two divergent land values. Researchers like Ley and Moos argued that the change in the workforce to young professionals increased the city's socio-cultural activities and fostered gentrification as there was a paradigm shift from manufacturing industries to knowledge industries (Ley 1986; Moos et al. 2018).

The definition of gentrification has evolved from Ruth Glass's conventional definition to a myriad of other definitions, such as rural gentrification and new-build gentrification (Lees et al. 2008). Gentrification can also be defined as "the transformation of a working-class or unoccupied core city neighbourhood into middle-class residential and/or commercial use" (Lees et al. 2008). For example, the city of San Francisco entailed a political-economic reconfiguration to adjust the urban environment to the knowledge economy's new demands. Direct displacement, indirect displacement, exclusionary displacement, displacement pressure, and social exclusion are all kinds of displacement identified due to the gentrification process (Morisson and Bevilacqua 2019). Different forms of gentrification based on their mechanism are synthesised from various literature and listed in Table 1.

3 Urban Growth in Bengaluru

Erstwhile Bangalore, and present Bengaluru, with an average economic growth rate of 8.5%, is one of the world's top ten fastest growing cities (Srinivas 1997; Paul et al. 2018). It grew out of a tiny settlement founded by a chieftain of Yelahanka Nada Prabhu dynasty named Kempe Gowda in 1537 A.D. (Kamath 1990; Nagendra et al. 2014). Bengaluru grew from a small 18-square-kilometer town to 737-square-kilometer metropolis in 2016, and it is continuously expanding (Annaswamy 2003; Bengaluru Development Authority 2017). Bengaluru is India's fifth largest urban agglomeration (Registrar General and Census Commissioner of India 2011). It is known as a high-tech industry centre and the home of India's highest number of IT firms and thus earning the designation of "India's Silicon Valley" (Britton 2017). The increasing worldwide recognition as the most dynamic city has made Bengaluru home to citizens from every state and diverse nationalities (Kelly 2017).

India is a popular Global Capability Center (GCC) location, with 25–30% of Fortune 500 companies establishing GCCs in the country (Pabari et al. 2021). Bengaluru is India's leading GCC destination, accommodating 34% of India's GCCs. Bengaluru accommodates 33% of India's tech expertise. Almost 44% of the migrants moving to the city have tech skills, compared to only 12% in Delhi and 11% in Mumbai (Dharma et al. 2020). The ratio of engineering colleges to the population

Table 1 Types of contemporary gentrification

Type of gentrification	Definition	Features
New-build gentrification	The process of demolition/reconstruction activities, as well as new developments of infill housing or corporate developments (Davidson and Loretta 2005; Rerat et al. 2010)	• Reinvestment in capital • Social upgrading of neighbourhood by higher income groups • Occurs near or within existing communities, a higher potential for conflict between long-term residents and newcomers • Direct or indirect displacement of low-income groups • Landscape change
Retail upscaling	The process that changes area's retail composition by 'boutiquing' of streetscapes (Zukin et al. 2009) and supermarkets that appeal to high income group consumers (Sullivan 2014)	• Development of selective product-based consumerism • Inequitable distribution to retail access due to high prices • Unable to serve low-income residents
Tourism gentrification	The phenomenon of changing area's historical ethnicity by commercialising ethnic cultures to promote tourism-based consumerism (Gotham 2005; Hackworth and Rekers 2005; Burnett 2014)	• Use of business improvement techniques to package ethnicity of neighbourhoods • Escalated housing prices due to changes in residential and commercial real estate • Transition in focus from ethnic population to tourist population, creating a sense of exclusion and alienation in ethnic residents
Peripheral gentrification	Process of gentrification promoting restructured housing on the peripheral locations (Uitermark and Duyvendak 2007; Bridge et al. 2012)	• Affluent social housing in a low-income neighbourhood • Increased population density due to multi-storeyed buildings • Varying socio-economic mix of residents
Transit oriented gentrification	The gentrification aided by the characteristics of transit proximate neighbourhoods (Ong et al. 2014; Chapple et al. 2017)	• Changes in employment profile of the neighbourhood due to accessibility • Increase in commercial and residential property values • High risks to pedestrians and bicyclists as these areas attract major vehicular traffic
Residential-commercial gentrification	The phenomenon of conversion of residential housing to cafés, restaurants, big retail outlets, and apparel stores (Yoon and Park 2018; Cho et al. 2020)	• Mounted rent and property value • Transformation in composition of residents and character of place • Large chain stores may disrupt social bonds and cohesiveness • High competitiveness in the area

(continued)

in Bengaluru is five times that of Delhi and 1.7 times that of Mumbai (Accel Partners 2019). Bengaluru Innovation Report 2019 highlights that the state capital of Karnataka is India's most millennial-friendly city, with strong employability rates and even being the best choice for women, and 37% of the population belongs to the age group of 15–35 years (Accel Partners 2019). Bengaluru's comparative advantage

Table 1 (continued)

Type of gentrification	Definition	Features
Rural gentrification	The transformation of former agricultural areas and other greenfield into new developments and the "subsequent displacement" of working-class rural residents because of rising local land and housing process (Philips 1993; Hackworth and Rekers 2005)	• Change towards peri-urbanisation • Growth of "marginal gentrifiers" • Asymmetries in class positions of householders • Change in role of workforce and lifestyles

Source Compiled by authors

in India's IT industry stems from crucial determinants, including favourable government policies, a high-quality workforce, and the availability of research laboratories (Subrahmanya 2019). The report further emphasised that the city has recorded more tech start-ups establishment since 2016 than Delhi and Mumbai combined. It has about 800 colleges, with over 100 of them being engineering colleges. The Indian Institute of Science (IISc), Indian Institute of Management Bangalore (IIM-B) and other important academic institutions are also located here. Every year, these educational institutions produce more than 90,000 engineering graduates (The Hindu 2018).

The Bangalore Urban Agglomeration (BUA) has more than doubled its share in the urban population of Karnataka, rising from 17.66 to 35.96% during 1951 to 2011. Since 1951, the population of the Bangalore Urban Agglomeration (BUA) has expanded by 11 times, with a 4.05% Compound Annual Growth Rate (CAGR) (Sudhira et al. 2007). The population growth for BUD and BMR reflects this rise. According to a comparative analysis of 25 global cities, Bengaluru is on a fast-growth trajectory. Compared to cities in the United States, where urbanisation is constrained in the core, significant spatial expansion in Bengaluru is seen in the city periphery (Schneider and Woodcock 2008). It is transforming from a mononucleated to a polycentric growth pattern, with rapid growth occurring in multiple periphery areas (Shaw and Satish 2007; Taubenböck et al. 2009). The BMR's growth pattern is characterised by Bengaluru City as the urban core. Four growth events have contributed to Bengaluru's transformation from a town to a metropolis. Firstly, the State Capital was relocated to Bengaluru from Mysore after India's independence (Raman 1994). Secondly, integration of the Cantonment with the city in 1949 (Verma et al. 2017). Thirdly, establishment of major Public Sector Undertakings/Higher Education Institutions (Subrahmanya 2017; Manimala 2017); and fourthly, development of IT/ITES/Biotech based Knowledge industries (since 1980s) (Hariharan and Biswas 2020a, b). The continual flow of immigrants from surrounding areas and other regions to Bengaluru has resulted in the region's urban growth. According to Census 2001, almost half of the population (45%) was classified as immigrants (Bengaluru Development Authority 2005).

The Bengaluru Metropolitan Region (BMR) is composed of three districts in Karnataka's Bangalore Revenue Division: Bengaluru Urban District (BUD), Bengaluru Rural District (BUR), and Ramanagara. BMR is 8005 square kilometres

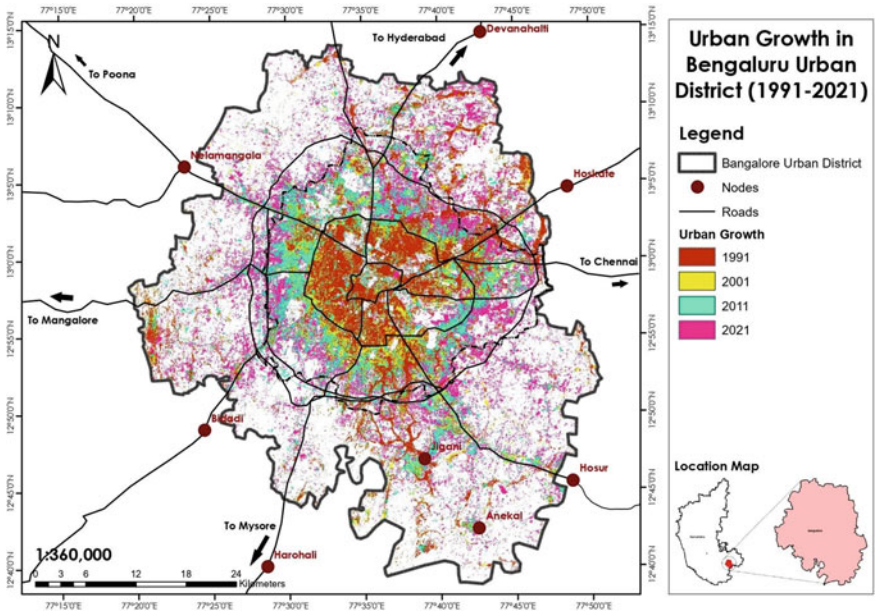


Fig. 5 Urban growth in Bengaluru urban district and major nodes in the area

in size (Bengaluru Development Authority 2017). The study area for the research is Bengaluru Urban District (BUD). Talukas in the BUD comprises North, South, East and Anekal. Figure 5 represents urban growth in BUD from 1991 to 2021. It has been analysed by assessing Remote Sensing (RS) data[1] in the geospatial software tool of ArcGIS. The method used for determining the urban growth is a pixel-based analysis using supervised classification. The total area of BUD is 2236 square kilometres. The urban area in BUD has significantly increased from 13.06 to 38.55%. The direction of growth is towards North-Eastern side in 2021, but it was towards South-Eastern side in 2001 and 2011. Figure 6 highlights all the satellite towns that have been engulfed by the core like Jigani, Kengerim Yeshwanthpur and Yelanhanka and even the small urban nodes have developed forming a radial network, including Anekal on Hosur Road, Bidadi & Ramanagara on Mysuru Road, Hoskote on Old Madras Road, Devenahlli on Bellary Road, Neelmangala and Dobaspete on Tumukuru Road (Sen 2013).

[1] Satellite images used for 1991 and 2001 are Landsat 5 (30 m), for 2011 and 2021 is Landsat 8 (30 m).

Fig. 6 Location of Bengaluru metropolitan area and satellite towns in the area

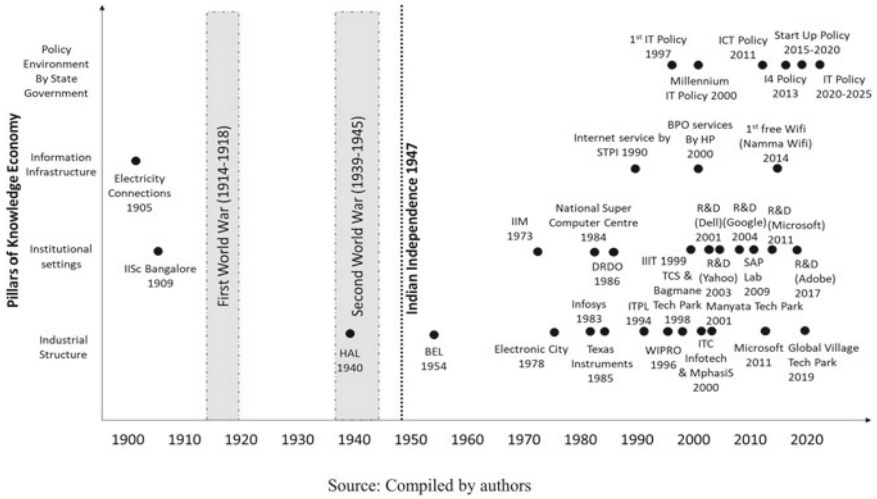
4 Industrial Restructuring and Urban Transformations in Bengaluru

Bengaluru has been recognised as the fastest growing urban regions within the country. The growth is attributed to the knowledge based industrial structure, an influx of specialised human resources, establishments of public sector companies and research and development (R&D) units (Subrahmanya 2017; Hariharan and Biswas 2020a, b). The network of "100 higher educational institutions" and conducive industrial environment promoting "small-scale and large-scale non-polluting industries" has favoured the city to become the hub of knowledge and innovation (Srinivas 1997; Manimala 2017).

Bengaluru's economy diversified from trading during the British period to Public Sector Undertaking (PSU) enabled manufacturing to the recent shift to IT/ITES industry. Bengaluru began as a trading centre from the Petta region in 1537, and in the 1800s, it developed after being designated as a British cantonment and administrative headquarters (Pani et al. 2010). Before 1940, the major industries contributing to Bengaluru's economic growth were Binny Mills, United Breweries, Tata Silk Farm (Basavangudi), Government Soap Factory (now Yeshwanthpur), Minerva Mills, Indian Tobacco Company (Cox Town) and Government Porcelain Factory (Bengaluru Development Authority 2017). The government extensively invested in big public sector enterprises such as Hindustan Machine Tools (HMT), Bharat Electronics Limited (BEL), Bharat Heavy Electricals Limited (BHEL) and Hindustan Aeronautics Limited (HAL) between 1940 and 1960 (Sen 2013). Rajajinagar and Dyavasandra industrial areas were established around the 1960s. Electronic City was founded in 1978 to encourage the development of electronic companies, and it has since grown one of the leading IT hubs in the world (Basant 2006).

Termed as the "Silicon Valley of India", Bengaluru metropolitan region has witnessed its regional development since the 1980s. The offshore development centre of Texas Instrument, established in 1985, strongly enabled the local software firms to serve as an IT interface between Indian knowledge and global technological developments (Plechero et al. 2020). Liberalisation strategies of the government for the knowledge-based sector in the 1990s increased the organisational network and capitalised on the growing outsourcing business from the West, especially Silicon Valley (Chatterji 2014). Globally, Bengaluru is among the most favoured knowledge cities and accommodates India's 40% IT based knowledge industries (Dezan Shira & Associates 2019). Population increased from 0.22 million in 1901 to 9.59 million in 2011 because of the evolution due to knowledge-based industries (KBIs) (Hariharan and Biswas 2020a, b). Immigration of skilled and unskilled labour into the industrial estates amplified the sectorial specialisation and thickened the multi-cultural environment (Sudhira et al. 2007). Nascent evolution of Bengaluru as the hub of an entrepreneurial ecosystem has embarked geographic concentration of human capital and many knowledge-based industries (Subrahmanya 2017). The elements involved in determining the formation of Bangalore as a Knowledge city is described in Fig. 7.

The economic development of Bengaluru as a knowledge city can be stated through its knowledge-based structures, the efficiency of institutions, the density of public and private organisations and the level of networks among these agents. The Bengaluru Urban District (BUD) accounts for the majority of Karnataka's "gross state domestic product" (GSDP). BUD alone contributed 1.73% to India's GDP and 34.36% to Karnataka's GSDP in 2014–2015 (Bengaluru Development Authority 2017). 14.97% of the employment share is dedicated to knowledge-based industries (KBIs). The areas with the highest concentrations of KBIs include Peenya, Whitefield, Electronic City, and areas of Bommasandra and Jigani (Bengaluru Development Authority 2017). The Electronic City in Bangalore is a key attraction that has prompted companies to congregate in the vicinity. Industries may be found throughout the entire stretch of NH-7 from Electronic City to Attibele and beyond, all the way to Hosur in Tamil Nadu. Manimala (2006) observes from the cluster



Source: Compiled by authors

Fig. 7 Elements of knowledge economy in Bengaluru

classification that the city's expansion may be segmented into four distinct periods of spatial development (Manimala 2006; Hariharan and Biswas 2020a, b). The four phases of spatial development of Bengaluru's knowledge city have been detailed out in Table 2.

Domestic start-ups and multinational corporations established offices in their own houses and commercial premises within the Central Business District (CBD) or surrounding locations, dependent on the firm's affordability during the first incubation period. The gradual shift of concentration of KBIs from CBDs towards the Electronic city situated on the Southern side of the city was witnessed in the Nucleation phase. The development of ITPL was one of the prime reasons for peripheral growth during the Y2K boom and dot com phase. Due to the low cost of real estate, many technology parks were established between the Electronic city and ITPL, which led to peripheral agglomeration. The establishment of the new international airport in 2008 shifted the direction of developmental activities of KBIs to the Northern direction of the city. IT/ITeS sector of KBIs accounts for 55% of the total demand of Bengaluru's real estate market and the average price increase in Bengaluru's residential areas. The approximate price increase is 23% from 2016 to 2020, which is greater than the average price growth in all other major cities, including Delhi NCR (18%), Mumbai (22%) and Pune (17%) (Ghosh and M 2020). The Southern side of Bengaluru includes Kanakapura, Bannergatta, Electronic city, Jigani, and Eastern area comprising Hoodi, Marathalli, Old Madras Road, Whitefield, Mahadevpura are most preferred by IT professionals (Sheikh et al. 2017).

The influx of huge human capital due to KBIs in new and old residential areas has resulted in various types of gentrifications. The present study has identified three types of gentrifications in the Eastern and Southern sides of the Bengaluru Urban District.

Table 2 Phases of spatial development of Bengaluru

Phase of development	Time period	Major events
Initial phase	1980–1991	• Establishment of Texas instrument in Bengaluru as the 1st MNC of India in 1985 (Kar 2016); • Central and regional governmental favourable liberalisation policies from 1991, for example, setting of Software Technology Park of India in Bengaluru in 1991 (Srinivas 1997; Saxenian 2001)
Nucleation phase	1991–1996	• High speed data connection links (Kumar 2014); • MNCs of US and Europe setting up their different units of operations in Bengaluru (Balasubramanyam and Balasubramanyam 2002); • Establishment of Information Technology Park Limited (ITPL) in Bengaluru through a collaboration between India and Singapore (YEOH and David 2005)
Y2K boom and dot com bust phase	1996–1999	• Growth of comprehensive gamut of services, especially outsourcing services offered by IT companies in Bengaluru across the world (Saini 2019)
Peripheral agglomeration phase I	2000 -2008	• Investment in infrastructural facilities like peripheral ring road boosted the growth of the high-tech knowledge-based development between Electronic city and ITPL (Kalra 2006)
Peripheral agglomeration phase II	2008 - Present	• Decongestion strategy through development of new international airport to mobilise the concentration of companies (Hariharan and Biswas 2020a, b)

Source Compiled by authors from (Hariharan and Biswas 2020a, b)

5 Research Methodology

The study takes the help of temporal and consequential policy evaluation methodology to build the foundation of the research (Haralambos et al. 2013). It follows an integrated approach of qualitative and quantitative methods. The qualitative method allows gathering in-depth insights through participant observation, literature reviews and experiencing social reality, whereas the quantitative method enables analysing spatial data (Brannen 1992; Duffy and Chenail 2011). These study areas/clusters are

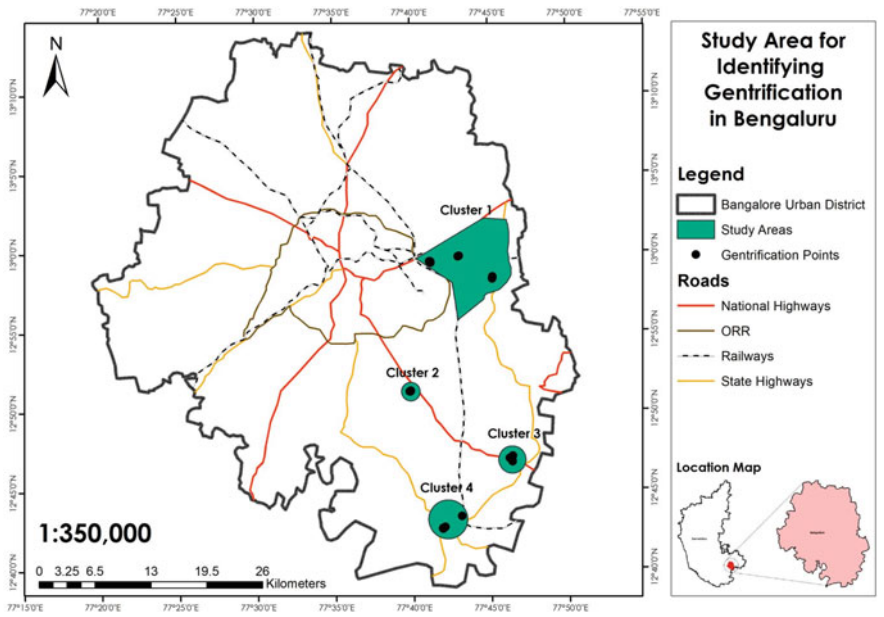


Fig. 8 Representation of Identified clusters in the study area

delineated based on three basic methods—reconnaissance survey, major transportation networks and direction of urban growth. Figure 8 exhibits these clusters in the BUD study area.

Many diverse fields, such as urban planning, landscape ecology, and urban modelling, have examined urban growth and development patterns extensively (Reis et al. 2015). Urban transformation such as gentrification can be described through analysing the spatial patterns of urban growth for a specific period (O'Sullivan 2002). The research uses pattern identification of different types of gentrifications through a patch based Cellular Automata model. Three patterns of gentrification are identified in the study area: new build, peripheral and rural. These patterns can be categorised according to their respective features, as mentioned in Table 1. New build gentrification is depicted by infilling type of pattern where new urban areas fill in the gaps between existing urban areas (Liu et al. 2010). The pattern of peripheral gentrification is demonstrated as an expansion of new urban areas towards the urban edge of existing urban areas as urban fringe development (Forman 1995; Liu, et al. 2012). Rural gentrification reflects the pattern of outlying character referring to minimum spatial connection with existing urban areas (Xu et al. 2007; Liu et al. 2010). The landuse/landcover data is procured from the USGS Earth explorer.[2] The temporal

[2] The United States Geological Survey (USGS) developed the EarthExplorer (EE) user interface, which allows users to search, browse, export metadata, and download data from satellite, aeroplane, and other remote sensing inventories online.

assessment of the remote sensing data for 2001, 2011 and 2021 are procured from the Landsat imageries.[3]

The major prospect of the study lies in the method of quantifying the pattern identification of urban growth. The study has adopted a patch-based method over a pixel-based method an many pixel-based analysis methods like Landuse-Landcover (LULC) classification examine each pixel's spectral characteristics of within a region of interest without taking into account any spatial or contextual information (Weih and Riggan 2010). The fast pace of urbanisation requires a method of analysis that can help identify the accurate pattern of urban growth (Lei et al. 2021). Many scholars have preferred patch-based analysis because of the growing number of clustered urban patches in a metropolitan area (Meentemeyer et al. 2013; Moghadam et al. 2018; Lei et al. 2021). A patch is a group of neighbouring cells representing a single land-use unit, but their attributes may differ (Wang and Marceau 2013). Landscape Expansion Index (LEI) has been utilised as a tool for patch-based analysis. It is critical to determine the neighbourhood rule that should be used to integrate pixels into patches. The study follows 8-cell neighbourhood or Moore neighbourhood rule that shares an edge or corner (Lei et al. 2021). LEI was proposed by Liu et al. (2010) where the classification process is based on the LEI in a buffer area around the new gentrified urban patches. The equation is as follows:

$$\mathrm{LEI} = 100 \times \mathrm{A}_0/(\mathrm{A}_0 + \mathrm{A}_v) \tag{1}$$

- LEI refers to Landscape Expansion Index of a new gentrified urban patch;
- A_0 is the intersection of existing urban patches and new gentrified urban patch's buffer area;
- A_v is the intersection of buffer area of the new gentrified patch and vacant land.

The following three rules have been followed for pattern identification of gentrified area.

(1) When LEI is larger than 50, the buffer zone of a new urban patch intersects with an existing urban patch; thus, the new urban patch is classified with the infilling property. This has been categorised as newly-build gentrification.
(2) When the LEI ranges between 0 and 50, the buffer zone of the new urban patch intersects with vacant land and the existing urban patch. This intersecting pattern signifies the characteristics of an urban area's expansion and is categorised as peripheral gentrification.
(3) When the value of LEI equals to 0, the buffer zone of a new urban patch is only composed of vacant lands. In this case, the vacant land is assumed as agricultural land. The new urban patch is determined to have an outlying property and is categorised as rural gentrification.

Figure 9 visualises types of gentrification patterns identified in the study area as per the LEI-8 neighbourhood cell method. The study has deployed the "LEI tool"

[3] Satellite images used for 2001 is Landsat 5 (30 m), for 2011 and 2021 is Landsat 8 (30 m).

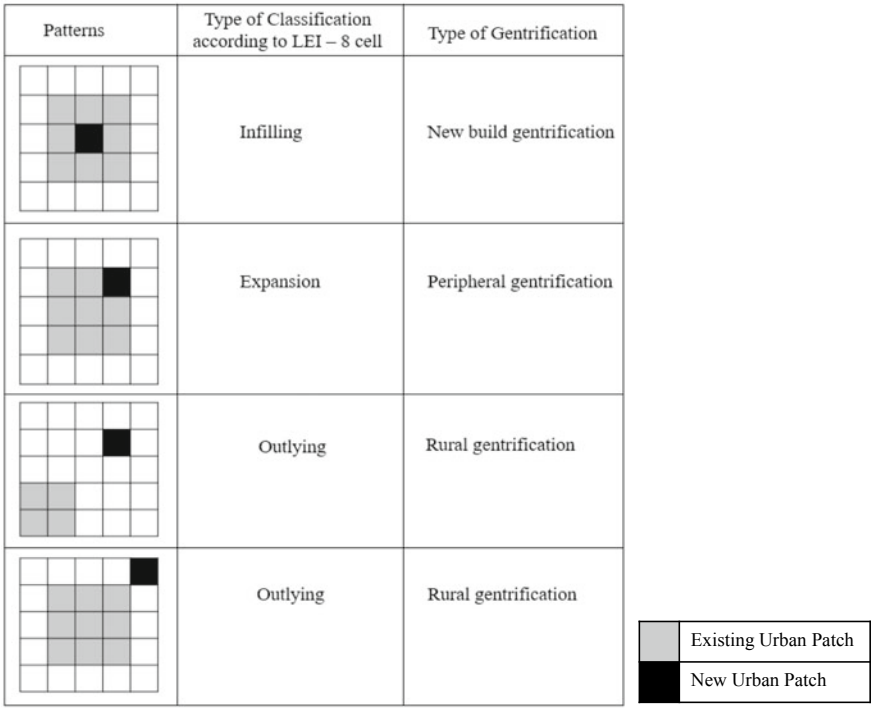


Fig. 9 Patterns of classification and gentrification identified in the study area

integrated with ArcGIS software and is available through the following website http://www.geosimulation.cn/LEI.html. The spatio-temporal assessment of four identified clusters based on LEI is for two decadal periods i.e., from 2001–2011 to 2011–2021. Figure 10 summarises the detailed methodology and helps to understand the overall framework of the research.

6 Analysing the Pattern of Gentrification in Bengaluru and Findings

The major contribution of this research to quantify the spatial pattern of urban growth and integrating the growth with the gentrification process through LEI. The LEI assessment has been carried out in the identified four clusters. Total LEI counts for the decade 2001–2011 are 776, and 2011–2021 are 1412. Table 3 shows the number of counts for both decades. Figures 11, 12, 13 and 14 are the GIS-based visualisation of LEI in the identified four clusters for both decades.

Figure 15 represents the types of LEI classification for both decades. The assessment highlights a rapid incremental phenomenon of peripheral gentrification in

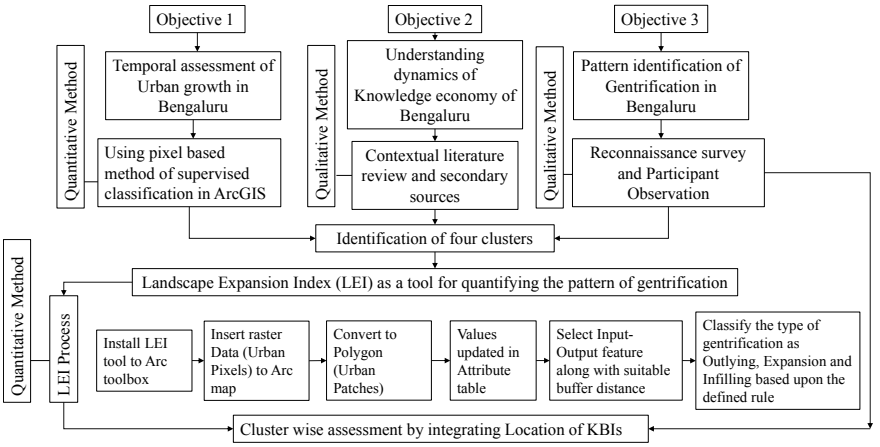


Fig. 10 Detailed research methodology

Table 3 Numbers of counts for LEI for different type of classification

Clusters	Outlying		Expansion		Infilling	
	2001–2011	2011–2021	2001–2011	2011–2021	2001–2011	2011–2021
Cluster 1	16	106	359	964	19	22
Cluster 2	0	0	12	27	1	9
Cluster 3	21	33	85	52	0	0
Cluster 4	37	64	225	135	1	0
Total	74	203	681	1178	21	31

Source Compiled by authors

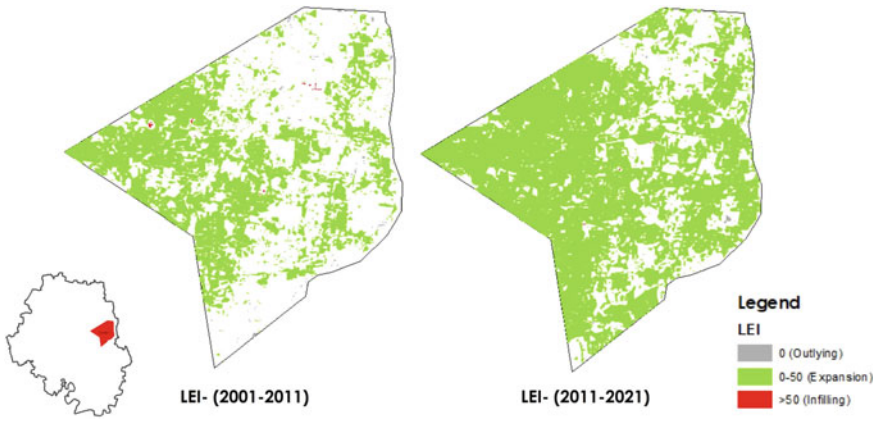


Fig. 11 Landscape expansion index (LEI) assessment in Cluster 1

Fig. 12 Landscape expansion index (LEI) assessment in Cluster 2

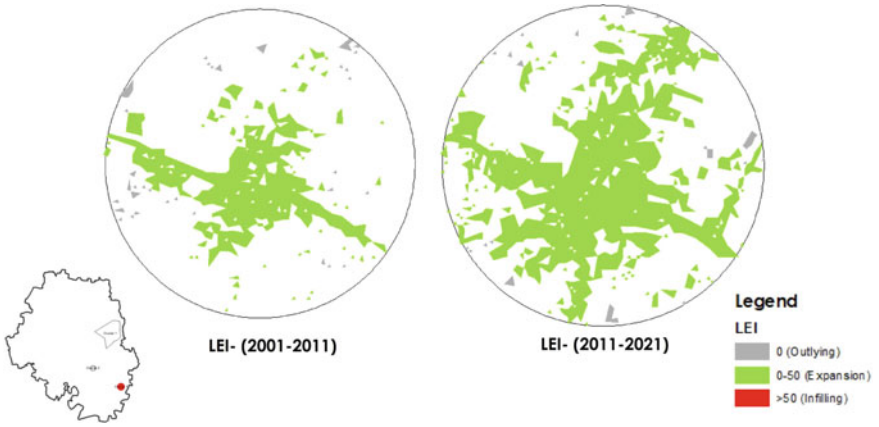


Fig. 13 Landscape expansion index (LEI) assessment in Cluster 3

cluster 1 and cluster 2. The infilling type of classification is least in all the clusters and insignificant in clusters 3 and 4. The majority of new urban patches intersecting with existing urban patches are present in clusters 1 and 2. The outlying classification is observed highest in cluster 1 and none in cluster 2. In clusters 3 and 4, the outlying classification is increasing, and the expansion classification is decreasing.

The interpretative approach through social survey and participant observation has helped to identify the gentrification locations. Table 4 demonstrates the gentrification locations in the identified clusters located in the Eastern and Southern areas of BUD. These clusters accommodate most of Bengaluru's Knowledge based industries (KBIs). Figure 16 demonstrates the temporal evolution for the year (1994–1995, 2003–2004 and 2014–2015) of major KBIs in all the four clusters. The detailed cluster wise map is presented in Fig. 17a, b. 64% of KBIs in the selected clusters

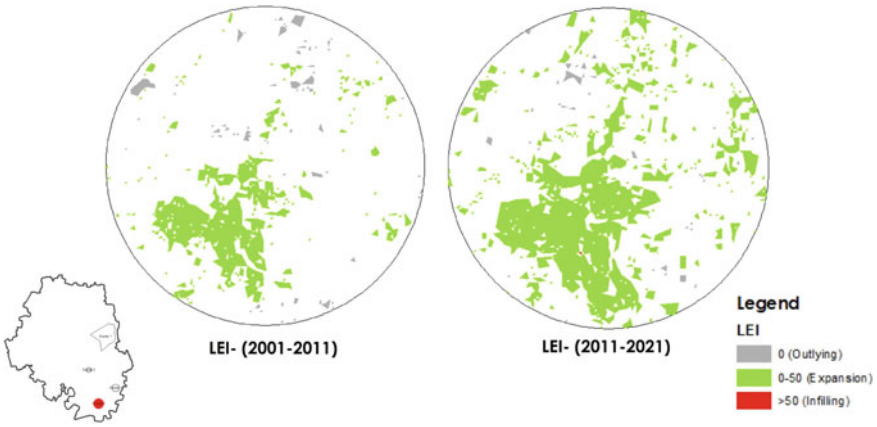


Fig. 14 Landscape expansion index (LEI) assessment in Cluster 4

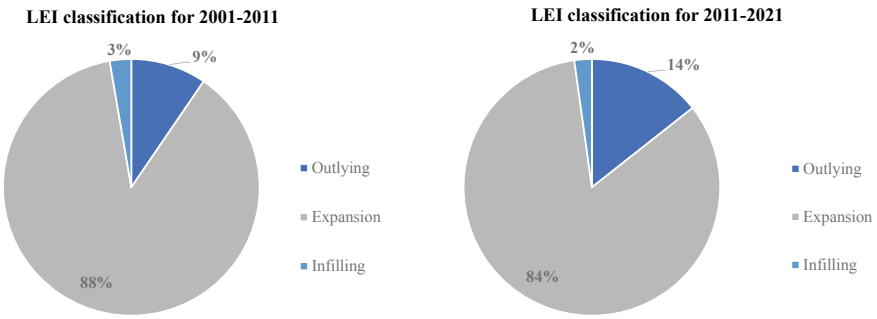


Fig. 15 Temporal comparison of LEI for the period 2001–2011 and 2011–2021

Table 4 Gentrification locations in identified Clusters for research in the study area

Cluster no.	Major gentrification locations	Phase of development
Cluster 1	Mahadevpura, Hoodi and Whitefield	Nucleation phase, Peripheral agglomeration I and Peripheral agglomeration II
Cluster 2	Electronic city	Initial phase, Nucleation phase
Cluster 3	Attibele	Peripheral agglomeration II
Cluster 4	Anekal	Peripheral agglomeration II

Source Compiled by authors

were established during the phase of Peripheral agglomeration II. Most of the KBIs are present in cluster 1 due to ITPL and other technology parks like Salarpuria G R tech park, Sigma soft tech park, Divyashree techno park in Whitefield and Bagmane tech park and Bhoruka park in Mahadevpura, respectively.

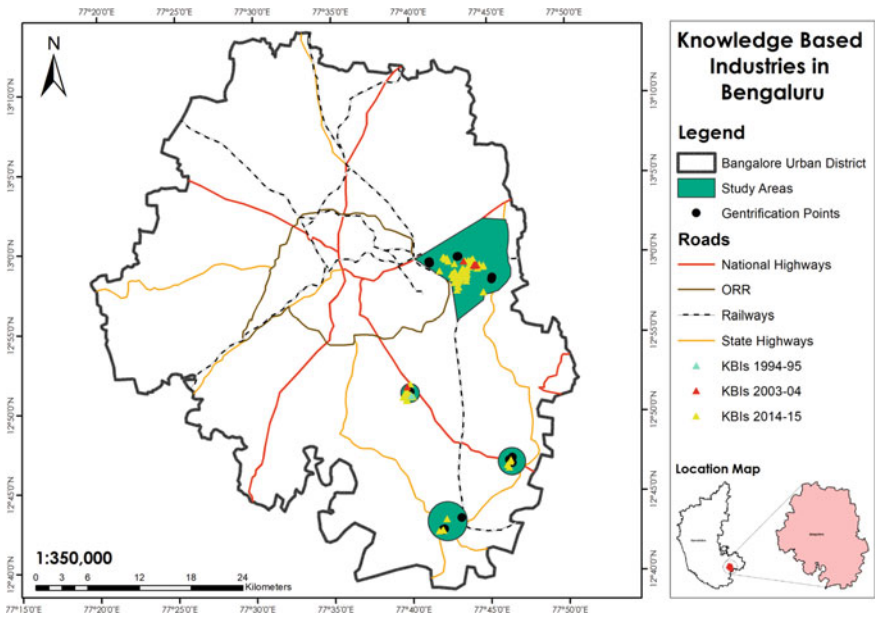


Fig. 16 Spatio-temporal evolution of KBIs in identified clusters

The gentrification process is witnessed at many locations of Bengaluru during the reconnaissance survey. The illustrations in Figs. 18 and 19 capture the ground situation of Clusters 1, 2, 3 and 4. In cluster 1, the gentrification pattern in Mahadevpura is an example of new build typology, whereas the gentrification pattern in Hoodi and Whitefield display the peripheral pattern. The peripheral gentrification in these areas is characterised by the development of high-rise apartments and the transformation of low-density areas into high density zones. In some areas, the traditional neighbourhoods are also transforming by mid-rise apartments, developed jointly by real estate developers and the plot owners.

The gentrification pattern in cluster 2 represents peripheral gentrification where urban expansion is happening on the edges. In Attibele in Cluster 3, rural gentrification is observed where multi-storeyed buildings are being developed on agricultural lands. In Anekal, in cluster 3, the gentrification pattern represents peripheral typology, with a characteristic of plotted development. The LEI confirms the conversion of more agricultural land to residential purposes in clusters 3 and 4. The analysis further emphasises that few of the new urban patches intersected with the existing urban patches in cluster 1. It reflects the lack of developable land availability in this cluster. The Electronic city and Whitefield are recognised as the software hub of Bengaluru, and these localities are amongst the most preferred locations for the knowledge workers (Sheikh et al. 2017).

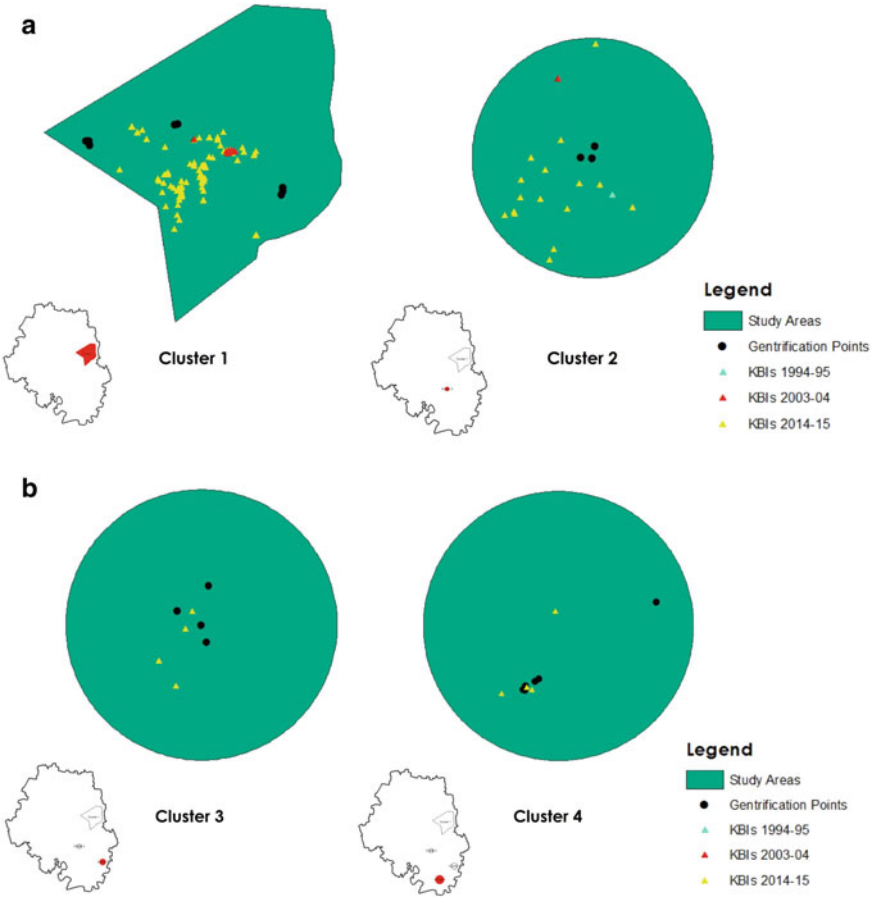


Fig. 17 **a** Spatio-temporal evolution of KBIs in Cluster 1 and Cluster 2; **b** Spatio-temporal evolution of KBIs in cluster 3 and cluster 4

The state government and private enterprises are continuously investing in the city's peripheral areas, fuelling the increasing residential supply and thus aggravating the gentrification process. When original residents are forced to leave their neighbourhood due to a drastic increase in property values, coercion, or buyouts, gentrification becomes a problem. Low-income neighbourhoods in Bengaluru are frequently being transformed into high-end neighbourhoods with housing alternatives such as high-rise apartments. This transformation leads to other types of gentrifications, transforming residential areas to cafés, apparel stores, large chain stores and restaurants, recognised as "commercial gentrification", causing skyrocketing rents and socio-cultural conflicts in residential neighbourhoods (Jeong et al. 2015; Ryu et al. 2020). There has been an increase of 50.9% pubs in Bengaluru from 2014 to 2018 (Shruthi 2018).

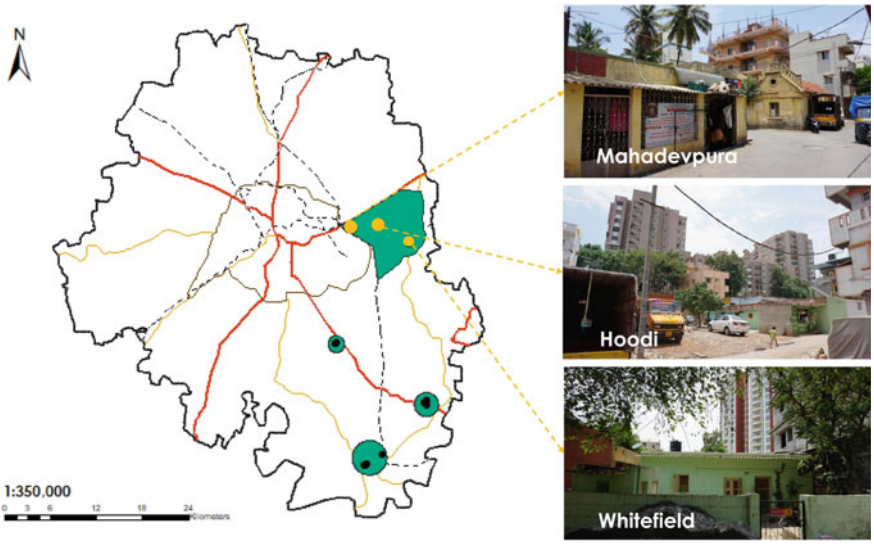


Fig. 18 Gentrified points in Cluster 1

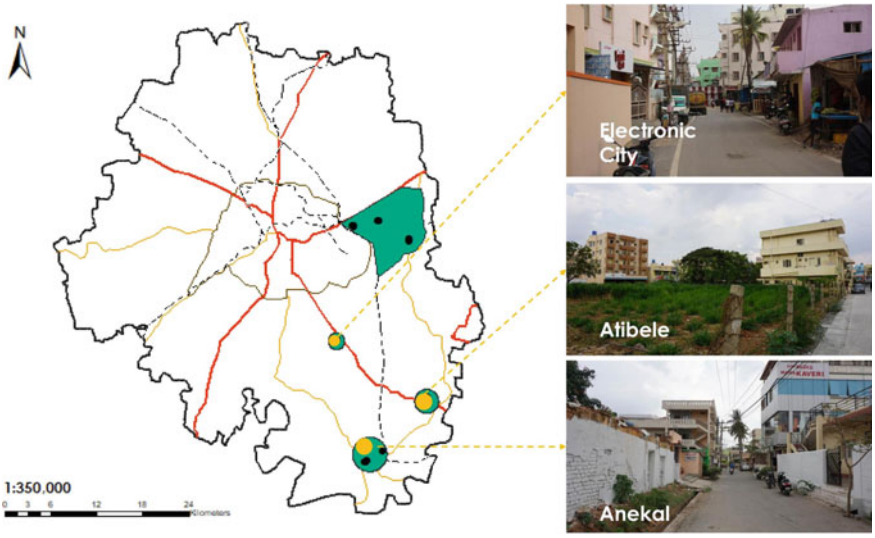


Fig. 19 Gentrified points in Cluster 2, Cluster 3, Cluster 4

7 Conclusion

The latest tides of knowledge driven development have intrinsically transformed the urban morphology of many cities. A basic approach has been adopted in the present

study to reflect the urban morphology of Bengaluru city by describing the patterns of landuse to understand a multitude of choices and decisions about locational attributes. Investigation of the knowledge economy in Bengaluru deciphered the genesis of Bengaluru as a knowledge city and factor attributing to its global recognition of being India's Silicon Valley, Global outsourcing city and fastest growing tech hub (Economic Times 2021). Bengaluru has not only witnessed influx of human capital and knowledge-based industries but is also continuously undergoing structural and spatial rearrangement, especially in the patterns, functions, densities and layouts of its neighbourhoods.

Temporal assessment of the urban growth pattern highlighted that the present growth direction of the city is towards the North, following the new Bengaluru international airport. However, the peripheral agglomeration is not visible between the Bengaluru international airport and ITPL. The growth direction in the previous decade was mainly towards the South-Eastern part of the city, between electronic city and ITPL. The over-saturation of the area also led many KBIs to locate their offices in Hyderabad (Hariharan and Biswas 2020a, b).

Bengaluru has still a very strong geographical inertia for attracting economic growth factors based on a study of its knowledge-based industries (Hariharan and Biswas 2020a, b). The advent of gentrification in Bengaluru is primarily influenced due to the drastic demographic change in the last three decades. These changes are attributed to the influx of human capital employed in knowledge-based industries in the city (Sen 2014; Asian Cities 2017). A high volume of human capital into the city from across the country and globe upscale its residential demand and capacity. The first and second phases of peripheral agglomeration witnessed maximum development in the knowledge economy as many technology parks emerged.

This chapter is an assessment of the patterns of gentrification influenced by knowledge-based industries in Bengaluru. 83% of the highlighted gentrified area are based on the feature of expansion or peripheral gentrification. Most of the peripheral agglomeration is witnessed in Cluster 1 constituting the neighbourhoods of Whitefield, Mahadevpura and Hoodi. Increasing percentage of rural gentrification in the study area re-emphasises on the rapid urban transformation of nearby rural areas. Infilling or new build construction were primarily witnessed in Cluster 1 and Cluster 2. The scope of new urban patches withing the existing urban areas are mostly based on the characteristic of reconstruction or redevelopment as many real estate projects for high rise buildings have been observed in cluster 1 and cluster 2. Electronic city became the focal arena of knowledge-based industries in the initial phase that catered to the economic foundations for many rural areas in proximity through cluster orientation. Anekal's and Attibele's huge housing market potential and availability of land for local clusters and support the core knowledge based industrial clusters to be more productive.

Landscape expansion index strives to be very useful tool to assess the spatial segregation based on the principle of patch based landuse classification. Further study on the impact of gentrification in the neighbourhoods of Bengaluru city can be

carried forward to evaluate the relationship of growth dependent variable and socio-economic performance. This will enrich with major frontiers to balance development and socio-economic inequalities for an improved regional landscape.

References

Accel Partners (2019) Bengaluru innovation report. Research, Bengaluru, Accel Partners, 3one4 Capital, IdeaSpring Capital

Annaswamy TV (2003) Bengaluru to Bangalore: urban history of Bangalore from the pre-historic period to the end of 18th century. Vengadam Publications, Bengaluru

Asian Cities (2017) Gentrification—inescapable in economic development? https://asiancities2017.wordpress.com/2017/02/13/gentrification-inescapable-in-economic-development/. Accessed 31 July 2021

Asian Development Bank (2007) Moving toward knowledge based economies: Asian experiences. Asian Development Bank, Mnaila

Atuesta LH, Hewings GJD (2019) Housing appreciation patterns in low-income neighborhoods: exploring gentrification in Chicago. J Hous Econ 44:35–47. https://doi.org/10.1016/j.jhe.2018.08.005

Autor D, Levy F, Murnane RJ (2003) The skill content of recent technological change: an empirical exploration. Q J Econ 118(4):1279–1333. https://doi.org/10.1162/003355303322552801

Balasubramanyam VN, Balasubramanyam A (2002) The software cluster in Bangalore. In: Dunning JH (ed) Regions, globalisation, and the knowledge economy. pp 349–363. https://doi.org/10.1093/0199250014.003.0014

Basant R (2006) Bangalore cluster: evolution, growth and challenges. Working Paper, Ahmedabad. Indian Institute of Management, Ahmedabad

Bengaluru Development Authority (2005) Bengaluru master plan 2015. Bengaluru Development Authority, Master Plan, Bengaluru

Bengaluru Development Authority (2017) Revised master plan for Bengaluru 2031. Bengaluru Development Authority, Master Plan, Bengaluru

Bevilacqua C, Pizzimenti P, Maione C (2017) S3: cluster policy and spatial-planning. Knowledge dynamics, spatial dimension and entrepreneurial discovery process. Scientific report MAPS-LED Project. MAPS-LED Project – Horizon 2020, Boston

Bounfour A, Edivinsson L (2006) Intellectual capital for communities: nations, regions, and cities. Butterworth-Heinemann, Boston

Brannen J (1992) Mixing methods: qualitative and quantitative research. Routledge, London. https://doi.org/10.4324/9781315248813

Bridge G, Butler T, Lees L (2012) Mixed communities—gentrification by stealth? Policy Press, Bristol

Britton M (2017) Global cities—the changing hierarchy. Oxford Economics, Research, Oxford

Burnett KE (2014) Commodifying poverty: gentrification and consumption in Vancouver's Downtown Eastside. Urban Geogr 35(2):157–176. https://doi.org/10.1080/02723638.2013.867669

Cappellin R (2007) The territorial dimension of the knowledge economy—collective learning, spatial changes, and regional and urban policies. Am Behav Sci 50(7):897–921

Carrillo FJ (2004) Capital cities: a taxonomy of capital accounts for knowledge cities. J Knowl Manag 8(5):28–46. https://doi.org/10.1108/1367327041058738

Carrillo FJ (2011) Knowledge cities—approaches, experiences and perspectives. Routledge, New York

Castells M (1989) The informational city. Information technology, economic restructuring, and the urban-regional process. Blackwell Publishers, Oxford

Census of India (2011) Migration Tables. Office of the Registrar General & Census Commissioner, New Delhi, India
Chapple K, Sideris AL, González SR, Kadin D, Poirier J (2017) Transit-Oriented Development & Commercial Gentrification: TOD Study. UC CONNECT, Los Angeles
Chatterji T (2014) Local mediation of global forces in transformation of the urban fringe. LAP LAMBERT Academic, Germany
Cho W, Kim M, Kim H, Kwon Y (2020) Transforming housing to commercial use: a case study on commercial gentrification in Yeon-nam District, Seoul. Sustainability 12:1–17. https://doi.org/10.3390/su12104322
Cohen M (1983) San Francisco's neighborhood commercial special use district ordinance: an innovative approach to commercial gentrification. Golden Gate University Law Review, pp 367–397
Davidson M, Loretta L (2005) New-build 'gentrification' and London's riverside renaissance. Environ Plan 37:1165. https://doi.org/10.1068/a3739
Davoudi S (2003) Polycentricity in European spatial planning: from an analytical tool to a normative agenda. Eur Plan Stud 11(8):979–999. https://doi.org/10.1080/0965431032000146169
Den Hertog P, Bergman E, Remoe S (2001) Innovative clusters: drivers of national innovation systems (enterprise, industry and services). OECD, Paris
Dezan Shira & Associates (2019) Bangalore: economy, industries, and infrastructure. https://www.india-briefing.com/news/city-spotlight-bangalore-6371.html/
Dharma A, Gupta N, Makkar A, Madan M, Tiwari A (2020) Global capability centres (GCCs) pulse survey 2020—driving the transformation agenda. Summary form. Ernst & Young LLP, New Delhi
Drucker PF (1992) The age of discontinuity, 2nd edn. Routledge, New York
Duffy M, Chenail RJ (2011) Values in qualitative and quantitative research. Couns Values 22–38. https://doi.org/10.1002/j.2161-007X.2009.tb00111.x
Dvir R (2005) Knowledge city, seen as a collage of human knowledge moments. In: Carrillo FJ (ed) Knowledge cities: approaches, experiences, and perspectives. Butterworth-Heinemann, Burlington, pp 245–272
Economic Times (2021) Bengaluru world's fastest growing tech hub, London second: Report. https://economictimes.indiatimes.com/tech/technology/bengaluru-worlds-fastest-growing-tech-hub-london-second-report/articleshow/80263653.cms?from=mdr. Accessed 29 Jul 2021
Edlund L, Machado C, Sviatschi M (2015) Bright minds, big rent: gentrification and the rising returns to skill. Institute for the Study of Labor, Bonn
Ergazakis K, Metaxiotis K, Psarras J (2006). An emerging pattern of successful knowledge cities' main features. In: Carrillo FJ (ed) Knowledge cities—approaches, experiences, and perspectives. Taylor & Francis, New York, pp 3–15
Feldman M, Francis J, Bercovitz J (2005) Creating a cluster while building a firm: entrepreneurs and the formation of industrial clusters. Reg Stud 39(1):129–141. https://doi.org/10.1080/0034340052000320888
Florida R (2002) The rise of creative class and how its transforming work, leisure, community & everyday life. Basic Books, New York
Florida R (2003) Entrepreneurship, creativity and regional economic growth. In: Hart DM (ed) The emergence of entrepreneurship policy: governance, start-ups, and growth. Cambridge University Press, Cambridge, pp 39–60
Forman RT (1995) Land mosaics: the ecology of landscapes and regions. Cambridge University Press, Cambridge
Ghosh M, Amaresha M (2020) Comparative analysis of price trends of residential real estate properties in Bangalore. Int J Commer Manag Res 70–73
Glaeser EL, Resseger M, Tobio K (2009) Inequality in cities. J Reg Sci 49(4). https://doi.org/10.1111/j.1467-9787.2009.00627.x
Glass R (1964) London: aspects of change. MacGibbon & Kee, London

Gotham KF (2005) Tourism gentrification: the case of New Orleans' Vieux Carre (French Quarter). Urban Stud 42(7):1099–1121. https://doi.org/10.1080/00420980500120881
Hackworth J, Rekers J (2005) Ethnic packaging and gentrification: the case of four neighborhoods in Toronto. Urban Aff Rev 41:211–236. https://doi.org/10.1177/1078087405280859
Hall P, Pain K (2006) The polycentric metropolis: learning from mega-city regions in Europe. Earthscan, London
Haralambos M, Holborn M, Chapman S, Moore S (2013) Sociology themes and perspectives, 8th edn. Collins, London
Hariharan AN, Biswas A (2020a) A critical review of the Indian knowledge based industry location policy against its theoretical arguments. Reg Sci Policy Pract 431–454
Hariharan AN, Biswas A (2020b) Global recognition of India's knowledge based industry evolution through empirical analysis. J Knowl Econ. https://doi.org/10.1007/s13132-020-00673-x
Hoyler M (2011) External relations of German cities through intra-firm networks—a global perspective. Raumforsch Raumordn 69:147–159. https://doi.org/10.1007/s13147-011-0100-8
Isaksen A (2006) Knowledge-based clusters and urban location: the clustering of software consultancy in Oslo. In: Cumbers A, MacKinnon D (eds) Clusters in urban and regional development. Routledge, New York, 187–204
Jeong Y, Heo J, Jung C (2015) Behind the bustling street: commercial gentrification of Gyeongridan, Seoul. Procedia Soc Behav Sci 170:146–154. https://doi.org/10.1016/j.sbspro.2015.01.024
Kalra R (2006) High technology and urban development in Bangalore, India. In: Gatrell JD, Reid N (eds) Enterprising worlds. The GeoJournal Library, Dordrecht, pp 71–81
Kamath S (1990) Chapter 2—History. In: Karnataka state gazetteer: Bangalore district, by Karnataka Gazatteer Department. Government of Karnataka, Bengaluru, pp 49–122
Kar SM (2016) Locating Bengaluru as India's Silicon valley. Artha J Soc Sci 15(2):49–68. https://doi.org/10.12724/ajss.37.3
Kelly J (2017) These are the most dynamic cities in the world—and they're not the ones you'd expect. https://www.weforum.org/agenda/2017/01/these-are-the-most-dynamic-cities-in-the-world-and-they-re-not-the-ones-you-d-expect. Accessed 4 July 2021
Kennedy M, Leonard P (2001) Dealing with neighbourhood change: a primer on gentrification and policy choices. The Brookings Institution Centre for Urban and Metropolitan Policy, Berkeley, CA
Komninos N (2002) Intelligent cities—innovation, knowledge, systems and digital spaces. Spon Press, New York
Kosta EB (2019) Commercial gentrification indexes: using business directories to map urban change at the street level. City Community 18(4):1101–1122. https://doi.org/10.1111/cico.12468
Krauss G, Stahlecker T (2001) New biotechnology firms in Germany: Heidelberg and the BioRegion Rhine-Neckar triangle. Small Bus Econ 17:143–153. https://doi.org/10.1023/A:1011145615243
Krugman P (1991) Geography and trade. MIT Press, Cambridge, MA
Kumar N (2014) Chapter 5—National Innovation Systems and the Indian Software Industry Development. In: Shyama V, Ramani (ed) Innovation in India—combing economic growth with inclusive development. Cambridge University Press, New Delhi, pp 143–185. https://doi.org/10.1017/CBO9781139794640.006
Lees L (1994) Gentrification in London and New York: an Atlantic gap? Hous Stud 9(2):199–217
Lees L, Slater T, Wyly E (2008) Gentrification. Routledge, London, UK
Lei Y, Flacke J, Schwarz N (2021) Does Urban planning affect urban growth pattern? A case study of Shenzhen, China. Lans Use Policy 101:1–13. https://doi.org/10.1016/j.landusepol.2020.105100
Ley D (1986) Alternative explanations for inner-city gentrification: a Canadian assessment. Ann Assoc Am Geogr 76(4):521–535
Liu X, Li X, Chen Y, Tan Z, Li S (2010) A new landscape index for quantifying urban expansion using multi-temporal remotely sensed data. Landsc Ecol 25:671–682. https://doi.org/10.1007/s10980-010-9454-5

Liu X, Ma L, Ai B, Li S, He Z (2012) Simulating urban growth by integrating landscape expansion index (LEI) and cellular automata. Int J Geogr Inf Sci 148–163. https://doi.org/10.1080/13658816.2013.831097
London B, Palen J (1984) Gentrification and neighbourhood revitalization. State University of New York Press, Albany, NY
Luthi S, Thierstein A, Bentlage M (2012) The relational geography of the knowledge economy in Germany: on functional urban hierarchies and localised value chain systems. Urban Stud 50(2):276–293. https://doi.org/10.1177/0042098012452325
Maillat D (1995) Territorial dynamic, innovative milieus and regional policy. Entrepeneurship Reg Dev Int J 7(2):157–165. https://doi.org/10.1080/08985629500000010
Maillat D (1998) From the industrial district to the innovative milieu: contribution to an analysis of territorialised productive organisations. Louvain Econ Rev 64(1):111–129
Manimala MJ (2006) Evolution of the Bangalore ICT cluster: the 'Crystal Growth' model. Ind High Educ 20:249–255. https://doi.org/10.5367/000000006778175775
Manimala MJ (2017) Bangalore: development through intercultural interaction. In: Piero (ed) Entrepreneurial renaissance—cities striving towards an era of rebirth and revival. Formica, Springer, pp 57–80
Mattar NA, Thierstein A, Förster A (2014) "Alternative futures": a methodology for integrated sustainability considerations, the case of Nuremberg West, Germany. Local Environ 19(6):677–701. https://doi.org/10.1080/13549839.2013.841135
McKinnish T, Walsh R, Kirk White T (2010) Who gentrifies low-income neighborhoods? J Urban Econ 67(2):180–193. https://doi.org/10.1016/j.jue.2009.08.003
Meentemeyer RK, Tang WW, Dorning MA, Vogler JB, Cunniffe NJ, Shoemaker DA (2013) FUTURES: multilevel simulations of emerging urban–rural landscape structure using a stochastic patch-growing algorithm. Ann Assoc Am Geogr 103:785–807
Meltzar R, Ghorbani P (2017) Does gentrification increase employment opportunities in low-income neighborhoods? Reg Sci Urban Econ 66:52–73. https://doi.org/10.1016/j.regsciurbeco.2017.06.002
Moghadam SA, Karimi M, Habibi K (2018) Simulating urban growth in a megalopolitan area using a patch-based cellular automata. In: Transactions in GIS. Wiley, pp 1–20. https://doi.org/10.1111/tgis.12309
Moos M, Revington N, Wilkin T, Andrey J (2018) To knowledge economy city: gentrification, studentification and youthification, and their connections to universities. Urban Stud 1–18
Morisson A, Bevilacqua C (2019) Balancing gentrification in the knowledge economy: the case of Chattanooga's innovation district. Urban Res Pract 12(4):472–492. https://doi.org/10.1080/17535069.2018.1472799
Nagendra H, Unnikrishnan H, Sen S (2014) Villages in the city: spatial and temporal heterogeneity in rurality and urbanity in Bangalore, India. Land 3:1–18. https://doi.org/10.3390/land3010001
O'Sullivan D (2002) Toward micro-scale spatial modeling of gentrification. J Geogr Syst 4:251–274. https://doi.org/10.1007/s101090200086
ODI (2009) Tools for policy impact. Overseas Development Institute, London
OECD (1996) The knowledge based economy. Organisation for Economic Co-operation and Development, Paris
Ong PM, Pech C, Ray R (2014) TOD impacts on businesses in Four Asian American neighbourhoods. UCLA Centre for the study of Inequality, UCLA TOD Study, Los Angeles
Van Oort FG (2003) Urban growth and innovation: spatially bounded externalities in the Netherlands. Ashgate Pub Ltd., London
Pabari S, Supriyo C, Ankur B (2021) Global capability centres (GCCs)—driving manufacturing innovations at scale. Research Report, Deloitte, New Delhi
Pani N, Radhakrishna S, Bhat KG (2010) Bengaluru, Bangalore, Bengaluru: imaginations and their times. Sage Publications India Pvt Ltd., New Delhi
Paul R, Kenway S, McIntosh B, Mukheibir P (2018) Urban metabolism of Bangalore City—a water mass balance analysis. J Indus Ecol 22(6):1413–1424. https://doi.org/10.1111/jiec.12705

Penco L (2013) The development of the successful city in the knowledge economy: toward the dual role of consumer hub and knowledge hub. J Knowl Econ. https://doi.org/10.1007/s13132-013-0149-4
Philips M (1993) Rural gentrification and the processes of class colonisation. J Rural Stud 9(2):123–140. https://doi.org/10.1016/0743-0167(93)90026-G
Plechero M, Kulkarni M, Chaminade C, Parthasarathy B (2020) Explaining the past, predicting the future: the influence of regional trajectories on innovation networks of new industries in emerging economies. Indus Innov. https://doi.org/10.1080/13662716.2020.1780419
Porter ME (1990) The competitive advantage of nations. Macmillan Press, London
Porter ME (1998) Clusters and the new economics of competition. Harward Business Review
Porter ME (2000) Location, competition, and economic development: local clusters in a global economy. Econ Dev Q 15–34
Raman A (1994) Bangalore-Mysore. Orient Longman Limited, Chennai
Raspe O, Van Oort F (2006) The knowledge economy and urban economic growth. Eur Plan Stud 14(9):1209–1233. https://doi.org/10.1080/09654310600933322
Registrar General and Census Commissioner of India (2011) Urban agglomeration and cities—census of India. Registrar General and Census Commissioner of India, Census, New Delhi
Reis JP, Silva EA, Pinho P (2015) Spatial metrics to study urban patterns in growing and shrinking cities. Urban Geogr 37:246–271. https://doi.org/10.1080/02723638.2015.1096118
Rerat P, Soderstrom O, Piguet E, Besson R (2010) From urban wastelands to new-build gentrification: the case of Swiss Cities. Popul Space Place 16:429–442. https://doi.org/10.1002/psp.595
Richardson J, Mitchell B, Franco J (2019) Shifting neighbourhoods: gentrification and cultural displacement in American Cities. Research Report, National Community Reinvestment Coalition, Washington D.C.
Ryu H, Kim D, Park J (2020) Characteristics analysis of commercial gentrification in Seoul focusing on the vitalization of streets in residential areas. Sustainability 12(21). https://doi.org/10.3390/su12218877
Saini J (2019) Y2K bug: how a bug helped India strengthen its IT Sector. https://medium.com/@jessicasaini/y2k-how-a-bug-helped-india-strengthen-its-it-sector-4753000be4bf. Accessed 29 July 2021
Saxenian AL (1983) The urban contradictions of Silicon Valley: regional growth and the restructuring of the semiconductor industry. Int J Urban Reg Res 7(2):237–262. https://doi.org/10.1111/j.1468-2427.1983.tb00592.x
Saxenian A (2001) Bangalore: the Silicon Valley of Asia? Working Paper no 91. Stanford University, Stanford
Schneider A, Woodcock CE (2008) Compact, dispersed, fragmented, extensive? A comparison of urban growth in twenty-five global cities using remotely sensed data, pattern metrics and census information. Urban Stud 45(3):659–692. https://doi.org/10.1177/0042098007087340
Schumpeter JA (1947) Capitalism, socialism and democracy. Routledge Classics, New York
Sen P (2013) Changing urban traits—a study of Bengaluru urban agglomeration, India. Asian Soc Sci 9(1):122–129. https://doi.org/10.5539/ass.v9n1p122
Sen P (2014) Suburbanisation and gentrification in Sathanuru satellite township, Bengaluru—an ultimate dilemma. Afro Asian J Soc Sci 1–10. https://www.theguardian.com/global-development/gallery/2012/apr/06/india-technology-not-helping-poor-in-pictures
Sengupta S (2010) The Bangalore story: the outsourcing capital of the world. Tholons, New York
Seo J-K (2002) Re-urbanisation in regenerated areas of Manchester and Glasgow: new residents and the problems of sustainability. Cities 19(2):113–121. https://doi.org/10.1016/S0264-2751(02)00006-9
Shaw A, Satish MK (2007) Metropolitan restructuring in post-liberalized India: separating the global and the local. Cities 24(2):148–163. https://doi.org/10.1016/j.cities.2006.02.001
Sheikh W, Dash M, Sharma K (2017) Trends in residential market in Bangalore, India. PRiMa Pract Res Mark 1–9. https://doi.org/10.13140/RG.2.2.33967.89768

Shruthi HM (2018) Bengaluru sees 50% increase in pubs in four years. https://www.thehindu.com/news/cities/bangalore/bengaluru-sees-50-increase-in-pubs-in-four-years/article24490251.ece. Accessed 29 July 2021

Smith N (1996) The new urban frontier: gentrification and the Revanchist City. Routledge, London and New York

Spencer GM, Vinodrai T, Gertler MS, Wolfe D (2010) Do clusters make a difference? Defining and assessing their economic performance. Reg Stud 44(6):697–715. https://doi.org/10.1080/00343400903107736

Srinivas S (1997) Urban development and the information technology industry: a study of Bangalore, India. UCL Press, London

Stehlin J (2015) The post-industrial "shop floor": emerging forms of gentrification in San Francisco's innovation economy. Antipode 48(2):474–493. https://doi.org/10.1111/anti.12199

Subrahmanya MHB (2017) How did Bangalore emerge as a global hub of tech start-ups in India? Entrepreneurial ecosystem—evolution, structure and role. J Dev Entrep (World Scientific Publishing Company) 22(1):22. https://doi.org/10.1142/S1084946717500066

Subrahmanya, M H Bala. 2019. Bangalore: a vibrant and dynamic Indian city with an uncertain future? https://www.urbanet.info/bangalore-economic-development/. Accessed 4 July 2021

Sudhira H, Ramachandra T, Subramanya MB (2007) City profile: Bangalore. Int J Urban Policy Plan 379–390

Sullivan DM (2014) From food desert to food mirage: race, social class, and food shopping in a gentrifying neighborhood. Adv Appl Sociol 4(1):30–35. https://doi.org/10.4236/aasoci.2014.41006

Tallmann S, Jenkins M, Henry N, Pinch S (2004) Knowledge, clusters, and competitive advantage. Acad Manag Rev 29(2):258–271

Taubenböck H, Wegmann M, Roth A, Mehl H (2009) Urbanization in India—spatiotemporal analysis using remote sensing data. Comput Environ Urban Syst 33(3):179–188. https://doi.org/10.1016/j.compenvurbsys.2008.09.003

The Hindu (2018) Bengaluru has the highest number of colleges in the country. https://www.thehindu.com/news/cities/bangalore/bengaluru-has-the-highest-number-of-colleges-in-the-country/article24648141.ece. Accessed 27 July 2021

Trippl M, Bergman EM (2014) Clusters, local districts, and innovative milieux. In: Fischer M, Nijkamp P (eds) Handbook of regional science. Springer, Berlin, Heidelberg, pp 439–456. https://doi.org/10.1007/978-3-642-23430-9_26

Uitermark J, Duyvendak JW (2007) Gentrification as a governmental strategy: social control and social cohesion in Hoogvliet, Rotterdam. Environ Plan A 39:125–141. https://doi.org/10.1068/a39142

Verma S, Chatterjee, Mandal NK (2017) Analysing urban sprawl and shifting of urban growth centre of Bengaluru City, India using Shannon's Entropy Method. J Settl Spat Plan 8(2):89–98. https://doi.org/10.24193/JSSP.2017.2.02

Wang F, Marceau DJ (2013) A patch-based cellular automaton for simulating land-use changes at fine spatial resolution. Trans GIS 17(8):828–846. https://doi.org/10.1111/tgis.12009

Weih RC, Riggan ND (2010) Object based classification vs Pixel based classification: comparative importance of Multi-resolution imagery. The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences XXXVIII-4/C7

World Bank (2007) Building knowledge economies: advanced strategies for development. World Bank, Washington DC

Xu C, Zhang C, An S, Yu W, Chen JM (2007) The spatiotemporal dynamics of rapid urban growth in the Nanjing metropolitan region of China. Landsc Ecol 22:925–937. https://doi.org/10.1007/s10980-007-9079-5

YEOH C, David D (2005) The Singapore edge in India's Silicon valley: new insights? In: Proceedings of the Pan-Pacific conference XII 2005. Research Collection Lee Kong Chian School of Business, Singapore, pp 438–440

Yoon Y, Park J (2018) Stage classification and characteristics analysis of commercial gentrification in Seoul. Sustainability 10(7). https://doi.org/10.3390/su10072440

Zukin S, Trujillo V, Frase P, Jackson D, Recuber T, Walker A (2009) New retail capital and neighborhood change: boutiques and gentrification in New York City. City Community 8(1):47–64. https://doi.org/10.1111/j.1540-6040.2009.01269.x

Chapter 4
Are New Towns in Developing Nations Designed for Sustainable Living? Investigating the Perception of the Residents from Navi Mumbai, India

Neenu Thomas, Ahana Sarkar, and Arnab Jana

1 Introduction

> 'Cities are where the battle for sustainable development will be won—or lost if we fail.'
> — Former UN Deputy Secretary General Jan Eliasson.

Cities serve as the home and provider to billions of people in the world. People are attracted to the urban areas due to the opportunities they provide and resource concentration. History has shown evidence of the human tendency to migrate towards urban areas from rural areas for a better living. Better living depends on several aspects such as job opportunities, access to basic infrastructure and services, and housing and transport conditions. The phenomenon of the urban population continuing to stay in urban areas and the rural population continuing to migrate to the urban areas has led to more than half of the human population living in the urban areas. About eighty percent of the population lives in urban areas in developed countries (UNCTAD 2020). In this race of urbanization, fast urbanization has been observed in the Global South (primarily African countries) in these recent decades, with a large number of these countries having annual population growth of more than one percent. The urban population of developing countries has risen from 45.34% in 2009 to 51.11% of the total population in 2019, and it is expected to reach 68.4% by 2050 (UNCTAD 2021). Nevertheless, the rapid urbanization and large population living in the urban areas result in the overburdened physical infrastructure and services, exploitation of

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P. Banerji and A. Jana (eds.), *Advances in Urban Design and Engineering*, Design Science and Innovation, https://doi.org/10.1007/978-981-19-0412-7_4

the ecology, and an increase in the number of slum dwellers. The global urbanization trend demonstrates that the demand for urban areas will continue to grow, and the urban authorities will continuously have to work for the smooth functioning of the urban system and promptly respond to the changes and emerging issues.

So, how is our world tackling the issue of excess demand for urban areas considering its limited land and infrastructural capacity? We all have to accept the truth that the urban areas in the world will exist for the foreseeable future. Moreover, several of these urban areas in developing countries are over-populated, unable to provide adequate, affordable, decent quality housing and infrastructure to all their population, losing their ecological share and balance, and deteriorating air, water, and land quality. Several of these issues have been attempted to solve through new policies, urban planning, and urban design strategies; however, the approach selected for the urban areas with a population above their carrying capacity must be different. The carrying capacity of an urban area is the maximum number of individuals that an urban area can sustain over time without destroying or degrading the environment, and it is determined by factors such as food availability, water, and space (Hartvigsen 2013). Conventionally, the new town development is identified as a planning opportunity and solution for large-scale urban issues. While the planning objective and approach of the new town development may be unalike by different developing authorities of the countries, typically in developing nations, new town development adjoining to a large city is considered as a sole solution for decongesting the existing city and providing affordable housing and access to basic amenities to all sections of the population. While we do not see the migration of the urban population to rural areas at large, we have seen the migration of the urban population to other urban areas. Human beings are attracted to a new place that can provide a better living. The new towns are expected to be modal towns which will provide better living and higher satisfaction to its future residents. Residents from large urban areas and urban agglomeration are shifted to the newly developed towns for living in better conditions such as affordable housing, good quality air and water, neighbourhood open spaces, infrastructures, and services.

The urban area covers just about 3% of the planet's area; however, it contributes to more than seventy percent of the global Greenhouse Gas (GHGs) emissions and two-thirds of the world's energy consumption (World Bank 2021). In addition to the urbanizations process leaving the urban system overburdened and ecology degraded, the safety and inclusivity of the urban space and infrastructure are rising concerns for several developing cities. Moreover, urban areas are the place that exhibits more social dualism due to the increasing informal settlements. While the new town development can be considered an apposite approach for urban demand requirements, will these new towns be part of the problems? New town development has an opportunity to be part of the solution by building a sustainable urban space for the current and future generations. Accounting for all the kinds of urban issues, the 11th Sustainable Development Goal (SDG 11) set up by United Nations General Assembly targets to achieve 'Sustainable cities and communities' by 2030. With the increasing awareness about urban sustainability and target to meet Sustainable Development Goals (SDG), several recent new town developments follow sustainable city concepts from

the initial planning stages. However, for conventional new town development, the determinants of sustainable planning remain elusive. The conceptual shortcomings include ineffectiveness in integrating sustainable planning principles to new towns and lack of people-centred development as recommended in SDG 11.

While the sustainability of the new towns developed with sustainability concepts can be evaluated even in the early development stage through their master plan, which provides development information (Fu and Zhang 2017), the conventionally developed new towns are difficult to be evaluated. However, the resident perception-based evaluation can provide information on satisfaction and sustainable living in the conventional new towns. Residents' satisfaction has been considered as an indicator for better living. The chapter explains the determinants of sustainable new town development and assesses 'Are new towns in developing nations designed for sustainable living? through the perception of the residents.'

The study elaborates on a case study of Navi Mumbai ('Navi' means 'New' in Marathi and Hindi), one of the largest planned cities in India. Navi Mumbai is described as a 'City of the twenty-first century' by the City and Industrial Development Corporation of Maharashtra (CIDCO), the development authority of Navi Mumbai. The planning of Navi Mumbai commenced in 1971.[1] Navi Mumbai was planned to decongest the Greater Mumbai, absorb the immigrants, and contain about two million population (Shaw 2004); however, the new town took decades to populate itself. The objective of the research is to conduct an empirical analysis that investigates the sustainability assessment of the new town 'Navi Mumbai' by elucidating inhabitants' perception towards their living, transport, and community well-being. This research would pave the way to identify determinants for sustainable new town planning and formulate environment-sensitive policies through the perspective of residents of the new towns. The following section discusses the determinants for developing sustainable urban areas in developing countries.

2 Determinants of Sustainable New Town Development

Sixty percent of the global population will live in the urban systems in the next two decades (John et al. 2019). As a result, urban expansion is happening in the existing urban systems subsequently increasing megacities (cities with more than 10 million inhabitants) worldwide (Kennedy et al. 2014). Rapid growth is observed in low- to middle-income countries of Africa and South Asia, putting massive pressure on infrastructure and resource consumption (Angel et al. 2012) and the formation of urban agglomerations. These countries have developed several new towns to attract people to new urban areas, thus reducing the burden of existing cities. However, some of these new towns have failed to attract the population and remain as ghost towns

[1] Several leading architects, civil engineers, and urban planners such as Charles Correa (Chief Architect), R. K. Jha (Chief Planner), Shirish Patel, and Pravina Mehta were involved in the initial planning of the new town (Perulli 2016).

(Jin et al. 2017; Williams et al. 2019). Ghost towns are a new urban development that is significantly under capacity, that is, space with fewer people and businesses than its capacity (Shepard 2015). Such effects have serious consequences ranging from social (such as significant social inequality), ecological (wasted land) to economic dimension (wasted investment) (Jin et al. 2017).

On the contrary, some of the new towns are getting populated fast and facing similar urban issues, such as carbon emission and social inequality, as in the old urban areas. The new towns are found to be big contributors to urban carbon emissions (Liu et al. 2018; Papa et al. 2016). Therefore, the new town development authority must have sustainable development approaches that attract people in present times and prevent the new town from being the hotspot of urban issues in the future.

A new town can be defined as a self-sustained planned urban space that is developed on unoccupied land or land with minimal human density to accommodate a large population by providing housing, infrastructure, and services. While the primary motive of the new town development is either to decongest the old city or to control ad-hoc settlement formation around the old city (Osborn 1942; Osborn and Whittick 1977), it is more important to build the new town sustainable. Several recent new town developments are built/building on the concept of the sustainable city or eco-city (e.g., Tianfu New Area in China, Amaravati in India, and Songdo IBD in South Korea). The concept of developing sustainable urban areas obtained global attention in the twenty-first century, especially due to the 2030 Agenda for Sustainable Development, adopted by all United Nations Member States in 2015 (United Nations 2015).

Although researchers, policymakers, and public administrations agree that sustainable development is a key objective that must be considered, there is no particular definition of 'sustainability' when applied to urban systems. The current concept of sustainable development is derived from the Brundtland Report (also known as Our Common Future). As per the report, Sustainable development is 'Development that meets the needs of the present without compromising the ability of future generations to meet their own needs' (World Commission on Environment and Development 1987). The report highlights three key aspects of sustainable development: social equity, economic growth, and environmental security. Since then, researchers and policymakers have evolved the concept of sustainable development either to build the places sustainable or to evaluate the sustainability level of the existing places and compare the sustainability levels of the different places. As a result, several sustainable development determinants or indicators were formed.

Similarly, new approaches to sustainable development and evaluation were introduced. For example, according to Kennedy et al. (2007), a sustainable urban system is an urban region that does not exceed the capacity of its hinterlands due to its inflows of materials and energy and the disposal of wastes. Here, the concept of urban metabolism is incorporated as a tool to assess the sustainable development of urban areas. All the advancements in recent years indicate the world has recognized the need for sustainable development in all kinds of countries, and therefore, they are working together towards developing a sustainable world. However, the sustainable

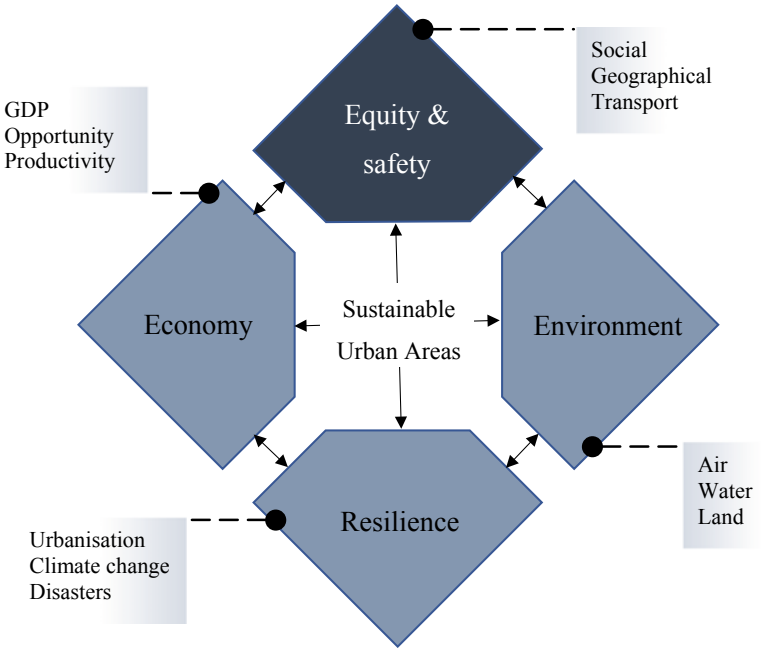

Fig. 1 Prime determinants of sustainability for new towns in developing countries

development determinants need not be identical for every urban area. The sustainability of an urban area depends on its population and its activities. The sustainable development determinants for an urban area should be determined considering the general urban issues faced by the urban areas in the region or country. Moreover, the policymakers and public administrations will have to act promptly to the changing behavior of the urban area and potential threats towards achieving sustainability. The following sub-sections discuss the details of the prime determinants of sustainability for developing countries (see Fig. 1) and suggestions for new town development in the twenty-first century.

2.1 Social, Geographical, and Transport Equity and Safety

The new town can become a place with large inequality as other old urban areas if the urban area has an unsystematic approach to development. The people from rural areas migrate to large urban spaces for economic growth and better access to services; however, they fail to obtain high-income jobs due to the lesser education or different skillset, thus increasing inequality in the income distribution, unemployment rates, poverty, cost of living, and/or social equity (Rama et al. 2021; Feleki et al. 2018). As a result, the urban areas showcase social dualism in their physical space (in the

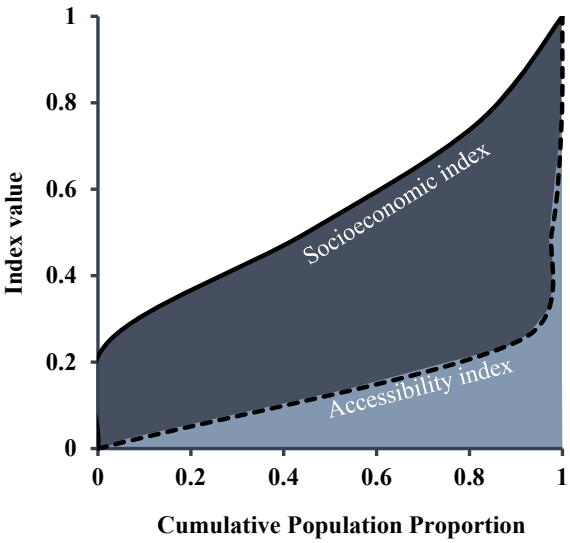

Fig. 2 Social and geographical inequity measure from Mumbai, India. *Source* Adopted from Thomas et al. (2019)

form of informal settlements) and social space (insensitive behavior towards low-income groups, increasing crime, and public safety). Simultaneously, urban areas in developing countries have exhibited disparity in access to social infrastructures (workplace, school, hospital, etc.) and transportation options. Figure 2 is a representative graph indicating the social and geographical inequity existing in developing countries. Geographical and transport inequity are generally the derivate of social inequity; hence, approaches to build geographical and transport equity benefit social coherence. The new towns must be built as a space with maximum urban equity (social, geographical, and transport equity, and safety).

The urban citizens have the challenge to meet their daily needs of water, sanitation, electricity, and transportation when there is a lack of reliable and affordable infrastructure and services provided by the municipal authority. The high-income group tends to access more reliable and convenient options providing extra cost. For example, they use privatized vehicles to travel for opportunities at distant places, live in gated communities with better infrastructure and services such as continuous water and electricity supply, and avail appliances that provide clean water, air, etc., while the rest of the citizens eventually choose mediocre or expensive arrangements, affecting their quality of life and productivity. Moreover, higher inequality can also harm well-being and the environment; that is, there can be an increase in atmospheric emissions and water pollution (Boyce 2018). Thus, there is a cumulative effect of urban inequity on the sustainability of that urban area as well as the global environment.

Sensitive planning can help solve the social, geographical, and transport equity issues. Informal settlements and large families living in small spaces are familiar scenes of the urban areas in low-income countries, resulting from a lack of affordable

housing. Urban residents from large cities may tend to move to new towns for affordable housing if it can provide better opportunities and space in their budget. Therefore, urban areas must be planned to accommodate all kinds of income groups. Mixed development can avoid the growth of informal settlements. People from different income groups should be sharing the public spaces, and their communities must not be segregated to increase social cohesion. In addition to housing, affordable transport, and accessibility to the workplace, public places and services play major roles in developing social inclusivity and improving urban equity.

The planning authority must have a vision for its space and population to build urban equity. Instead of segregating a section of the population with gated communities, we need to prioritize building safer communities with reliable and affordable services where the residents with different social statuses can interact daily. A large proportion of low-income people are commuting with active modes (such as walking or bicycle); however, most urban authorities focus on infrastructure developments for motorized transportation. The infrastructures in the new towns must be developed for its citizens, not for the new developments invented to reduce the people's hardship. While the motorized vehicle can provide an undeniable amount of opportunities to the people, such options must be restricted wisely by building more walkable urban areas and providing accessible and affordable public transportation. The infrastructure for active modes (footpath and cycle lanes) and public transport needs to be given priority to reduce the inequity in the urban spaces.

Urban equity is the catalyst for other determinants while building a sustainable urban area because any inequity may affect the economic and environmental balance and resilience of the urban area. Hence, social, geographical, and transport inequity can be a major challenge for new town development in developing countries.

2.2 Economy, Opportunities, and Productivity

Urban areas contribute to more than 80% of the global gross domestic product (GDP) (World Bank 2021), and economic growth is a primary objective of the urban areas. There are two major issues faced by urban areas in developing countries while concentrating on economic growth, which are difficult to be rectified in the old urban areas but should be considered while developing new towns.

First, the scalability of the urban area is that the urban areas do not have the space to accommodate new opportunities and increase demand for infrastructure. An urban area should attract people through the establishments it has and the opportunities it can provide. The planning authority plays a major role in encouraging innovations, businesses, entrepreneurship, and investments in urban areas. In the current world, the industrial association is not the sole option to attract a large population; other income-generating options such as technology parks and tourism can have a place in the urban area. The planning of the new towns is pivotal for accommodating any such opportunities for generations. Therefore, physical form and the land use pattern should be developed considering multiple dimensions and changes that can occur

in the future in terms of opportunities, population growth, and the infrastructure and service needs for them. The fast-paced development attracts the people towards the urban areas, resulting in over-crowded spaces and overburdened infrastructures if there is no proper planning. In addition, the urban area should be capable of providing jobs to people from different economic and occupation sectors. If else, the unemployment rate will increase, thereby increasing poverty and forming informal settlements (slums). The planning measures are taken accounting for the heterogeneity of the society and the future population to avoid the unsustainable sprawl existing in the old cities.

Secondly, economic development can have unfavourable impacts on the social system and environment. Developing countries are in the transition phase, and they compromise on the ecosystem while struggling for economic growth (Nazneen et al. 2021). Several times, the urban authorities fail to evaluate the carrying capacity of the urban area and environmental effects while determining for fast economic developments. The new towns will be a new core for the environmental deterioration and social inequality if the authorities fail to incorporate approaches to restrict such adverse effects by enforcing relevant policies and planning strategies.

Although access to good infrastructure and services, such as water, electricity, transportation, education, and hospitals, is a determinant that attracts people towards the urban area, the effort, time, and money spent for availing the infrastructure and services are crucial indicators suggesting sustainability of the urban system. Economic growth is associated with the productivity of the urban area, which depends on its citizens' stability and efficiency. However, the urban areas in the Global South display disparity among the urban residents regarding accessibility to infrastructure and services, and a large population of about 70% or more are under-served by the municipal infrastructures (Mahendra et al. 2021). Thus, a massive gap in service accessibilities is observed between the privileged citizens and the rest of the urban residents, which forces the under-privileged to procure the necessary services through alternative or informal arrangements that affect their health, well-being, and livelihood. Such effects cause poverty and environmental exploitation that lead to loss of attractiveness of the new towns. Thus, the provision of safe, reliable, and affordable infrastructure and service for all the urban residents is a key determinant for developing countries to build a sustainable urban area.

Further, the urban areas should be growing smart with the rapid technological advancements happening in the world. The young and middle-age groups who are the major immigrants to the urban areas are riveted to the impression of technological advancements. Public administrations in developing countries are taking 'smart city' initiatives to make the urban system smart and convenient for their citizens (Tan and Taeihagh 2020.).

2.3 Environmental Quality

Urban areas are the predominant consumer of natural resources, and they impact three major resources: water, air, and soil. The urban areas contribute to more than seventy percent of the global Greenhouse Gas (GHGs) emissions (World Bank 2021), consume seventy-five percent of the natural resources, and generate fifty percent of global waste (Rama et al. 2021). Further, several urban areas face a shortage of clean water, waste management issues, and a lack of green space. As discussed in Sects. 2.1 and 2.2, higher inequality can also harm the environment by increasing atmospheric emissions and water pollution.

Three key approaches to improve environmental quality for the new town are identified and discussed here. First, act to preserve natural resources and balance the share of water bodies, green and open spaces in the urban areas. The urban area must have dedicated spaces for natural or man-made water bodies, green spaces as nature parks or forests, and open areas as playgrounds and neighbourhood parks. Majorly, future planning or sprawl should not affect the share of these natural resources. Second, the self-sustainability of the urban system, that is, the urban system must be producing, recycling, reducing, and reusing the resources it requires—for example, efficient and affordable water and waste management units, food and energy production, etc. Third is to reduce Greenhouse Gas (GHG) emissions through policy and planning measures. In order to protect biodiversity and the ecosystem, authorities can play an important role in integrating sustainability concerns in policy plans and focusing on green infrastructure (Valente et al. 2020). Besides, transportation and commerce play an important role in GHG emissions. New towns must promote active mode and public transport through several approaches. These include providing safer pedestrian paths and bicycling routes, developing the city along transit routes, providing safer, accessible, and affordable public transport, and providing the public and social infrastructures easily accessible through geographical equity and mixed-use development.

2.4 Resilience

Urbanization, climate changes, and unanticipated disasters affect people, places, economy, and environment in numerous ways. Urban areas are encountering several natural calamities such as flooding in recent years, which could be due to climate and spatial changes. Urban areas are the most challenged during all kinds of disasters, including epidemics. The high-density urban areas in low-income countries suffer the most during such instances of disasters. The rapid changes distress unplanned and informal settlements massively, and it is identified that about ninety percent of urban expansion in developing countries is informal and unplanned settlements or built near hazard-prone areas such as coastal areas (World Bank 2021). Thus, building resilient urban areas is identified as another prime determinant for the new

town development. Urban authority plays a major role in building resilient cities at different stages, as described below.

(i) Site selection stage through feasibility study (understanding the vulnerability, risks, and impacts) to identify the exposure risk,
(ii) Planning stage to reduce the vulnerability by determining the carrying capacity and appropriate building bye-laws, and land use distribution, primarily, service planning (water, sanitation, energy, transportation, and communication), and social infrastructure planning (accessible, affordable, and adequate emergency infrastructures such as health facilities, fire station, and transport options), and
(iii) Functioning or growing stage through recovery, adapting, and transforming actions for rapid changes due to urbanization, climate changes, and disasters. The actions can be accomplished through immediate policy plans and adopting innovations and technological advancements to aid urban areas to be resilient to the changes.

While adapting to innovations and technological advancements can support adjusting to the changes and reduce the negative impacts, certain other technologies and innovations can affect the environment, such as motorized transport modes and non-degradable wastes. Thus, the urban area needs to restrain the use of some innovations that affect the environment through policy and planning approaches. The resilience among the urban residents also is depended upon their socio-economic characteristics. The high-income group is generally more resilient to the changes as they tend to acquire their needs faster, providing money, while the vulnerable groups (like low-income people) suffer the most if the government does not support them or attempt to build urban equity. Figure 3 demonstrates the effect of the determinants on the sustainability of the urban area.

An urban area developed and functioning upholding sustainability principles would be providing a higher standard of living and satisfaction to its citizens. For this study, we hypothesize that 'a well-planned sustainable city would derive higher satisfaction from living and travel environment which is a subject of non-polluting trips'. Exploratory analysis coupled with statistical logistic regression models were applied to understand the residents' mode choice behaviour for short and leisure trips, weekday and weekend trips with respect to their socio-economic and demographic characteristics. This study would pave the way to identify determinants for sustainable new town planning and formulate environment-sensitive policies by reducing travel-based carbon footprint through efficient city planning.

3 Data and Methodology

This section focuses on the investigation methodology adopted for the study by describing the data collection methodology, study area, and research methodology. Thereby, the conceptual framework, hypotheses, modelling techniques, and the

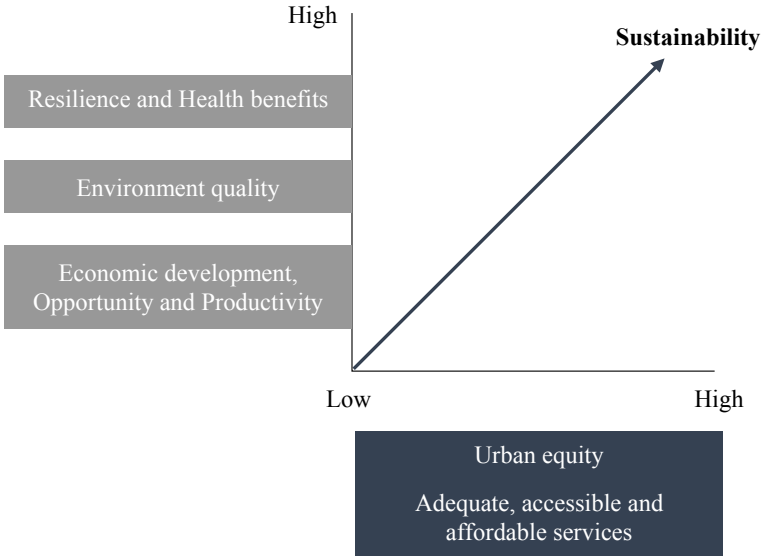

Fig. 3 Effect of the determinants on the sustainability of the urban area

description of the variables used in the models were elaborated in the following way.

3.1 Study Area

The new town of Navi Mumbai, a part of this mega region, was primarily designed to relieve Mumbai of unprecedented urbanization stress and growing population pressure (Jana and Sarkar 2018). A satellite city of area 108.6 km^2 is composed of 14 development nodes laid along a longitudinal transport corridor. Among these 14 nodes, the centrally located nodes of Belapur and Nerul were selected for this study. While Belapur is currently denoted as the 'Central Business District (CBD)' of Navi Mumbai, Nerul was selected for its typical residential neighbourhood character. Belapur with a total area of 24.5 km^2, and total population of 92,520, whereas Nerul with a total population of 3, 13,144 and 14.90 km^2 area hold a residential land use share of 67.34% and 25.16%, respectively. As illustrated in Fig. 4, the grid-iron pattern of residential development is observed in Belapur, while Nerul has witnessed a mixture of radial and grid-iron development.

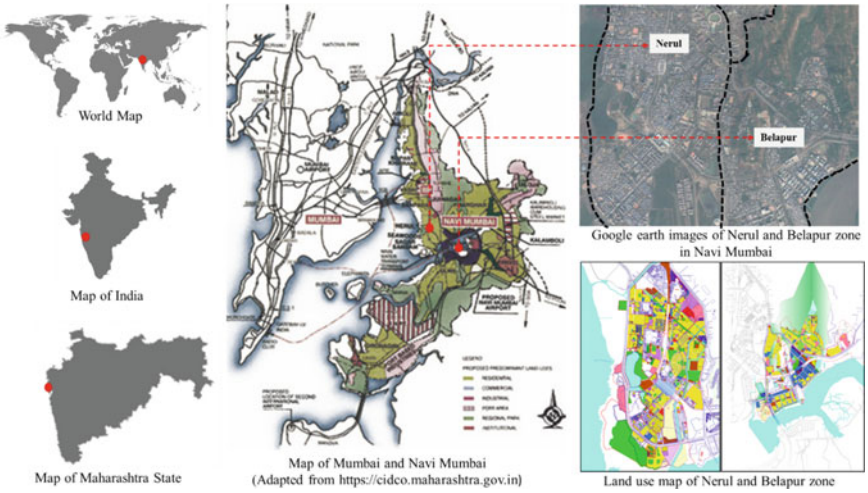

Fig. 4 Regional setting of the two studied sectors of Navi Mumbai. *Source* CIDCO website

3.2 Data Collection

The survey was conducted for 212 households between the months of August 2019 and October 2019. A major attempt was made to collect a representative sample across all the sectors of the two zones and reduce sampling bias. Personal face-to-face interviews of individuals were conducted at their households capturing the revealed preferences. In addition, face-to-face (F2F) computer aided personal interview (CAPI) survey questionnaires were selected to conduct the surveys, owning to their higher response rate. The main intention of the survey was to explore the residential satisfaction levels of the residents of the new town, who had recently shifted from other locations. Table 1 represents the general characteristics.

The survey was created in order to investigate the satisfaction and safety levels of the new town residents. The survey questionnaire was segregated into sections: Part I—socio-economic status of the households, their present and previous locations, and other household attributes; Part II—details of different facilities the households use, the distances of the facilities from the houses, their usage frequency, and overall satisfaction levels. In Part III, five-point scales marking '5' for very satisfied and '1' for very dissatisfied were utilized for understanding the households' satisfaction levels regarding the transport and living environment in the new towns. Data pertaining to the perception of safety and security of the households were also noted. Concerning residential satisfaction and well-being-specific investigation, questions also focused on the levels of happiness before and after shifting to Navi Mumbai.

The survey was conducted in both English and Hindi while making it comparable with the international studies. In the questionnaire, the general individual and household-level data was followed by information concerning the residential environment. A pilot survey of 20 households, taking 10 from each of the two zones,

Table 1 Profile of surveyed respondents in Navi Mumbai

Category	Sub-category	Percent
Zone	Belapur	66.98
	Nerul	33.09
Household income	3000–9000	11.79
	9001–18,000	43.86
	18,001–27,000	24.05
	27,001–40,000	14.62
	40,001–50,000	1.41
	50,001–65,000	2.83
	65,001–75,000	0.47
	75,001–90,000	0.47
	90,001–150,000	0
	More than 90,000	0.47
Type of house	Detached house	52.8
	High-rise apartment	40.5
	Villa	4.71
	Others (chawl)	1.88
House ownership status	Own	72.17
	Rent	27.83
Previous location	In-state migration	88.68
	Out-state migration	11.32

was conducted initially, followed by a field survey of 250 households. Finally, 212 samples were sorted for further analysis.

Out of 212 samples, 142 samples were collected from the Belapur zone, while 70 samples were collected from the Nerul zone. It was also observed that while approximately 11% of the studied population had shifted to Navi Mumbai from other states such as West Bengal, Rajasthan, Karnataka, and Bihar, the remaining 88.68% belonged to the in-state migrant sector.

4 Exploratory Findings and Discussion

4.1 Built-Environment Setting

The survey observed two major typologies of houses in Navi Mumbai, with 52.8% of detached houses and 40.5% high-rises. These findings corroborate with the reconnaissance survey, where detached individual-level houses and villas were observed in Belapur, whereas apartments and multi-storied cooperative housing were found

Fig. 5 Built-environment and street network pattern in Nerul. *Source* Authors

to manifest the built-environment character of Nerul as seen in Fig. 5. Around 72% of the households owned the houses, with 27% population paying monthly house rents in the range of 5000–1000INR (USD 69.69–139.38). 37.7% of the houses were found new with an age of less than or equal to 10 years, while the rest of the built-structures aged 11–25 years. While low- to medium-rise single houses were mostly observed in the inner sectors, the high-rises were bounded by high-rises.

An important character of Sector 8 of Belapur node is the CIDCO Artist Village, a residential neighbourhood designed by architect Charles Correa, where high-density incremental housing could be achieved with low-rise courtyard homes. Based on clusters of between seven and 12 pairs of houses arranged around communal courtyards, the buildings did get space to extend (see Fig. 6).

Owing to the medium slope of the land, and excessive rainfall during monsoon season, the specially designed centralized drainage canal as shown in Fig. 7 aids in streaming out the excess rainwater especially for 4 months a year.

Fig. 6 Built-environment and street network pattern in Belapur. *Source* Authors

Fig. 7 Nullah or drainage canal in Artist village, Belapur. *Source* Authors

4.2 Facility

The different facilities that were asked out included work office, supermarket, departmental store, kindergarten, school, hospital, pharmacy, gym, beauty salon, parks, bus stop, etc. While only community-level green belts and parks were found in Nerul, hierarchical arrangements of neighbourhood green belts, parks, and community-level parks were found in Belapur. Reconnaissance survey identified the presence of kindergarten, community centres, health care, and markets in close proximity to the residential zones. It was also observed that around 66 and 87.82% of the studied population used non-motorized mode to avail hospital and pharmacy. While 50% of the population had to use motorized mode for using the facility of supermarkets, departmental stores and regular local markets were found in close proximity with only 10% of motorized trips. Figure 8 also demonstrates the presence of local educational institutions within the residential communities, hence resulting in 72 and 86% of non-motorized trips for kindergartens and schools. Around 67% of the population

Fig. 8 Neighbourhood facilities in Navi Mumbai. *Source* Authors

used non-motorized trips for availing bank services. However, 50% of commuting trips were observed motorized.

4.3 Residential Satisfaction

Using results from household interviews with residents in two different sectors of the satellite town of Navi Mumbai—Belapur and Nerul, this section investigates several measures of neighbourhood and community satisfaction levels. On the neighbourhood scale, the best predictor of satisfaction was the respondents' rating of the living environment. At community or nodal scale, extent of community planning in the new town and accessibility to work and local facilities were important components of community appeal and satisfaction. In addition, the study also asked respondents to indicate their current satisfaction with the area followed by probes to get at the reasoning for the community rating. Quality of living components such as pavement quality of road network, width of vehicular road network and pedestrian paths, provision of parking space, and amount of public greenery. The respondents were asked on a 5-point scale. Figure 9 explains that satisfaction rates were high for all the afore-mentioned components, both the nodes of Belapur and Nerul. The planned areas scored well, with over 80% of the respondents being 'satisfied' or 'very satisfied' with the neighbourhood and residential environment in Navi Mumbai as shown in Fig. 9. Around 87% of the respondents were satisfied with the quality and width of the road network, which also corroborates with the observations from Fig. 10. Highest positive response was retrieved in case of the provision of the number of parking spaces.

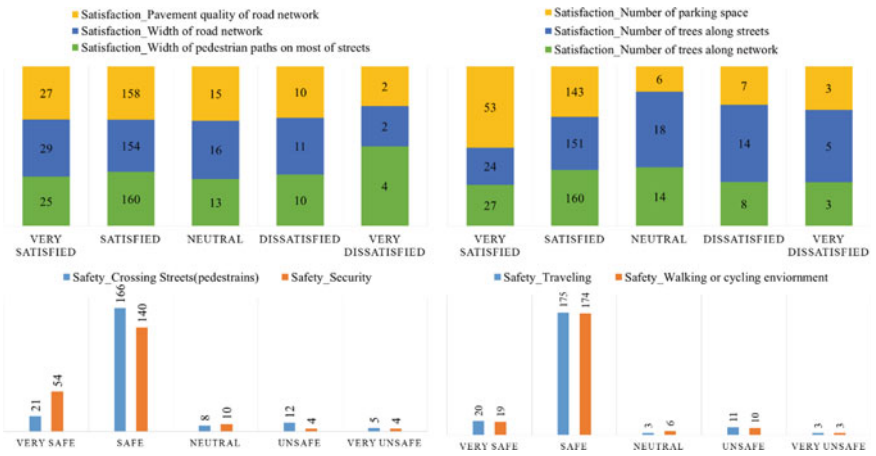

Fig. 9 Results of residential satisfaction survey

Fig. 10 Transport and living environment. *Source* Authors

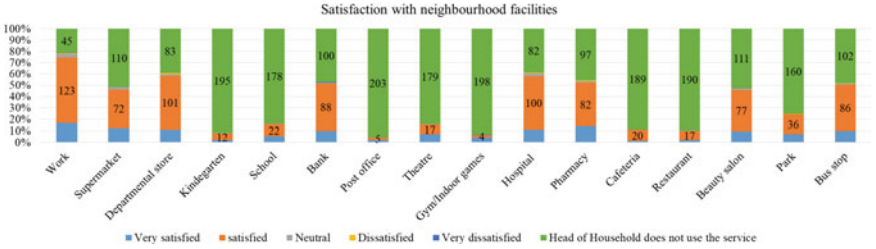

Fig. 11 Satisfaction levels with accessibility to community-level services in Navi Mumbai. *Source* Authors

In the study reported here, the length of the questionnaire precluded the depth of some dimensions of resident responses to their environments. Among these dimensions, an integrally crucial factor was the safety quotient. An effort was made to include a more comprehensive array of possible determinants of neighbourhood satisfaction. Safety quotient was found high in transport environment especially regarding travelling and cycling or walking environment, with 85–90% respondents marking 'safe' or 'very safe'.

The interview also provided a measure of 15 plausible local facilities other than work, and information pertaining to the respondents' overall satisfaction concerning the accessibility to the facilities was collected. Figure 11 explains that the most significant local community-level services required in a new town included commuting, departmental store, hospital, and pharmacy where the residents. While services like the post office, gym/indoor games, and restaurants are rarely used by the head of households or respondents, around 60–70% of respondents were reckoned to be highly satisfied with commuting and medical facilities.

4.4 Reasons for Shifting to Navi Mumbai

Integrally crucial measures often overlooked in new town studies is the reason behind shifting to the new areas on the one hand and happiness level after shifting to the new towns. Figure 12 (left) elucidates the reasons stated by the respondents for shifting

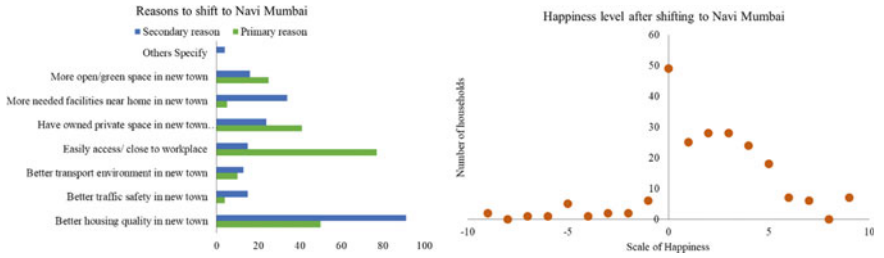

Fig. 12 Reasons to move to Navi Mumbai (left) and happiness levels after shifting to Navi Mumbai (right)

to Navi Mumbai. In this study, in order to apprehend the plausible factors behind shifting, the respondents were asked to emphasize and rank two specific reasons.

It was observed that the most preferred primary reason behind moving to Navi Mumbai was higher easy accessibility to the workplace, where around 80% of the respondents preferred to stay in close proximity to their workplace and hence shifted to Navi Mumbai (Zehner 1971). The results corroborate with another study conducted in 13 American new towns where one of the new community selection criteria was the nearness to workplace. This can be attributed to the presence of the CBD area and offices, especially in the Belapur node. However, around 85% of the respondents selected 'better quality of housing in new town' as the secondary reason behind shifting to a new town. New towns are often characterized by highly planned neighbourhoods with improved quality of housing characteristics and services. In addition, they tend to feature clustered service and recreational facilities in proximity to residential areas, connoting middle-class vision of 'good life'. While most new town related researches have focused on the performance of community service systems like elementary schools, health care, recreation, shopping, and transportation accessibility as fundamental criteria for assessing the quality of life of new towns (Omar 2009; Burby et al. 1975), this study reveals that improved built-environment is an integrally crucial factor behind selecting and shifting to a particular new town. Another important measure was the change in house ownership status. This study identified that around 45% of the respondents had shifted to Navi Mumbai as they owned a private house. Extremely affordable land prices in Navi Mumbai with respect to the core island city of Mumbai has pushed the middle-income group (MIG) to settle down in owned residences in the new town, which would otherwise have been impossible in the heart of Mumbai. Other reasons included the availability of higher facilities and public greenery.

Figure 12 (right) demonstrates the difference in happiness levels of the interviewed respondents after shifting to a new town. Surprisingly, it was observed that there was no change in happiness level for 25% of the population even after shifting to a planned neighbourhood. 9.5% of respondents expressed decreased happiness, with increased happiness for 67.4% of respondents. A more grounded understanding concerning the reasons behind the decreased happiness should be performed for this behaviour.

5 Conclusion

The study showcased that Navi Mumbai has well-satisfied its primary target of housing the excess urban population of Mumbai. Apart from delivering its citizens with improved housing opportunities, easier access to their work places it has offered convenience, comfort, and liveable environment. The access to varying transportation choices along with well-planned roads as well as social and public infrastructure such as parks, markets, shopping centres, bus terminals etc. access to these facilities and overall, better and safe environment has increased the residential satisfaction among the Navi Mumbai inhabitants, thereby achieving success in terms of sustainability. Despite few studies have highlighted the unaffordability of the housing choices in Navi Mumbai, thereby losing the purpose of serving as a satellite town, this study showcases that Navi Mumbai have served the purpose of serving as a sustainable township at various levels.

Acknowledgements The material presented in this manuscript is based in part upon work supported by the Ministry of Human Resource Development (MHRD), the Government of India (GoI) project titled CoE-FAST (14MHRD005). The authors acknowledge the support extended by the residents of the SRA colony for helping us access the units in resettlement colonies. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the MHRD, GoI.

References

Angel S, Parent JL, Civco DL, Blei AM (2012) Atlas of urban expansion. Choice Rev Online 50(03):50–122750–1227. https://doi.org/10.5860/choice.50-1227

Boyce JK (2018) The environmental cost of inequality. Sci Am 319(5):72–77. https://doi.org/10.1038/scientificamerican1118-72

Burby RJ, Weiss SF, Zehner RB (1975) A national evaluation of community services and the quality of life in American New Towns. Public Adm Rev 35(3):229–239. https://doi.org/10.2307/974756

Feleki E, Vlachokostas C, Moussiopoulos N (2018) Characterisation of sustainability in urban areas: an analysis of assessment tools with emphasis on European cities. Sustain Cities Soc 43:563–577. https://doi.org/10.1016/j.scs.2018.08.025

Fu Y, Zhang X (2017) Planning for sustainable cities? A comparative content analysis of the master plans of eco, low-carbon and conventional new towns in China. Habitat Int 63:55–66. https://doi.org/10.1016/j.habitatint.2017.03.008

Hartvigsen G (2013) Carrying capacity, concept of. Encycl Biodivers 695–701. https://doi.org/10.1016/b978-0-12-384719-5.00020-4

Jana A, Sarkar S (2018) Disparate housing strategies and practices of public and private enterprises in India: analysis of middle class housing and new towns. Cities 72:339–347

Jin X, Long Y, Sun W, Lu Y, Yang X, Tang J (2017) Evaluating cities' vitality and identifying ghost cities in China with emerging geographical data. Cities63:98–109. https://doi.org/10.1016/j.cities.2017.01.002

John B, Luederitz C, Lang DJ, von Wehrden H (2019) Toward sustainable urban metabolisms. from system understanding to system transformation. Ecol Econ 157:402–414. https://doi.org/10.1016/j.ecolecon.2018.12.007

Kennedy C, Cuddihy J, Engel-Yan J (2007) The changing metabolism of cities. J Ind Ecol 11(2):43–59

Kennedy C, Stewart ID, Ibrahima N, Facchini A, Mele R (2014) Developing a multi-layered indicator set for urban metabolism studies in megacities. Ecol Ind 47:7–15. https://doi.org/10.1016/j.ecolind.2014.07.039

Liu L-Y, Zheng B-H, Bedra KB (2018) Quantitative analysis of carbon emissions for new town planning based on the system dynamics approach. Sustain Cities Soc 42:538–546. https://doi.org/10.1016/j.scs.2018.08.006

Mahendra A, King R, Du J, Dasgupta A, Beard VA, Kallergis A, Schalch K (2021) Seven transformations for more equitable and sustainable cities. Washington DC

Nazneen S, Hong X, Ud Din N, Jamil B (2021) Infrastructure-driven development and sustainable development goals: subjective analysis of residents' perception. J Environ Manag 294:112931. https://doi.org/10.1016/j.jenvman.2021.112931

Omar DB (2009) Assessing residents' quality of life in Malaysian new towns. Asian Soc Sci 5:94

Osborn F (1942) New towns after the war, 2nd edn. J. M. Dent and Sons ltd, London. First Pub 1918

Osborn J, Whittick A (1977) New towns: their origins, achievements, and progress, 3rd edn. Leonard Hill, London, First Pub 1963

Papa R, Gargiulo C, Zucaro F (2016) Towards the definition of the urban saving energy model (UrbanSEM). Smart Energy Smart City 151–175. https://doi.org/10.1007/978-3-319-31157-9_9

Perulli P (2016) The urban contract: community, governance and capitalism. Taylor & Francis, United Kingdom

Rama M, Andrade E, Moreira MT, Feijoo G, González-García S (2021) Defining a procedure to identify key sustainability indicators in Spanish urban systems: development and application. Sustain Cities Soc 70:102919. https://doi.org/10.1016/j.scs.2021.102919

Shepard W (2015) Ghost cities of China. The story of cities without people in the world's most populated country (Asian Arguments). East Asian Sci Technol Soc Int J 13:3:471–473. https://doi.org/10.1215/18752160-7341559

Shaw A (2004) The making of Navi Mumbai. Orient Longman, India

Tan SY, Taeihagh A (2020) Smart city governance in developing countries: a systematic literature review. Sustainability 12. https://doi.org/10.3390/su12030899

Thomas N, Bandyopadhyay S, Jana A (2019) Investigating the association of individual and neighborhood characteristics with travel time: empirical evidences from Mumbai, India. J East Asia Soc Transp Stud 13. https://www.jstage.jst.go.jp/article/easts/13/0/13_238/_pdf/-char/en

UNCTAD (2020) Total and urban population. UNCTAD E-handbook of statistics 2020. https://stats.unctad.org/handbook/Population/Total.html

UNCTAD (2021) Total and urban population, annual. Unctad.org. United Nations conference on trade and development. unctadstat.unctad.org/wds/TableViewer/tableView.aspx?ReportId=97

United Nations (2015) The 2030 agenda and the sustainable development goals

Valente D, Pasimeni MR, Petrosillo I (2020) The role of green infrastructures in Italian cities by linking natural and social capital. Ecol Indic 108:105694. https://doi.org/10.1016/j.ecolind.2019.105694

Williams S, Xu W, Tan SB, Foster MJ, Chen C (2019) Ghost cities of China: identifying urban vacancy through social media data. Cities 94:275–285. https://doi.org/10.1016/j.cities.2019.05.006

World Bank (2021) Urban development. Overview. http://www.worldbank.org/en/topic/urbandevelopment/overview

World Commission on Environment and Development (1987) Report of the World Commission on Environment and Development: our common future towards sustainable development 2. Part II. Common challenges population and human resources. https://sustainabledevelopment.un.org/content/documents/5987our-common-future.pdf

Zehner R (1971) Neighborhood and community satisfaction in new towns and less planned suburbs. J Am Plann Assoc 37:379–385

Chapter 5
Urban Flood Risk Mapping: A State-of-the-Art Review on Quantification, Current Practices, and Future Challenges

Subhankar Karmakar, M. A. Sherly, and Mohit Mohanty

1 Introduction

Many cities across the globe have been facing accelerated flood risk due to booming urbanization and dense population (Shen et al. 2019; Smith et al. 2019), climate-change-induced extreme rainfall and sea-level rise (Winsemius et al. 2015; Paprotny and Terefenko 2017), tides and storm surges (Wahl et al. 2015; Ikeuchi et al. 2017), cyclones (Hernández et al. 2017), and land subsidence (Miller and Shirzaei 2019). The International Disaster Database, CRED (2015), estimates that around 43% of all natural disasters (floods, storms, droughts, earthquakes, extreme temperature, and others) that occurred worldwide during 1995–2015 were due to floods, accounting for 56% of the disaster-affected population (as shown in Fig. 1). The Asiatic region, with one-third of the Earth's land surface, is the most prone to frequent floods according to the flood events statistics collected globally during 1900–2013. Asia accounts for 41 and 61% of the total number of flood events and total economic damages,

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P. Banerji and A. Jana (eds.), *Advances in Urban Design and Engineering*, Design Science and Innovation, https://doi.org/10.1007/978-981-19-0412-7_5

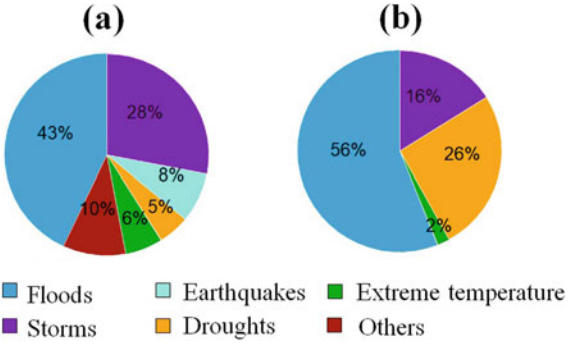

Fig. 1 **a** Occurrence of natural disasters, and **b** Per cent of people affected by natural disasters worldwide during 1995–2015 (*Source* CRED/UNISDR 2015)

respectively, while the Americas account for 23 and 17%, Africa for 20 and 1%, Europe for 13 and 19%, and Oceania (and Australia) for 3 and 2%, respectively (see Fig. 2).

Hirabayashi et al. (2013) assessed the trend of global flood risk in the twenty-first century using different climate models, and found a clear, positive trend in the likelihood of floods, especially in Southeast Asia, Eastern Africa, Peninsular India, and the northern half of the Andes. Arnell and Gosling (2016) indicate a strong likelihood that the current 100-yr flood would occur twice as frequently across 40% of the global regions, taking the global risk to more than 187% in 2050. The study also highlights that the most adverse impacts of climate change on floods would be noticed in Asia. The same finding is supported in a study by Winsemius et al. (2015), who also recommend that the high- and low-income countries should consider investing substantially in suitable adaptation measures to combat serious flood impacts at a later period. Numerous other studies have reported on the possible rise in flood risk

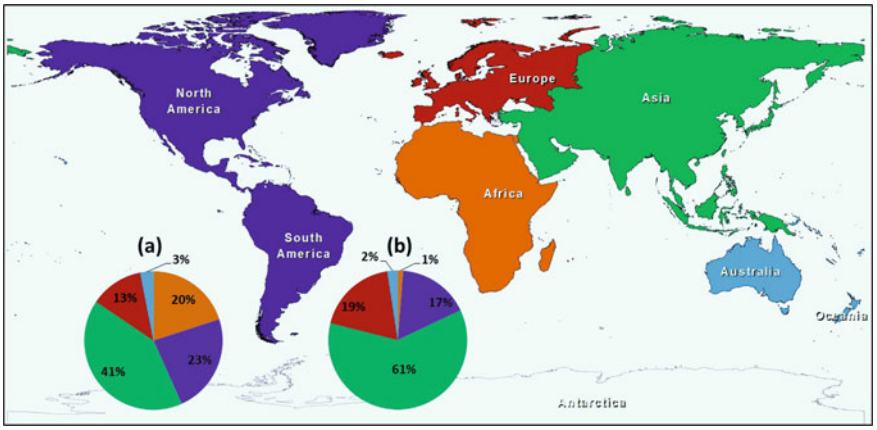

Fig. 2 **a** Occurrence of floods, and **b** Economic damages due to floods worldwide during 1900–2015 according to EM-DAT (*Source* http://www.emdat.be/database)

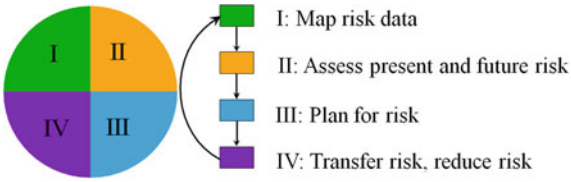

Fig. 3 Cyclic process of flood risk management (adapted from FEMA (2012))

at national and local scales (Bouwer et al. 2010; Te Linde et al. 2011; Alfieri et al. 2016; Jenkins et al. 2017; Xu et al. 2019).

Urban floods are the result of not just natural phenomena but also various anthropogenic activities (Chang and Franczyk 2008; WMO 2008; NDMA 2010; Ranger et al. 2011). A root cause analysis is essential to propose necessary preventive and remedial measures against urban floods. The two primary causes of the increasing trend of urban floods can be attributed to climate change and urbanization. Climate change is expected to influence rainfall, temperature, sea level, and land subsidence (Trenberth et al. 2007; Blöschl et al. 2017). The main indicator of urbanization is land use/land cover (LULC), which becomes more impervious with rapid urbanization (Blum et al. 2020). Slovic (1987) states that there is '*wisdom as well as error*' in public attitude and perception of risk. Basic conceptualization of risk is different for the general public, which reflects legitimate concerns that are typically omitted in an expert risk assessment; hence, people's participation is a critical input for any flood risk management programmes. This calls for efficient and effective flood risk management, which consists of risk mapping, risk assessment, and risk management planning. The whole procedure is cyclic with a feedback loop system (FEMA 2012) as shown in Fig. 3.

There are numerous works in the field of urban flood risk mapping (Barredo and Engelen 2010; Karmakar et al. 2010; Dewan 2013; Darabi et al. 2019; Zhou et al. 2019); however, none of these studies addresses all relevant factors of hazard, exposure, and vulnerability under a single framework. Although vulnerability is a key component of risk mapping, unfortunately, its assessment and quantification are often less advanced than hazard mapping and quantification (Birkmann 2007), which is evident from the existing works of flood risk mapping.

Moreover, there are several contradictions in the conceptualization of vulnerability and its assessment by technocrats and social scientists (Cutter 1996; Cutter et al. 2000, 2003; Kumpulainen 2006; Vojinovic and Abbott 2012; Sherly et al. 2015). Most of the earlier literature on flood vulnerability consider physical, infrastructure, and economic vulnerabilities; however, social vulnerability is also an important factor, and has been ignored often by technocrats. The present chapter describes various components of urban flood risk and their recent scientific developments. In doing so, it also highlights the current research trends and future challenges with risk mapping. The study also highlights the importance of considering the flood vulnerability aspect in flood risk mapping, and entails the need to provide an equal emphasis on both scientific understandings as well as social aspects.

2 Urban Flooding

Floods in urban areas occur either due to local drainage problems, river overflows, coastal storm surges and wave actions, flash floods, or a combination of all of these (O'Donnell and Thorne 2020). Most of the coastal cities across the globe are at high flood risk that includes cities such as Guangzhou, Mumbai, Kolkata, Guayaquil, Shenzhen, Miami, Tianjin, New York, Ho Chi Minh City, New Orleans, Jakarta, Abidjan, Chennai, Surat, and so on (Hallegatte et al. 2013). Urban flooding differs from rural flooding in many aspects, and the consequences of flooding become more severe in urban areas due to the higher density of population and concentration of economic resources such as infrastructure, commercial centres, and so on. Moreover, the flooding pattern becomes more complicated when natural drainage lines get altered due to modification of landscapes, stormwater networks, buildings, and other constructions (Alves et al. 2020). A clear understanding of these differences (as shown in Table 1) is essential for the formulation of an appropriate methodology for flood risk management. The increasing trend of floods can be attributed to climate change and urbanization, which are explained in the following subsections.

2.1 Implications of Climate Change on Flood Risk

The Intergovernmental Panel on Climate Change (IPCC) attribute the first root cause of ever-increasing flood risk to climate change: 'Warmer and wetter' (Kerr 2007; Hoegh-Guldberg et al. 2018). Projected changes in rainfall patterns result in more intense rains that can cause severe floods due to the 'warmer-gets-wetter' mechanism

Table 1 Differences between urban flooding and rural flooding

Aspect	Urban flooding	Rural flooding
Cause of flooding	Mostly occurs when drainage capacity of sewer network is exceeded by the storm flow	Occurs when a river overflows its embankments and occupies the nearby lands
Areal extent	The entire city can be affected either directly or indirectly	Only areas closer to the river get affected mostly
Affected population	The worst affected regions of urban floods are often highly populated and centres of economic activities and critical facilities	The flood-affected areas are often sparsely populated and incur more agricultural damages
Evacuation	Flash floods can cause havoc, leaving no time for evacuation. Both transportation and accessibility to resources are severely affected during floods, which aggravate the risk of damage	There is time for evacuation to safer areas based on the river stage

(Amann et al. 2015; Li et al. 2019a, b). This mechanism is evident more in urban areas due to the 'urban heat island effect' that is a result of increased impervious surfaces, buildings, and air pollution (Shastri et al. 2015; Paul et al. 2016; Zhou et al. 2017; He et al. 2019). Furthermore, atmospheric circulation influences storm tracks, consequently, dry areas become drier while wet areas become wetter. There are several studies that investigate the influence of climate change on flood risk (see Cunderlik and Simonovic 2007; Simonovic 2012; Bowering et al. 2014; Peck et al. 2014; Arnell and Gosling 2016; Mahmoud and Gan 2018, Xu et al. 2019; Haer et al. 2020).

2.2 *Impact of Urbanization on Flood Risk*

The second root cause of the increasing trend of floods is urbanization, which shows a clear upward trend with a pronounced and rapid transition from rural to urban areas in countries that are not well developed, increasing their vulnerability and exposure to floods. Figure 4 shows the current and projected trend of urbanization during 1950–2050 by a study conducted by UNDESA (2015). This study also reports that 233 out of 633 largest cities or urban agglomerations around the world are located in or near areas with a high risk of flooding, which may affect a population of 663 million in terms of social, economic, environmental, and infrastructural vulnerabilities. The vulnerability referred to here is an intrinsic characteristic of an urban region as per

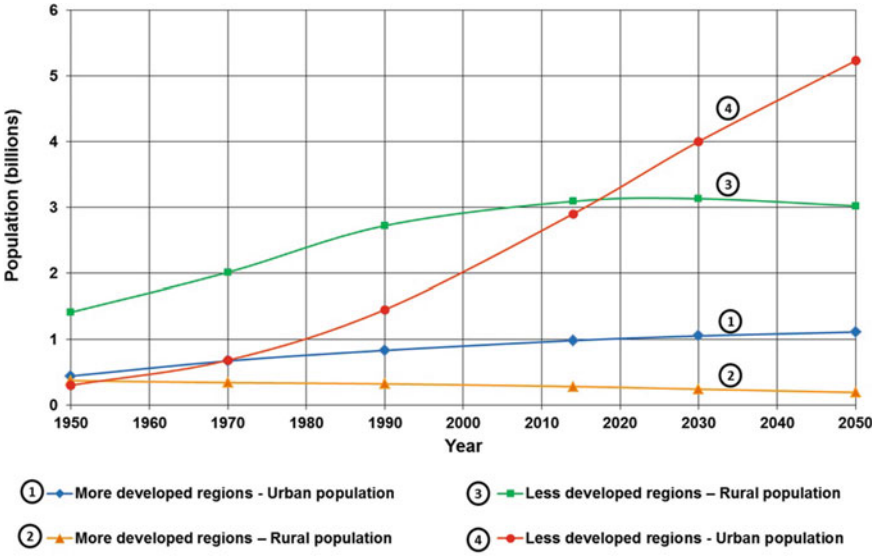

Fig. 4 Urban and rural populations by development group during 1950–2050 (Data *source* UNDESA 2015)

Blaikie et al. (1994), and it determines the region's degree of susceptibility, coping capacity, and resilience to floods.

LULC has a complex influence on multiple components of the hydrological cycle, namely infiltration, interception, resistance to overland flow, surface retention, and evapotranspiration (Coutu and Vega 2007; Sun et al. 2018). As a result, the relationship between land use and storm runoff is extremely complicated (Liu et al. 2005; Barredo and Engelen 2010). A study conducted by the United States Department of Agriculture (USDA 2001) gives a typical example of the effect of urbanization. The study concludes that contribution to surface runoff from precipitation may increase from 10 to 55% when land-use change occurs from natural ground cover to almost 100% of the impervious area, while infiltration may reduce from 50 to 15%. Subsequently, the higher proportion of urbanized areas increases the extent of flood lines (Nirupama and Simonovic 2007; Jung et al. 2011; Brody et al. 2013) and, thus, results in higher flood risk. The inefficient drainage system in many urban areas, combined with impervious catchments due to poorly planned development activities, results in excessive runoff during heavy rainfall (Shahapure et al. 2010). Consequently, flooding occurs more frequently, inundating large areas within a few hours and continuing for several days. The prediction of exact locations of areas at flood risk (known as chronic flood spots) is also a crucial task. Low-lying areas are the worst affected because the runoff will accumulate at these points. The spatial distribution of flood risk can be modelled using GIS-integrated flood simulation tools. Karmakar et al. (2010) investigated how flood risk at one location might impact a neighbourhood due to the interdependent nature of a neighbourhood resource, its accessibility, and availability.

2.3 Flood Risk

In the context of natural or human-induced hazards, Crichton (1999) defines risk as the probability of a loss, and this depends on three elements: hazard, vulnerability, and exposure. If any of these three elements of risk increases or decreases, so does the risk. Oppenheimer et al. (2014) provide a generalized concept of risk, which is the result of the interaction of hazard, vulnerability, and exposure. They further identify that changes in both the climate system and socio-economic processes are central drivers to modifications in risk. Figure 5 illustrates the generalized concept of flood risk. Here, the three circles represent the three components of risk, namely hazard, exposure, and vulnerability, whereas the area under each circle indicates the magnitude of each component. The intersection of the circles will form a spherical triangle and its area represents the magnitude of risk.

According to the United Nations Department of Humanitarian Affairs UNDHA (1992), risk is the expected loss (of lives, persons injured, property damaged, and economic activity disrupted) due to a particular hazard for a given area and reference period. Flood risk is expressed here as a function of hazard, exposure, and vulnerability. A flood risk map consists of a hazard map and vulnerability map, where the

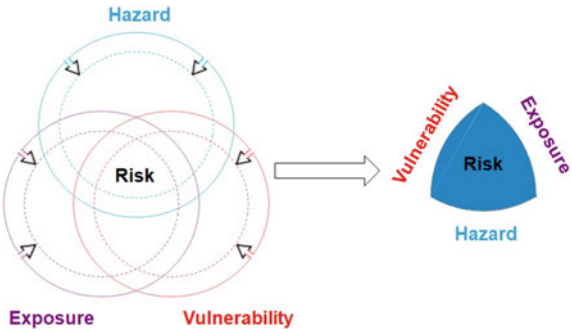

Fig. 5 Construct and components of flood risk

exposure may be integrated in terms of land use and soil type (Peck et al. 2007; Barredo and Engelen 2010; Karmakar et al. 2010; Hallegatte et al. 2010; Ranger et al. 2011; Müller 2012; Dewan 2013; Mohanty et al. 2020a). The components of urban flood risk mapping are explained in detail in the following sections.

3 Estimation and Mapping of Flood Hazard

Flood hazard is defined as the probability of occurrence of a disastrous event of a particular magnitude or severity (Baldassarre et al. 2009). There are multiple approaches to mapping flood hazard, which can be broadly divided into paleo-hydrological (Benito et al. 2004; Bajard et al. 2020; Toonen et al. 2020), hydro-geomorphological (Lastra et al. 2008; Camarasa-Belmonte and Soriano-García 2012; Motevalli and Vafakhah 2016; Samela et al. 2017), and hydrological-hydraulic (Bates and Horritt 2005; Tyrna et al. 2018; Moftakhari et al. 2019).

In this review, we focus on the third approach which is relevant to urban flood modelling studies. A flood hazard map is a vital component for appropriate land-use planning in flood-prone areas, as they provide crucial information to increase awareness of the likelihood of flooding among the public, local authorities, and other organizations (Macchione et al. 2019). They also encourage the people living and working in flood-prone areas to find out more about the local flood risk, and to take appropriate actions. Such maps can be prepared from flood simulation where the various component models of flood hazard map are design rainfall model and rainfall-runoff model—the latter consists of floodplain inundation (2D) and channel flow routing (1D) models. Figure 6 shows a simplified framework for urban flood hazard mapping that considers a three-way hydrodynamically coupled flood modelling.

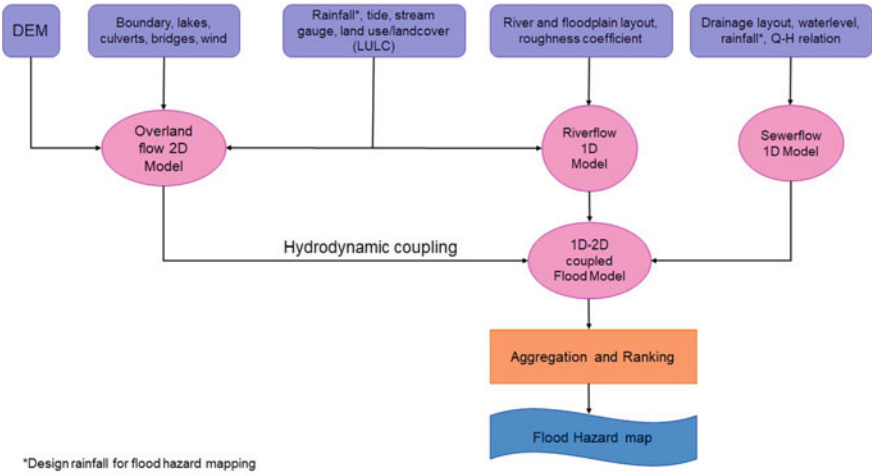

Fig. 6 A simplistic framework for urban flood hazard mapping

3.1 Design Rainfall Model

Design rainfall time series is a critical input to risk-based hydrologic analyses of flood risk mapping (Zhang and Singh 2007; Sherly et al. 2016; Mohanty et al. 2018), including design of hydraulic structures like stormwater drains, culverts, levees, etc. (Verstraten et al. 2019).

The concept of design rainfall is based on event-based flood modelling with its main components as frequency or return period, total depth, duration, and temporal pattern, which can be estimated through intensity–duration–frequency (IDF) curves or depth-duration-frequency (DDF) curves along with a design temporal pattern (Wenzel 2013). IDF curves provide constant rainfall intensity values for various combinations of duration and return period (Sivapalan and Blöschl 1998; Grimaldi and Serinaldi 2006), whereas DDF curves plot rainfall depth values (Buishand 1991; Overeem et al. 2008). Here, DDF curves show the flexibility of using either synthetically derived temporal patterns (Prodanovic and Simonovic 2004) or observed temporal patterns (Rahman et al. 2002), while IDF curves can be combined with synthetic patterns only. Here, the temporal pattern may be derived synthetically or through analysis of the observed patterns, while the spatial pattern may be obtained through spatial interpolation techniques such as Kriging, inverse distance weighted (IDW) method (Brath et al. 2003; Durrans and Kirby 2004), or assumed to be constant across a small catchment.

3.2 Rainfall-Runoff Model

As urban flooding is a combination of subcritical and supercritical flows that are hindered by buildings and other structures along the flow path, urban flood modelling has always been a challenging task using typical one-dimensional (1D) and two-dimensional (2D) numerical codes (Patro et al. 2009; Wang et al. 2019). 1D models require post-processing to produce realistic flood lines, as they are unable to resolve complex floodplain flow fields. The planar GIS method, where potential flood lines are extended along lines of equal elevation, may be inadequate for characterizing urban flooding as hydraulic connectivity, mass and momentum conservation must be taken into account for accurate mapping of urban flooding events (Bates and Horritt 2005; McMillan and Brasington 2008). Moreover, McMillan and Brasington (2008) find that the hydraulic approximations required in a 1D model do not allow the representation of lateral momentum transfer between river and floodplain. Also, it cannot account for the pressure gradients that cause large variations in the water flow rates between two areas. At the occurrence of any flood defence failure, there may be increased flood flows through complex urban areas and in such situations, only 2D models are capable of providing a dynamic representation of water transport onto and around the floodplain (Teng et al. 2017). However, 2D models find it impossible to model structural elements which are typically 1D with supercritical or pressurized flow conditions (Gilles and Moore 2010). Hence, 2D shallow water equations may be used for overland flow modelling while 1D form may be sufficient for channel flow routing.

3.2.1 Floodplain Inundation Model (Overland Flow Model)

The shallow water continuity equation in 2D floodplain can be written as (Chow et al. 1988)

$$\frac{\partial \xi}{\partial t} + \frac{\partial p}{\partial x} + \frac{\partial q}{\partial y} = I_{eff,t} \tag{1}$$

$$I_{eff,t} = P_t - E_t - S_t - W_t - I_t \tag{2}$$

where ξ is surface elevation, p and q are flux densities along x and y directions, and $I_{eff,t}$, P_t, E_t, S_t, W_t, and I_t are effective precipitation, rainfall depth, evapotranspiration, surface storage loss, wetting loss, and infiltration loss at time 't', respectively.

The 2D shallow water equations for momentum conservation along x and y directions may be expressed as follows:

$$\frac{\partial p}{\partial t} + \frac{\partial\left(\frac{p^2}{h}\right)}{\partial x} + \frac{\partial\left(\frac{pq}{h}\right)}{\partial y} + gh\frac{\partial \xi}{\partial x} + \frac{gp\sqrt{p^2+q^2}}{C^2h^2} - \frac{1}{\rho_w}\left(\frac{\partial(h\tau_{xx})}{\partial x} + \frac{\partial\left(h\tau_{xy}\right)}{\partial y}\right)$$
$$- \Omega_q - fVV_x + \frac{h}{\rho_w}\frac{\partial p_a}{\partial xy} = 0 \tag{3}$$

$$\frac{\partial q}{\partial t} + \frac{\partial\left(\frac{q^2}{h}\right)}{\partial y} + \frac{\partial\left(\frac{pq}{h}\right)}{\partial x} + gh\frac{\partial \xi}{\partial y} + \frac{gp\sqrt{p^2+q^2}}{C^2h^2} - \frac{1}{\rho_w}\left(\frac{\partial\left(h\tau_{yy}\right)}{\partial y} + \frac{\partial\left(h\tau_{xy}\right)}{\partial x}\right)$$
$$- \Omega_q - fVV_y + \frac{h}{\rho_w}\frac{\partial p_a}{\partial xy} = 0 \tag{4}$$

Here, $p = hu$ and $q = hv$ where u and v are the depth-averaged velocities along x and y directions, where h (x,y,t) is water depth $(= \xi - I_{\text{eff,t}})$, $C(x, y)$ is Chezy resistance, g is acceleration due to gravity, $f(V)$ is wind friction factor, V, V_x, V_y (x, y, t) are wind speed and its components in x and y directions, Ω (x, y) is Coriolis parameter (latitude dependent), p_a (x, y, t) is atmospheric pressure, ρ_w is density of water, and τ_{xx}, τ_{xy}, τ_{yy} are components of effective shear stress (Chow et al. 1988).

3.2.2 Channel Flow Model

The governing equations for channel flow modelling are the Saint–Venant's equations of 1D open channel hydraulics that consist of conservation of continuity and momentum as given below (Chow et al. 1988)

$$\frac{\partial A}{\partial t} + \frac{\partial Q}{\partial x} = 0 \tag{5}$$

$$\frac{\partial Q}{\partial t} + \frac{\partial}{\partial x}\left(\frac{\alpha Q^2}{A}\right) + gA\frac{\partial h}{\partial x} + \frac{gQ|Q|}{C^2AR} = 0 \tag{6}$$

where Q is discharge, A is flow area, q is lateral inflow, h is stage above datum, C is Chezy resistance coefficient, R is hydraulic or resistance radius, and α is momentum distribution coefficient (Chow et al. 1988).

3.2.3 Sewer/Stormwater Flow Model

For an urban region, sewer or stormwater network consisting of a pipe network plays an important role in the drainage of floodwaters (Martins et al. 2018). The hydraulics of pipe flow varies based on its flow state as free surface flow or pressurized flow. The continuity and momentum equations for unsteady flow through pipes can be described as follows (Rossman 2006):

$$\frac{\partial A}{\partial t} + \frac{\partial Q}{\partial x} = 0 \tag{7}$$

$$\frac{\partial Q}{\partial t} + \frac{\partial}{\partial x}\left(\frac{Q^2}{A}\right) + gA\frac{\partial h}{\partial x} + gAS_f = gAS_0 \tag{8}$$

where Q is discharge, A is flow area, y is flow depth, g is acceleration due to gravity, x is distance in the flow direction, t is time, S_0 is bottom slope, and S_f is friction slope.

3.2.4 Hydrodynamic Coupling of 1D-2D Models

In urban flood modelling, dynamic coupling of 1D and 2D models has been the focus of recent researchers to avoid limitations of stand-alone 1D or 2D approaches (Leandro et al. 2009; Martínez et al. 2018; Noh et al. 2018). Due to computational limitations, hydraulic models have typically solved 1D St.-Venant equations, which are computationally efficient, but cannot accurately model complex topography. Recent advances in computational capacity have made 2D solvers more feasible (Kalyanapu et al. 2011; Hou et al. 2020). A 2D model can accurately model complex topography, but it is not computationally efficient as a 1D model, and has difficulty in modelling in-channel structures. Advantages of both types of models can be combined by coupling 1D and 2D models. Hence, a combination of the 1D model of the channel and/or sewer network with a 2D model of the floodplain can yield better results in terms of accuracy and computational efficiency in hydraulic modelling (Noh et al. 2018). Flood plain modelling may involve dynamic prediction of inundation areas within complex urban areas that comprise constructions, channels, tunnels, or roadwork in addition to the natural marshes and plains, which may determine flow paths and flood wave propagation. To overcome all limitations of manual coding, which requires enormous computational effort and time, there are a number of commercially available flood simulation packages that include ANSYS CFX (www.ansys.com), SOBEK (https://www.deltares.nl/en/software/sobek/), Delft3D (https://oss.deltares.nl/web/delft3d), FLO-2D, (https://flo-2d.com/), MIKE-FLOOD (https://www.mikepoweredbydhi.com/), and TUFLOW (https://www.tuflow.com/). The modelling tools must be chosen as per the application and requirements of the site (Mohanty 2019). A list of the most widely used 1D, 2D, and 1D-2D coupled flood models and their sources is outlined in Table 2.

3.3 Flood Hazard Ranking

Flood hazard can be expressed as a function of both flood severity and probability. Flow depth and velocity are the two main attributes of flood severity, which can

Table 2 Widely used 1D, 2D, and 1D-2D coupled flood models

	Model name	Developer	Source
1D model	HEC-RAS	US Army Corps of Engineers	http://www.hec.usace.army.mil/software/hec-ras
	SIPSON	University of Exeter	Not available
	MASCARET	Electricite de France-Recherche & Developpement (EDF-R&D) in collaboration with Centre d'Etudes Techniques Maritimes et Fluviales (CETMEF)	Not available
	InfoWorks RS	Innovyze	https://www.innovyze.com/en-us/products/infoworks-icm
	FASTER	Cardiff University	Not available
	SOBEK suite	DELTARES	https://www.deltares.nl/en/software/sobek/
	Flood Modeller Pro 1D solvers	CH2M Hill (formerly Halcrow Group)	https://www.floodmodeller.com/downloads/
	MIKE 11/MIKE HYDRO River	Danish Hydraulic Institute	https://www.mikepoweredbydhi.com/products/mike-flood
	TUFLOW ESTRY	BMT WBM	https://www.tuflow.com/
2D model	HEC-RAS 2D	US Army Corps of Engineers	http://www.hec.usace.army.mil/software/hec-ras
	Flowroute-i	Ambiental	https://www.ambientalrisk.com/
	TELEMAC 2D	Electricite de France	http://www.opentelemac.org/
	InfoWorks 2D	Innovyze	https://www.innovyze.com/
	SOBEK Suite	DELTARES	https://www.deltares.nl/en/software/sobek/
	Flood Modeller Pro 2D solvers	CH2M Hill	https://www.floodmodeller.com/
	MIKE 21 HD (Classic rectangular and flexible mesh)	DHI	https://www.mikepoweredbydhi.com/products/mike-21

(continued)

Table 2 (continued)

	Model name	Developer	Source
	TUFLOW Classic, 2D TUFLOW and GPU TUFLOW FV	BMT WBM	https://www.tuflow.com/
	CaMa-Flood	Tokyo University	http://hydro.iis.u-tokyo.ac.jp/~yamadai/cama-flood/index.html
1D-2D coupled model	UIM + SIPSON	University of Exeter	Not available
	TUFLOW CLASSIC	BMT WBM	https://www.tuflow.com/
	Flood Modeller Pro	CH2M	https://www.floodmodeller.com/
	SOBEK suite	DELTARES	https://www.deltares.nl/en/software/sobek/
	MIKE Flood	DHI	https://www.mikepoweredbydhi.com/products/mike-flood
	InfoWorks ICM	Innovyze	https://www.innovyze.com/en-us/products/infoworks-icm
	TRENT	Nottingham University	Not available
	LISFLOOD-FP	University of Bristol	http://www.bristol.ac.uk/geography/research/hydrology/models/lisflood/
	XPSWMM XPSTORM	XP Solutions	https://www.innovyze.com/en-us/products/xpstorm

be obtained by performing flood modelling (Mohanty et al. 2020a). As large flood events occur less frequently, flood probability is inversely related to magnitude. Flood hazard can thus be calculated as a discrete combined function of the event intensity (severity of the event) and return period (frequency). To define the event intensity, most of the existing methods use a combination of flow depth and velocity (O'Brien and Garcia 2012; Costabile et al. 2020). The three well-known methods are the Austrian method (Fiebiger 1997), the U.S. Bureau of Reclamation method (USBR 1988), and the Swiss method (OFEE 1997). The Austrian method calculates the total energy defined as $h + v^2/2\,g$, where h is the flow depth, v is the velocity, and g is the gravitational acceleration. The USBR method considers hazard as a combination of depth and velocity. They prepared charts and graphs for differentiating the magnitude of hazard for different categories such as adults, cars, and houses. The Swiss method determines the intensity in terms of a combination of h and the product of h and v. This

method has the advantage of assigning high intensities to high depths independently of the velocities. Also, intensities are calculated as a function of the maximum water depth generated throughout the event and the product of the maximum velocity multiplied by the maximum depth. Currently, there are very few works on urban flood hazard mapping that apply both coupled flood modelling and hazard ranking. Figure 7 illustrates a typical flood hazard ranking criteria adopted in the MAPPER module of the FLO-2D flood model. Figure 8 describes the representative efforts on urban flood inundation mapping and flood hazard mapping.

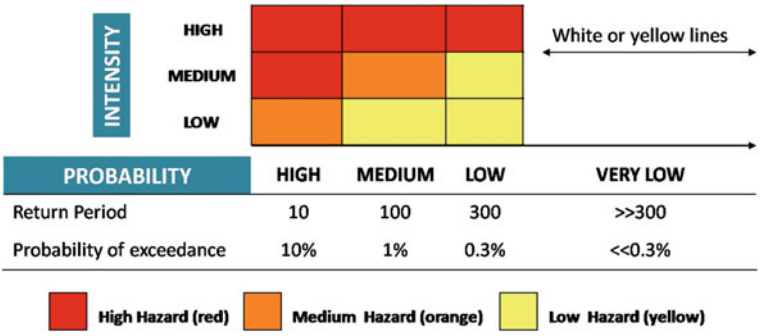

Fig. 7 Criteria of hazard rating in MAPPER (Conceptualized from FLO-2D 2009)

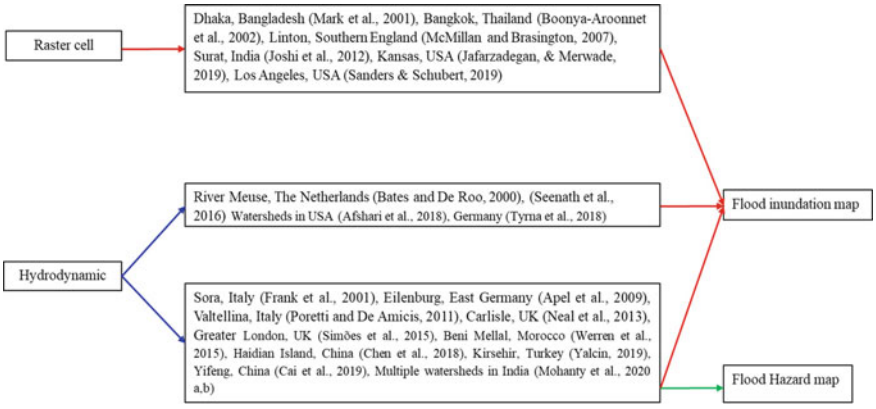

Fig. 8 Representative past efforts made on coupled 1D-2D urban flood inundation/hazard mapping

3.4 A Representative Flood Hazard Mapping of an Urban Catchment

The Mithi River catchment is one of the severely flood-affected regions in Mumbai City (Ghosh et al. 2020). The catchment, located at the heart of the city, is an urban-industrial ecosystem with its outlet at the mouth of the Arabian Sea (Sherly et al. 2015; Pathak et al. 2020). The catchment upstream comprises steep hilly regions, followed by relatively flat and highly industrialized areas, whereas the downstream has very sensitive mangrove wetlands estuary and slums. A coupled 1D-2D flood modelling approach is applied here to model overland flow and river flow using the FLO-2D flood model. FLO-2D is one of the most versatile flood modelling tools (Dimitriadis et al. 2016). The model has an in-built MAPPER module for generating flood hazard (Erena et al. 2018). This tool assumes flood hazard levels at a specific location as a function of both flood intensity and probability. Flood intensity is defined by flow depth and velocity. Flood probability is inversely related to flood magnitude. Flood hazard level is then defined as a discrete combined function of the event intensity (severity of the event) and return period (frequency). In this study, the flood modelling is performed by considering a 6-h and 100-yr return event design rainfall time series (Sherly et al. 2016), along with other relevant details such as river channel geometry, high-resolution Digital Elevation Model, river, lakes, buildings, and LULC (Fig. 9). The limits between the probability regions are defined for return periods of 10, 100, and 300 years, considering that the event of 10 years is highly probable, the event of 100 has an intermediate probability of occurrence, and the event of 300 years has a low probability of occurrence.

4 Flood Vulnerability

The word ‘Vulnerability’ is derived from its Latin root ‘vulnerable’, which means ‘to wound’, therefore vulnerability is the capacity to be wounded (Kates 1985; Dow 1992; Turner et al. 2003). Its assessment explores the social, economic, and political conditions that are likely to affect the capacity of individuals or communities to cope with or adapt to hazards (Cutter 1996). It is a powerful analysis that describes states of susceptibility to harm and for guiding the analysis of actions to enhance well-being through reduction of risk (Adger 2006). As per O’Brien et al. (2004), Adger (2006), and Füssel (2007), vulnerability (in the context of climate change) may be expressed as the combination of 3 components: Adaptive Capacity, Sensitivity, and Exposure. Adaptive capacity is the ability of a system to adjust to actual or expected climate stresses. Sensitivity is the degree to which a system will respond to a change in climate, either positively or negatively, and Exposure is the degree to which people are exposed to hazards. It has four dimensions: System refers to a population group, an economic sector, a geographical area, or a natural system. Attribute is the valued attributes of the vulnerable system that is threatened by its

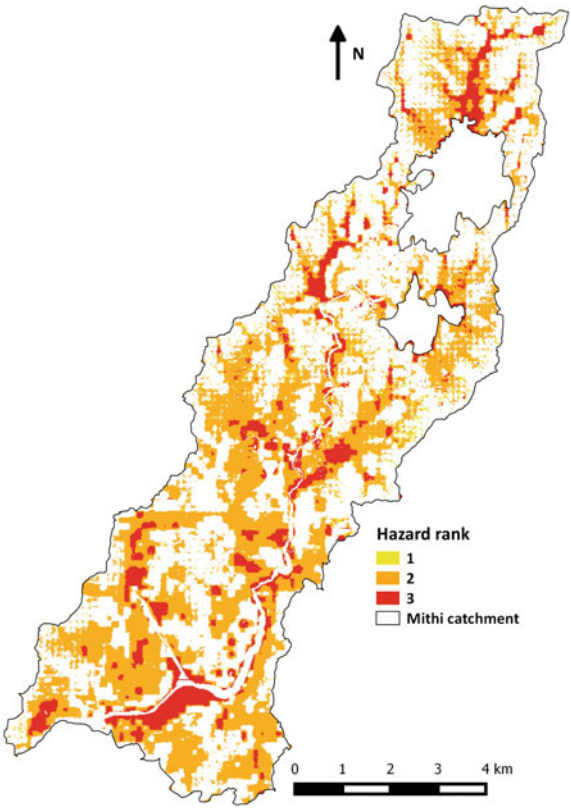

Fig. 9 Flood hazard map generated for Mithi catchment in Mumbai, India, using 6-h and 100-yr return event design rainfall in FLO-2D flood model

exposure to an extreme event, Hazard is a potentially damaging influence on a system, and Temporal Reference is the time period of interest.

Vulnerability is one of those terms that seems to defy consensus usage showing many different connotations, depending on the research orientation and perspective. There is no consensus about the precise meaning of the term vulnerability in the scientific literature, and it seems to be open to interpretation. In general terms, all definitions relate vulnerability to the consequences of hazard impacts, are able to cause damage and losses to a given element or set of elements at risk, and are expressed as the percentage of loss. Among social scientists, there is a quite convergence of opinion that vulnerability can be expressed in terms of variation in people's (system's) capacity to cope with hazards (Few 2003).

To sum up, the definitions of vulnerability tend to fall into two broad categories in terms of

- (potential) damage caused to a system by a particular hazard or climate-related event (hazards and impacts approach), or
- state that exists within a system before it encounters an external hazardous event.

In the former perspective, the role of the system in mediating the outcomes of hazards is downplayed or neglected. In the latter formulation, vulnerability is a property of a system ('inherent vulnerability' or, in the case of people, 'social vulnerability' (Adger et al. 2004) and it is the interaction of hazard with system vulnerability that produces an outcome/disaster (Brooks 2003).

4.1 Frameworks of Vulnerability

Vulnerability lies not only among individuals or groups but also inherent in social relations and processes. The technology should aim at the overall progress of the society in a sustainable fashion. There are various frameworks of vulnerability depending on the contextual goals to be achieved, namely Double structure of vulnerability (Bohle 2001), Sustainable livelihood framework (Chambers and Conway 1992; DFID 1999), Framework of hazard and risk (Davidson and Shah 1997; Bollin et al. 2003), ISDR framework for disaster risk reduction (UN/ISDR 2004), Vulnerability in the global environmental change community (Turner et al. 2003), Onion framework (Bogardi and Birkmann 2005), Pressure and release model (PAR model) (Blaikie et al. 1994; Wisner et al. 2004), Holistic approach to risk and vulnerability assessment (Cardona 1999), BBC conceptual framework (Bogardi and Birkmann 2005; Cardona 1999), Vulnerability to access relative eco-system vulnerability to climate change (Lee et al. 2018), Conceptual framework for vulnerability study of socio-ecosystem (Berrouet et al. 2018), and Vulnerability to climate change (Li et al. 2019a, b). The various conceptual frameworks mentioned above differ in scope and thematic focus. Different vulnerability frameworks serve different disciplinary groups and consequently there is no generally applicable model that can satisfy all specific needs. The heterogeneous views on vulnerability are reflected in various analytical concepts and models of how to systematize it. These conceptual models are an essential step towards the development of methods to assess vulnerability and systematic identification of relevant indicators. Once the final set of vulnerability indicators are chosen from a set of potential indicators, the next step is to perform mathematical operations for quantification of vulnerability.

4.2 Classification of Vulnerability

Vulnerability is broadly classified into natural and human vulnerability (Dibben and Chester 1999; Alcántara-Ayala 2002). Natural vulnerability depends on the threatening natural hazards, related to geographical location, such as volcanic vulnerability, flooding vulnerability, land sliding vulnerability, tsunamis vulnerability, hurricane vulnerability, and so on. Human vulnerability is based on social, economic, political, and cultural systems of human activities. Peck et al. (2007) and Karmakar et al. (2010) classify human vulnerability into four non-intersecting classes, i.e., Social,

Economic, Infrastructure, and Physical. Social vulnerability refers to individual characteristics of people that relate to their differential incapability to deal with hazards (Blaikie et al. 1994; Ebert and Kerle 2008; Adger 2000). It emphasizes on reaction, response, and resistance of a population to a disastrous event. The various influencing factors include initial well-being, livelihood and resilience, self- and social protection, lack of access to resources, certain beliefs and customs, weak individuals, and lack of public awareness (Cutter et al. 2003; Alcántara-Ayala 2002; Ebert and Kerle 2008). These social factors shape the susceptibility of various communities to damage and govern their ability to respond. Barroca et al. (2006) identify that understanding the role of societies in causing, reacting to, and remediating the effect of flood hazards is inevitable in effective flood risk reduction plans.

Economic vulnerability is defined by damage indicators expressed in monetary terms. Commercial structures play an important role as their damages define the loss of revenue (Aroca-Jiménez et al. 2018). Moreover, economic centres are the areas where hazards can have adverse impacts on local economy. An economic centre may get affected by the loss of income associated with business interruptions and the loss of jobs associated with business closures at the occurrence of a devastating disaster (Noy and Yonson 2018). Age of a building is an indicator of economic vulnerability, because all buildings get affected due to damages but certain buildings and their structural characteristics are susceptible to greater damages than others (Flax et al. 2002).

Infrastructure vulnerability can be expressed in terms of facilities, resources, or lifelines in a community (Seppänen et al. 2018; Ouyang et al. 2019). The critical facilities include schools, emergency shelters, hospitals, public buildings, nursing homes, and facilities for fire and rescue, police, utilities, communications, etc., and transportation facilities such as road networks, road bridges, and railways (Dong et al. 2020). Infrastructure components are important for the movement of population, communications, and public safety. The inundation of such facilities interrupts traffic and hampers communications, resulting in higher stress in the exposed population. Inundation may also hinder important emergency routes and damage the roads (Zhang and Alipour 2019).

The physical or biophysical vulnerability usually considers biologically susceptible indicators such as wetlands. Wetlands are the most productive ecosystem on earth (Mustow et al. 2005; Campbell et al. 2020). The concept of biophysical vulnerability has been evolved from global environmental change research, which describes the extent to which a system is vulnerable to adverse effects of climate change and its ability to adapt to such impacts. There is one more term adaptive capacity that may be defined as the capacity of a community or an individual to resist or cope with hazards. The indicators that relate to adaptive capacity may include literacy, employment, evacuation camps, transportation, emergency help, and so on.

4.3 Flood Vulnerability Assessment

The IPCC's third Assessment Report (AR3) described vulnerability as 'function of the character, magnitude, and rate of climate variation to which a system is exposed, its sensitivity, and its adaptive capacity (IPCC 2001). The report defines vulnerability as 'the degree to which a system is susceptible to or unable to cope with, adverse effects of climate change, including climate variability and extremes'. This definition is analogous to the one reported in the latest report of IPCC's AR5 (IPCC 2014). Vulnerability to impacts is essentially a multi-dimensional concept, encompassing social, infrastructure, economic, and physical factors. Flood vulnerability assessment starts with the goals or the objectives to be achieved. The various themes of vulnerability are chosen based on the goals defined. The indicators for each vulnerability theme are selected based on the criteria. Once the geospatial data collection for the indicators is completed, statistical operations are performed to obtain a vulnerability index. Figure 10 illustrates a framework for generating a flood vulnerability map. Vulnerability is usually considered to be a function of a system's ability to cope with stress and shock. The construction of a vulnerability index requires a method of

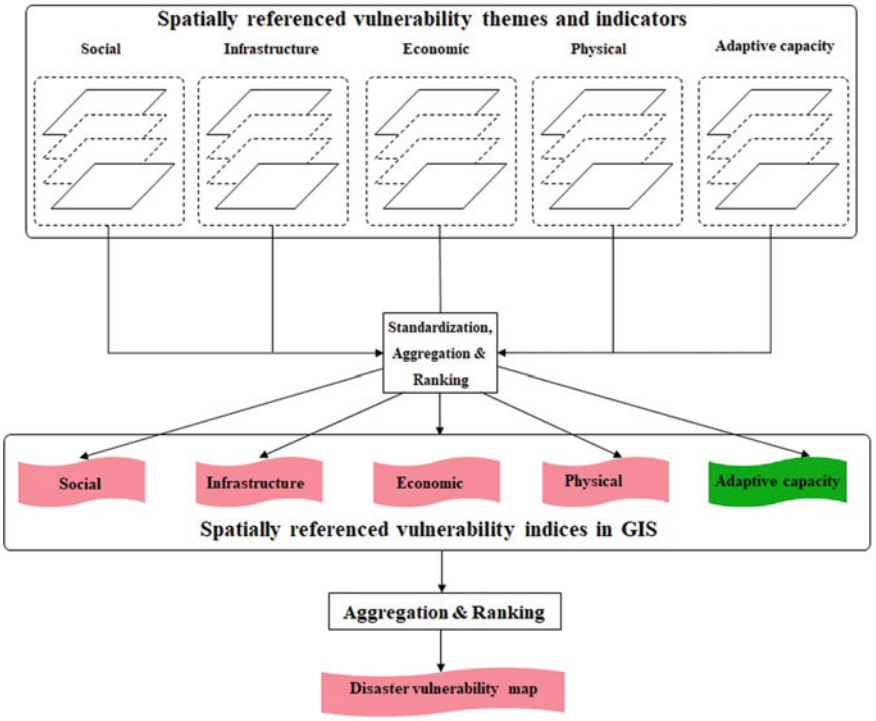

Fig. 10 Framework of disaster vulnerability mapping (after Karmakar et al. (2010))

aggregation. These aggregation operations calculate, display, and validate the indicators of vulnerability, finally obtaining a composite vulnerability index. Prior to aggregation, normalization (standardization) of indicators is performed as the units of different vulnerability indicators vary.

It is necessary to transform all indicators into a single unit. Normalizing means adjusting the values measured on different scales to a notionally common scale, often prior to aggregation. It helps to bring all units of indicators into a single alignment. Normalized values allow the comparison of different indicators in a way that eliminates anomalies. The traditional mathematical expression of standardizing vulnerability index considers only the maximum value as follows:

$$VI_i = \frac{V_i}{V^{\max}} \tag{9}$$

where $V^{\max}$ is the maximum value or count of the indicator for all units and VI_i is the value or count of the indicator for the *i*th unit. The vulnerability index may also be calculated by standardizing the counts of indicators as follows:

$$Vul_i^{std} = \frac{Vul_i - Vul_i^{\min}}{Vul_i^{\max} - Vul_i^{\min}} \tag{10}$$

where Vul_i^{std} is the standardized vulnerability index of the *i*th unit; $Vul_i^{\max}$ and $Vul_i^{\min}$ are the maximum and minimum counts of a vulnerability indicator; Vul_i is the count pertaining to the *i*th unit.

The above equation offers an improvement over the traditional standardization (Cutter et al. 2000; Wu et al. 2002; Chakraborty et al. 2005; Collins et al. 2009), as it considers both maximum and minimum values in the expression and ensures that the vulnerability values are within [0, 1] interval and are always non-negative. Different methods of aggregation include averaging (Rygel et al. 2006; Chandel 2010; Karmakar et al. 2010), maximization (Chandel 2010), Analytic Hierarchy Process (AHP) (Wei et al. 2004; Dewan 2013), Data Envelopment Analysis (DEA) (Wei et al. 2004; Huang et al. 2011; Saein and Saen 2012; Sherly et al. 2015; Mohanty et al. 2020b), and so on. The different methods of forming classes in vulnerability index are cluster analysis, equal interval, quantile division, standard deviation, subjective division based on empirical experience (Brooks et al. 2005; Zhou and Wu 2009), Pareto ranking (Rygel et al. 2006), and so on.

5 Flood Risk Mapping

Flood risk is a function of three components, namely hazard, exposure, and vulnerability (Koks et al. 2015). The essential elements of a flood risk map are hazard map (exposure integrated in terms of land use and soil type) and vulnerability map (Peck

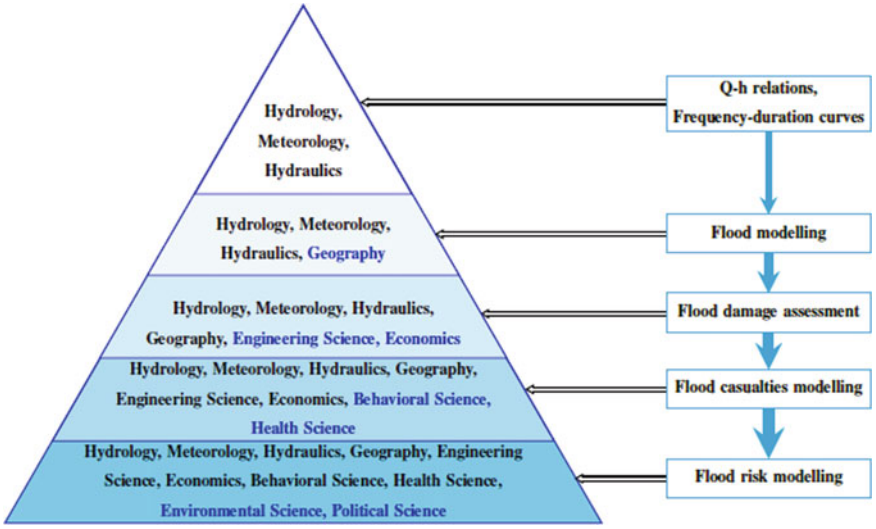

Fig. 11 Levels of flood risk modelling chain (Conceptualized from Marchand 2019)

et al. 2007; Barredo and Engelen 2010; Karmakar et al. 2010; Hallegatte et al. 2010; Ranger et al. 2011; Müller 2012; Dewan 2013; Mohanty et al. 2020a). Flood risk maps indicate potential adverse consequences associated with floods under several probabilities, expressed in terms of the indicative number of inhabitants potentially affected, type of economic activity of the area potentially affected, installations that might cause accidental pollution in case of flooding, and other information which the region considers useful (Prinos et al. 2008). The process of flood risk modelling integrates many disciplines depending on the level of the details to be modelled starting from a simple flood probability modelling to a full-fledged flood risk modelling (Sherly 2016). The hierarchical levels of flood risk modelling along with the disciplines involved are shown in Fig. 11. Figure 12 shows representative past efforts on flood risk mapping in urban regions.

6 Conclusions

Major coastal megacities in the world have been facing elevated degrees of flood damage annually. Recurrent flooding has been causing tangible and intangible effects. The tangible effects like damage to population and assets can be quantified, while the intangible effects like psychological impacts are not amenable to quantification. In the context of the increasing trend of urban floods mainly due to climate change and urbanization, urban flood risk mapping is the first step of flood risk assessment for an urban region. A flood risk map paves the path to a comprehensive flood risk management strategy, as it divides a region into various risk zones based on the

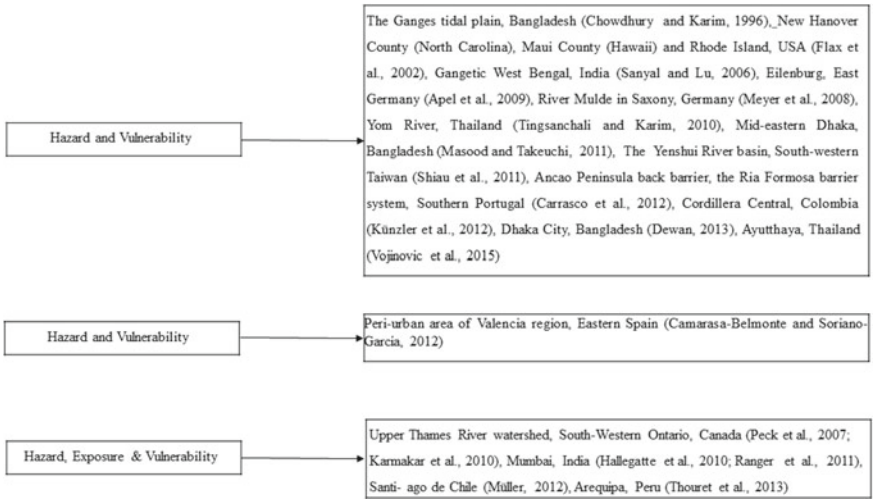

Fig. 12 Representative past efforts on urban flood risk mapping

results of flood risk analysis. Such a map acts as a tool for the public, experts, and administration for decision-making in tandem with flood risk management agencies.

The climate change is likely to alter rainfall patterns, which would affect the characteristics of flood hazard maps. Urban flooding becomes more severe in coastal urban areas as the simultaneous occurrence of heavy rainfall and high tidal waves can be detrimental, besides, it may further worsen with sea-level rise and land subsidence due to climate change. Hence, hydrological modelling must incorporate the effect of climate change for a realistic future projection of flood risk (i.e., non-stationarity/trend). For effective management of flood risk, it is equally important to give due consideration to information flow on various aspects of flood disaster to the ground level. The knowledge on regions affected by different levels of flood hazard, vulnerability, and risk is vital not only for the citizens but also to various governmental agencies, disaster managers, and policy makers. This information system will allow a wide range of users gain relevant knowledge on flood risk, directing improvements in the existing flood management strategies.

References

Adger WN (2000) Institutional adaptation to environmental risk under the transition in Vietnam. Ann Assoc Am Geogr 90:738–758. https://doi.org/10.1111/0004-5608.00220

Adger WN (2006) Vulnerability. Glob Environ Chang 16:268–281. https://doi.org/10.1016/j.gloenvcha.2006.02.006

Adger WN, Brooks N, Kelly M, Bentham G, Agnew M, Eriksen S (2004) New indicators of vulnerability and adaptive capacity. Tech. Rep. 7. Tyndall Centre for Climate Change Research, Norwich

Afshari S, Tavakoly AA, Rajib MA, Zheng X, Follum ML, Omranian E, Fekete BM (2018) Comparison of new generation low-complexity flood inundation mapping tools with a hydrodynamic model. J Hydrol 556:539–556

Alcántara-Ayala I (2002) Geomorphology, natural hazards, vulnerability and prevention of natural disasters in developing countries. Geomorphology 47:107–124. https://doi.org/10.1016/s0169-555x(02)00083-1

Alfieri L, Feyen L, Di Baldassarre G (2016) Increasing flood risk under climate change: a pan-European assessment of the benefits of four adaptation strategies. Clim Chang 136(3–4):507–521

Alves A, Vojinovic Z, Kapelan Z, Sanchez A, Gersonius B (2020) Exploring trade-offs among the multiple benefits of green-blue-grey infrastructure for urban flood mitigation. Sci Total Environ 703:134980

Amann B, Szidat S, Grosjean M (2015) A millennial-long record of warm season precipitation and flood frequency for the North-western Alps inferred from varved lake sediments: implications for the future. Quatern Sci Rev 115:89–100

Apel H, Aronica GT, Kreibich H, Thieken AH (2009) Flood risk analyses—how detailed do we need to be? Nat Hazards 49:79–98. https://doi.org/10.1007/s11069-008-9277-8

Arnell NW, Gosling SN (2016) The impacts of climate change on river flood risk at the global scale. Clim Chang 134(3):387–401. https://doi.org/10.1007/s10584-014-1084-5

Aroca-Jiménez E, Bodoque JM, García JA, Díez-Herrero A (2018) A quantitative methodology for the assessment of the regional economic vulnerability to flash floods. J Hydrol 565:386–399

Bajard M, Poulenard J, Sabatier P, Bertrand Y, Crouzet C, Ficetola GF, et al (2020) Pastoralism increased vulnerability of a subalpine catchment to flood hazard through changing soil properties. Palaeogeogr Palaeoclimatol Palaeoecol 538:109462

Baker VR, Kochel RC, Patton PC (1988) Flood geomorphology, 1st edn. Wiley, New York

Barredo JI, Engelen G (2010) Land use scenario modeling for flood risk mitigation. Sustainability 2:1327–1344. https://doi.org/10.3390/su2051327

Barroca B, Bernardara P, Mouchel JM, Hubert G (2006) Indicators for identification of urban flooding vulnerability. Nat Hazard Earth Syst Sci 6:553–561. https://doi.org/10.5194/nhess-6-553-2006

Bates PD, Horritt MS (2005) Modelling wetting and drying processes in hydraulic models. In: Bates PD, Lane SN, Ferguson RI (eds) Computational fluid dynamics: applications in environmental hydraulics, chap. 6, 1st edn. Wiley, England. https://doi.org/10.1002/0470015195

Bates PD, De Roo APJ (2000) A simple raster-based model for flood inundation simulation. J Hydrol 236:54–77

Benito G, Lang M, Barriendos M, Llasat MC, Francés F, Ouarda T, Varyl T, Enzel Y, Bárdossy A, Coeur D, Bobée B (2004) Use of Systematic, palaeoflood and historical data for the improvement of flood risk estimation. Rev Sci Methods Nat Hazards 31:623–643

Berrouet LM, Machado J, Villegas-Palacio C (2018) Vulnerability of socio-ecological systems: a conceptual Framework. Ecol Ind 84:632–647

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

Blaikie P, Cannon T, Davis I, Wisner B (1994) At risk: natural hazards, people's vulnerability and disasters, 1st edn. Routledge, London, New York

Blöschl G, Hall J, Parajka J, Perdigão RA, Merz B, Arheimer B et al (2017) Changing climate shifts timing of European floods. Science 357(6351):588–590

Blum AG, Ferraro PJ, Archfield SA, Ryberg KR (2020) Causal effect of impervious cover on annual flood magnitude for the United States. Geophys Res Lett 47(5)

Bogardi JJ, Birkmann J (2005) Vulnerability assessment: the first step towards sustainable risk reduction. In: Malzahn D, Plapp T (eds) Disasters and society: from hazard assessment to risk reduction. Logos Verlag Berlin, Berlin, pp 75–82

Bohle H-G (2001) Vulnerability and criticality: perspectives from social geography. In: Newsletter of the international human dimensions programme on global environmental change, pp 1–6

Bollin C, Cárdenas C, Hahn H, Vatsa KS (2003) Disaster risk management by communities and local governments. Inter-American Development Bank, Washington, D.C.
Boonya-Aroonnet S, Weesakul S, Mark O (2002) Modelling of urban flooding in Bangkok. In: Proceedings of the ninth international conference on urban drainage (9ICUD), Portland, USA
Bornstein RD (1968) Observations of the urban heat island effect in New York City. J Appl Meteorol 7:575–582. https://doi.org/10.1175/1520-0450(1968)007%3c0575:OOTUHI%3e2.0.CO;2
Bouwer LM, Bubeck P, Aerts JC (2010) Changes in future flood risk due to climate and development in a Dutch polder area. Glob Environ Chang 20(3):463–471
Bowering EA, Peck AM, Simonovic SP (2014) A flood risk assessment to municipal infrastructure due to changing climate part I: methodology. Urban Water J 11:20–30. https://doi.org/10.1080/1573062X.2012.758293
Brath A, Castellarin A, Montanari A (2003) Assessing the reliability of regional depth-duration-frequency equations for gaged and ungaged sites. Water Resour Res 39:1–12. https://doi.org/10.1029/2003WR002399
Brody SD, Blessing R, Sebastian A, Bedient P (2013) Delineating the reality of flood risk and loss in Southeast Texas. Nat Hazard Rev 14:89–97. https://doi.org/10.1061/(ASCE)NH.1527-6996.0000091
Brooks N, Adger WN, Kelly PM (2005) The determinants of vulnerability and adaptive capacity at the national level and the implications for adaptation. Glob Environ Chang 15:151–163. https://doi.org/10.1016/j.gloenvcha.2004.12.006
Brooks N (2003) Vulnerability, risk and adaptation: a conceptual framework. Tech. Rep. Working Paper 38. Tyndall Centre for Climate Change Research, Norwich
Buishand TA (1991) Extreme rainfall estimation by combining data from several sites. Hydrol Sci J 36:345–365. https://doi.org/10.1080/02626669109492519
Camarasa-Belmonte A, Soriano-García J (2012) Flood risk assessment and mapping in peri-urban Mediterranean environments using hydro-geomorphology. Application to ephemeral streams in the Valencia region (eastern Spain). Landsc Urban Plan 104:189–200. https://doi.org/10.1016/j.landurbplan.2011.10.009
Campbell E, Marks R, Conn C (2020) Spatial modeling of the biophysical and economic values of ecosystem services in Maryland, USA. Ecosyst Serv 43:101093
Cardona OD (1999) Environmental management and disaster prevention: two related topics: a holistic risk assessment and management approach. In: Ingleton J (ed) Natural disaster management. Tudor Rose, London
Carrasco AR, Ferreira Ó, Matias A, Freire P (2012) Flood hazard assessment and management of fetch-limited coastal environments. Ocean Coast Manag 65:15–25
Chakraborty J, Tobin GA, Montz BE (2005) Population evacuation: assessing spatial variability in geophysical risk and social vulnerability to natural hazards. Nat Hazard Rev 6:23–33
Chambers R, Conway GR (1992) Sustainable rural livelihoods: practical concepts for the 21st century. In: IDS Discussion Paper 296, Institute of Development Studies, University of Sussex, Brighton, UK, pp 1–42
Chandel G (2010) Vulnerability assessment to natural and environmental hazards. Master's thesis, Indian Institute of Technology Bombay, Mumbai, India
Chang H, Franczyk J (2008) Climate change, land-use change, and floods: toward an integrated assessment. Geogr Compass 2:1549–1579. https://doi.org/10.1111/j.1749-8198.2008.00136.x
Chen W, Huang G, Zhang H, Wang W (2018) Urban inundation response to rainstorm patterns with a coupled hydrodynamic model: a case study in Haidian Island, China. J Hydrol 564:1022–1035
Chow VT, Maidment DR, Mays LW (1988) Distributed flow routing. In: Applied hydrology, chap. 9, 1st edn. Tata McGraw-Hill, New Delhi, pp 272–309
Chowdhury JU, Karim MF (1996) A risk-based zoning of storm surge prone area of the Ganges Tidal Plain. J Civ Eng 24:221–233
Collins TW, Grineski SE, Aguilar M (2009) Vulnerability to environmental hazards in the Ciudad Juárez (Mexico)—El Paso (USA) metropolis: a model for spatial risk assessment in transnational context. Appl Geogr 29:448–461. https://doi.org/10.1016/j.apgeog.2008.10.005

Costabile P, Costanzo C, De Lorenzo G, Macchione F (2020) Is local flood hazard assessment in urban areas significantly influenced by the physical complexity of the hydrodynamic inundation model? J Hydrol 580:124231

Coutu GW, Vega C (2007) Impacts of land use changes on runoff generation in the east branch of the Brandywine creek watershed using a GIS-based hydrologic model. Middle States Geogr 40:142–149

CRED/UNISDR (2015) The human cost of weather-related disasters: 1995–2015. Centre for Research on the Epidemiology of Disasters, Brussels, Belgium

Crichton D (1999) The risk triangle. In: Ingleton J (ed) Natural disaster management. Tudor Rose, London, pp 102–103

Cunderlik JM, Simonovic SP (2007) Inverse flood risk modelling under changing climatic conditions. Hydrol Process Int J 21(5):563–577

Cutter SL (1996) Vulnerability to environmental hazards. Progr Human Geogr 20:529–539

Cutter SL, Boruff BJ, Shirley WL (2003) Social vulnerability to environmental hazards. Soc Sci Q 84:242–261. https://doi.org/10.1111/1540-6237.8402002

Cutter SL, Mitchell JT, Scott MS (2000) Revealing the vulnerability of people and places: a case study of Georgetown County, South Carolina. Ann Assoc Am Geogr 90:713–737. https://doi.org/10.1111/0004-5608.00219

Darabi H, Choubin B, Rahmati O, Haghighi AT, Pradhan B, Kløve B (2019) Urban flood risk mapping using the GARP and QUEST models: a comparative study of machine learning techniques. J Hydrol 569:142–154

Davidson RA, Shah HC (1997) An urban earthquake disaster risk index. Tech. Rep. 121, The John A. Blume Earthquake Engineering Center, Department of Civil and Environmental Engineering, Stanford University, Stanford, CA

Dewan A (2013) Floods in a megacity: geospatial techniques in assessing hazards, risk and vulnerability. Springer, Dordrecht Heidelberg New York London. https://doi.org/10.1007/978-94-007-5875-9

DFID (1999) Sustainable livelihoods guidance sheets: framework, Section 2. Tech. Rep. Subsection 2.1. Department for International Development, London

Di Baldassarre G (2012) Floods in a changing climate: inundation modelling, 1st edn. Cambridge University Press, New York. https://doi.org/10.1017/CBO9781139088411

Di Baldassarre G, Castellarin A, Montanari A, Brath A (2009) Probability-weighted hazard maps for comparing different flood risk management strategies: a case study. Nat Hazards 50(3):479–496

Dibben C, Chester DK (1999) Human vulnerability in volcanic environments: the case of Furnas, São Miguel, Azores. J Volcanol Geotherm Res 92:133–150. https://doi.org/10.1016/S0377-0273(99)00072-4

Dimitriadis P, Tegos A, Oikonomou A, Pagana V, Koukouvinos A, Mamassis N, Koutsoyiannis D, Efstratiadis A (2016) Comparative evaluation of 1D and quasi-2D hydraulic models based on benchmark and real-world applications for uncertainty assessment in flood mapping. J Hydrol 534:478–492. https://doi.org/10.1016/j.jhydrol.2016.01.020

Dong S, Esmalian A, Farahmand H, Mostafavi A (2020) An integrated physical-social analysis of disrupted access to critical facilities and community service-loss tolerance in urban flooding. Comput Environ Urban Syst 80:101443

Dow K (1992) Exploring differences in our common future(s): the meaning of vulnerability to global environmental change. Geoforum 23:417–436. https://doi.org/10.1016/0016-7185(92)90052-6

Durrans S, Kirby JT (2004) Regionalization of extreme precipitation estimates for the Alabama rainfall atlas. J Hydrol 295:101–107. https://doi.org/10.1016/j.jhydrol.2004.02.021

Ebert A, Kerle N (2008) Urban social vulnerability assessment using object-oriented analysis of remote sensing and GIS Data. A case study for Tegucigalpa, Honduras. In: The international archives of the photogrammetry, remote sensing and spatial information sciences, vol XXXVII. Part B7. International Society for Photogrammetry and Remote Sensing, pp 1307–1312

Erena SH, Worku H, De Paola F (2018) Flood hazard mapping using FLO-2D and local management strategies of Dire Dawa city, Ethiopia. J Hydrol Reg Stud 19:224–239

Fedeski M, Gwilliam J (2007) Urban sustainability in the presence of flood and geological hazards: the development of a GIS-based vulnerability and risk assessment methodology. Landsc Urban Plan 83:50–61

FEMA (2012) What is risk MAP?, Tech. Rep. 1-877-FEMA MAP, Federal Emergency Management Authority, Washington, D.C., USA

Few R, Flooding, vulnerability and coping strategies: local responses to a global threat. Prog Dev Stud, 3, 43–58. https://doi.org/10.1191/1464993403ps049ra

Feyen L, Dankers R, Bódis K, Salamon P, Barredo JI (2011) Fluvial flood risk in Europe in present and future climates. Clim Chang 112:47–62. https://doi.org/10.1007/s10584-011-0339-7

Fiebiger G (1997) Hazard mapping in Austria. J Torrent Avalanche Landslide Rockfall Eng 61:1531–2164

Flax LK, Jackson RW, Stein DN (2002) Community vulnerability assessment tool methodology. Nat Hazard Rev 3:163–176. https://doi.org/10.1061/(asce)1527-6988(2002)3:4(163)

FLO-2D (2009) FLO-2D mapper manual, Version 2009. Arizona, USA

Frank E, Ostan A, Coccato M, Stelling GS (2001) Use of an integrated one dimensional-two dimensional hydraulic modelling approach for flood hazard and risk mapping. In: Falconer RA, B WR (eds) River basin management, vol 50 of Transactions on ecology and the environment. WIT Press, Southampton, pp 99–108. https://doi.org/10.2495/RM010091

Füssel H-M (2007) Vulnerability: a generally applicable conceptual framework for climate change research. Glob Environ Chang 17:155–167. https://doi.org/10.1016/j.gloenvcha.2006.05.002

Ghosh M, Mohanty MP, Kishore P, Karmakar S (2020) Performance evaluation of potential inland flood management options through a three-way linked hydrodynamic modelling framework for a coastal urban watershed. Hydrol Res

Gilles D, Moore M (2010) Review of hydraulic flood modeling software used in Belgium, The Netherlands, and the United Kingdom. International Perspectives in Water Resource Management, IIHR – Hydroscience & Engineering, University of Iowa

Grimaldi S, Serinaldi F (2006) Design hyetograph analysis with 3-copula function. Hydrol Sci J 51:223–238. https://doi.org/10.1623/hysj.51.2.223

Haer T, Husby TG, Botzen WW, Aerts JC (2020) The safe development paradox: an agent-based model for flood risk under climate change in the European Union. Glob Environ Chang 60:102009

Hallegatte S, Green C, Nicholls RJ, Corfee-Morlot J (2013) Future flood losses in major coastal cities. Nat Clim Chang 3:802–806

Hallegatte S, Henriet F, Patwardhan A, Narayanan K, Ghosh S, Karmakar S, Patnaik U, Abhayankar A, Pohit S, Corfee-Morlot J, Herweijer C, Ranger N, Bhattacharya S, Bachu M, Priya S, Dhore K, Rafique F, Mathur P, Naville N (2010) Flood risks, climate change impacts and adaptation benefits in Mumbai: an initial assessment of socio-economic consequences of present and climate change induced flood risks and of possible adaptation options, Environment Working Papers, Tech. Rep. 27, OECD Publishing

He BJ, Zhu J, Zhao DX, Gou ZH, Qi JD, Wang J (2019) Co-benefits approach: opportunities for implementing sponge city and urban heat island mitigation. Land Use Policy 86:147–157

Hernández Ayala JJ, Keellings D, Waylen PR, Matyas CJ (2017) Extreme floods and their relationship with tropical cyclones in Puerto Rico. Hydrol Sci J 62(13):2103–2119

Hirabayashi Y, Mahendran R, Koirala S, Konoshima L, Yamazaki D, Watanabe S, Kim H, Kanae S (2013) Global flood risk under climate change. Nat Clim Chang 3:816–821

Hoegh-Guldberg O, Jacob D, Bindi M, Brown S, Camilloni I, Diedhiou A, et al (2018) Impacts of 1.5 C global warming on natural and human systems. Global warming of 1.5°C. An IPCC Special Report

Hou J, Kang Y, Hu C, Tong Y, Pan B, Xia J (2020) A GPU-based numerical model coupling hydrodynamical and morphological processes. Int J Sediment Res

Huang J, Liu Y, Ma L (2011) Assessment of regional vulnerability to natural hazards in China using a DEA model. Int J Disast Risk Sci 2:41–48. https://doi.org/10.1007/s13753-011-0010-y

Ikeuchi H, Hirabayashi Y, Yamazaki D, Muis S, Ward PJ, Winsemius HC et al (2017) Compound simulation of fluvial floods and storm surges in a global coupled river-coast flood model: model

development and its application to 2007 Cyclone Sidr in Bangladesh. J Adv Model Earth Syst 9(4):1847–1862

IPCC (2001) Climate change 2001: The Scientific Basis. In: Houghton JT, Ding Y, Griggs DJ, Noguer M, van der Linden PJ, Dai X, Maskell K, Johnson CA (eds) Contribution of working Group I to the third assessment report of the intergovernmental panel on climate change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 881 pp

IPCC (2014) Climate change 2014: synthesis report. In: Core Writing Team, Pachauri RK, Meyer LA (eds) Contribution of working Groups I, II and III to the fifth assessment report of the intergovernmental panel on climate change. IPCC, Geneva, Switzerland, 151 pp.

Jafarzadegan K, Merwade V (2019) Probabilistic floodplain mapping using HAND-based statistical approach. Geomorphology 324:48–61

Jenkins K, Surminski S, Hall J, Crick F (2017) Assessing surface water flood risk and management strategies under future climate change: Insights from an agent-based model. Sci Total Environ 595:159–168

Joshi PM, Sherasia NK, Patel PD (2012) Urban flood mapping by geospatial technique: a case study of Surat City. IOSR J Eng 2:43–51

Jung I-W, Chang H, Moradkhani H (2011) Quantifying uncertainty in urban flooding analysis considering hydro-climatic projection and urban development effects. Hydrol Earth Syst Sci 15:617–633. https://doi.org/10.5194/hess-15-617-2011

Kalyanapu AJ, Shankar S, Pardyjak ER, Judi DR, Burian SJ (2011) Assessment of GPU computational enhancement to a 2D flood model. Environ Model Softw 26(8):1009–1016

Karmakar S, Simonovic SP, Peck A, Black J (2010) An information system for risk-vulnerability assessment to flood. J Geogr Inf Syst 2:129–146

Kates RW (1985) The interaction of climate and society. In: Kates RW, Ausubel J, Berberian M (eds) Climate impact assessment: studies of the interaction of climate and society, chap. 1. Wiley, Chichester, UK

Kerr RA (2007) Global warming is changing the world. Science 316(5822):188–190

Koks EE, Jongman B, Husby TG, Botzen WJW (2015) Combining hazard, exposure and social vulnerability to provide lessons for flood risk management, Enviro Sci Policy 47(42–52):1462–9011. https://doi.org/10.1016/j.envsci.2014.10.013. https://www.sciencedirect.com/science/article/pii/S1462901114002056

Kumpulainen S (2006) Vulnerability concepts in hazard and risk assessment. In: Schmidt-Thomé P (ed) Natural and technological hazards and risks affecting the spatial development of European Regions. Geological Survey of Finland special paper, Geological Survey of Finland, pp 65–74

Künzler M, Huggel C, Ramírez JM (2012) A risk analysis for floods and lahars: case study in the Cordillera Central of Colombia. Nat Hazards 64:767–796

Lastra J, Fernández E, Díez-Herrero A, Marquínez J (2008) Flood hazard delineation combining geomorphological and hydrological methods: an example in the Northern Iberian Peninsula. Nat Hazards 45:277–293. https://doi.org/10.1007/s11069-007-9164-8

Leandro J, Chen AS, Djordjević S, Savić DA (2009) Comparison of 1D/1D and 1D/2D coupled (sewer/surface) hydraulic models for urban flood simulation. J Hydraul Eng 135(6):495–504

Lee CKF, Duncan C, Owen HJF, Pettorelli N (2018) A new framework to assess relative ecosystem vulnerability to climate change. Conserv Lett 11(2):e12372

Li G, Zhang F, Jing Y, Liu Y, Sun G (2017) Response of evapotranspiration to changes in land use and land cover and climate in China during 2001–2013. Sci Total Environ 596:256–265

Li L, Cao R, Wei K, Wang W, Chen L (2019a) Adapting climate change challenge: a new vulnerability assessment framework from the global perspective. J Clean Prod 217:216–224

Li Z, Sun Y, Li T, Ding Y, Hu T (2019b) Future changes in East Asian summer monsoon circulation and precipitation under 1.5 to 5 °C of warming. Earth's Future 7(12):1391–1406

Liu YB, Smedt F, Hoffmann L, Pfister L (2005) Assessing land use impacts on flood processes in complex terrain by using GIS and modeling approach. Environ Model Assess 9:227–235

Macchione F, Costabile P, Costanzo C, De Santis R (2019) Moving to 3-D flood hazard maps for enhancing risk communication. Environ Model Softw 111:510–522

Mahmoud SH, Gan TY (2018) Urbanization and climate change implications in flood risk management: developing an efficient decision support system for flood susceptibility mapping. Sci Total Environ 636:152–167

Marchand M (2009) Modelling coastal vulnerability. IOS Press, Amsterdam, Netherlands

Mark O, Apirumanekul C, Kamal MM, Praydal G (2001) Modelling of urban flooding in Dhaka City. In: Brashear RW, Maksimovic C (eds) Proceedings of urban drainage modeling, chap. 31. American Society of Civil Engineers, pp 333–343. https://doi.org/10.1061/40583(275)32

Martínez C, Sanchez A, Toloh B, Vojinovic Z (2018) Multi-objective evaluation of urban drainage networks using a 1D/2D flood inundation model. Water Resour Manag 32(13):4329–4343

Martins R, Leandro J, Djordjević S (2018) Influence of sewer network models on urban flood damage assessment based on coupled 1D/2D models. J Flood Risk Manag 11:S717–S728

Masood M, Takeuchi K (2011) Assessment of flood hazard, vulnerability and risk of mid-eastern Dhaka using DEM and 1D hydrodynamic model. Nat Hazards 61:757–770. https://doi.org/10.1007/s11069-011-0060-x

McMillan HK, Brasington J (2007) Reduced complexity strategies for modelling urban floodplain inundation. Geomorphology 90:226–243

McMillan HK, Brasington J (2008) End-to-end flood risk assessment: a coupled model cascade with uncertainty estimation. Water Resour Res 44:W03 419

Meyer V, Scheuer S, Haase D (2008) A multicriteria approach for flood risk mapping exemplified at the Mulde river, Germany. Nat Hazards 48:17–39

Miller MM, Shirzaei M (2019) Land subsidence in Houston correlated with flooding from Hurricane Harvey. Remote Sens Environ 225:368–378

Moftakhari H, Schubert JE, AghaKouchak A, Matthew RA, Sanders BF (2019) Linking statistical and hydrodynamic modeling for compound flood hazard assessment in tidal channels and estuaries. Adv Water Resour 128:28–38

Mohanty MP, Sherly MA, Karmakar S, Ghosh S (2018) Regionalized design rainfall estimation: an appraisal of inundation mapping for flood management under data-scarce situations. Water Resour Manag 32(14):4725–4746

Mohanty MP, Vittal H, Yadav V, Ghosh S, Rao GS, Karmakar S (2020a) A new bivariate risk classifier for flood management considering hazard and socio-economic dimensions. J Environ Manag 255:109733

Mohanty MP, Sherly MA, Ghosh S, Karmakar S (2020b) Tide-rainfall flood quotient: an incisive measure of comprehending a region's response to storm-tide and pluvial flooding. Environ Res Lett 15(6):064029

Mohanty MP (2019) A comprehensive mapping of flood risk in changing climate: an application to Jagatsinghpur District, Odisha. Ph.D. Thesis, Indian Institute of Technology Bombay, Mumbai, India

Motevalli A, Vafakhah M (2016) Flood hazard mapping using synthesis hydraulic and geomorphic properties at watershed scale. Stoch Environ Res Risk Assess 30(7):1889–1900

Müller A (2012) Flood risks in a dynamic urban agglomeration: a conceptual and methodological assessment framework. Nat Hazards 65:1931–1950. https://doi.org/10.1007/s11069-012-0453-5

Mustow SE, Burgess PF, Walker N (2005) Practical methodology for determining the significance of impacts on the water environment. Water Environ J 19:100–108. https://doi.org/10.1111/j.1747-6593.2005.tb00557.x

NDMA (2010) Management of urban flooding. National Disaster Management Guidelines, National Disaster Management Authority, Government of India, NDMA Bhawan, New Delhi

Neal J, Keef C, Bates P, Beven K, Leedal D (2013) Probabilistic flood risk mapping including spatial dependence. Hydrol Process 27:1349–1363. https://doi.org/10.1002/hyp.9572

Nirupama N, Simonovic SP (2007) Increase of flood risk due to urbanization: a Canadian example. Nat Hazards 40:25–41. https://doi.org/10.1007/s11069-006-0003-0

Noh SJ, Lee JH, Lee S, Kawaike K, Seo DJ (2018) Hyper-resolution 1D–2D urban flood modelling using LiDAR data and hybrid parallelization. Environ Model Softw 103:131–145

Noy I, Yonson R (2018) Economic vulnerability and resilience to natural hazards: a survey of concepts and measurements. Sustainability 10(8):2850

O'Brien JS, Garcia R (2012) New approaches for alluvial fan flood hazard. In: French RH, Miller JJ (eds) Flood hazard identification and mitigation in semi- and arid environments. World Scientific Publishing, Singapore, pp 59–88

O'Brien K, Leichenko R, Kelkar U, Venema H, Aandahl G, Tompkins H, Akram J, Bhadwal S, Barg S, Nygaard L, West J (2004) Mapping vulnerability to multiple stressors: climate change and globalization in India. Glob Environ Chang 14:303–313

O'Donnell EC, Thorne CR (2020) Drivers of future urban flood risk. Philos Trans R Soc A 378(2168):20190216

OFEE (1997) Consideration of flood hazards for activities with spatial impact. In: Loat R, Petrascheck A (eds) The environment in practice VU-7505-E. Federal Office for the Environment FOEN, Bern

Oke TR (1982) The energetic basis of the urban heat island. Q J R Meteorol Soc 108:1–24. https://doi.org/10.1002/qj.49710845502

Olivera F, Maidment D (1999) Geographic Information Systems (GIS)-based spatially distributed model for runoff routing. Water Resour Res 35:1155–1164. https://doi.org/10.1029/1998WR900104

Oppenheimer M, Campos M, Warren R, Birkmann J, Luber G, O'Neill B, Takahashi K (2014) Emergent risks and key vulnerabilities. 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. In: Field CB, Barros VR, Dokken DJ, Mach KJ, Mastrandrea MD, Bilir TE, Chatterjee M, Ebi KL, Estrada YO, Genova RC, Girma B, Kissel ES, Levy AN, MacCracken S, Mastrandrea PR, White LL (eds). Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp 1039-1099. https://www.ipcc.ch/site/assets/uploads/2018/02/WGIIAR5-Chap19_FINAL.pdf

Ouyang M, Tian H, Wang Z, Hong L, Mao Z (2019) Critical infrastructure vulnerability to spatially localized failures with applications to Chinese railway system. Risk Anal 39(1):180–194

Overeem A, Buishand A, Holleman I (2008) Rainfall depth-duration-frequency curves and their uncertainties. J Hydrol 348:124–134. https://doi.org/10.1016/j.jhydrol.2007.09.044

Paprotny D, Terefenko P (2017) New estimates of potential impacts of sea level rise and coastal floods in Poland. Nat Hazards 85(2):1249–1277

Pathak S, Liu M, Jato-Espino D, Zevenbergen C (2020) Social, economic and environmental assessment of urban sub-catchment flood risks using a multi-criteria approach: a case study in Mumbai City, India. J Hydrol 125216

Patro S, Chatterjee C, Mohanty S, Singh R, Raghuwanshi NS (2009) Flood inundation modeling using MIKE FLOOD and remote sensing data. J Indian Soc Remote Sens 37:107–118. https://doi.org/10.1007/s12524-009-0002-1

Paul S, Ghosh S, Oglesby R, Pathak A, Chandrasekharan A, Ramsankaran RAAJ (2016) Weakening of Indian summer monsoon rainfall due to changes in land use land cover. Sci Rep 6(1):1–10

Peck AM, Bowering EA, Simonovic SP (2014) A flood risk assessment to municipal infrastructure due to changing climate part II: case study. Urban Water J 11:519–531. https://doi.org/10.1080/1573062X.2013.781760

Peck A, Karmakar S, Simonovic SP (2007) Physical, economical, infrastructural and social flood risk—vulnerability analyses in GIS. Water Resources Research Report, The University of Western Ontario, Canada

Poretti I, De Amicis M (2011) An approach for flood hazard modelling and mapping in the medium Valtellina. Nat Hazards Earth Syst Sci 11:1141–1151. https://doi.org/10.5194/nhess-11-1141-2011

Prinos P, Kortenhaus A, Swerpel B, Jiménez JA, Samuels P (2008) Review of flood hazard mapping. In: Integrated flood risk analysis and management methodologies. FLOODsite, HR Wallingford, UK

Prodanovic P, Simonovic SP (2004) Generation of synthetic design storms for the Upper Thames River Basin. Water Resources Research Report 15, Department of Civil and Environmental Engineering, The University of Western Ontario

Rahman A, Weinmann P, Hoang T, Laurenson E (2002) Monte Carlo simulation of flood frequency curves from rainfall. J Hydrol 256:196–210. https://doi.org/10.1016/S0022-1694(01)00533-9

Ranger N, Hallegatte S, Bhattacharya S, Bachu M, Priya S, Dhore K, Rafique F, Mathur P, Naville N, Henriet F et al (2011) An assessment of the potential impact of climate change on flood risk in Mumbai. Clim Change 104:139–167

Rossman LA (2006) Storm water management model quality assurance report: dynamic wave flow routing. Tech. Rep. EPA/600/R-06/097 U.S. Environmental Protection Agency, Cincinnati, OH

Rygel L, O'sullivan D, Yarnal B (2006) A method for constructing a social vulnerability index: an application to hurricane storm surges in a developed country. Mitig Adapt Strat Glob Chang 11:741–764. https://doi.org/10.1007/s11027-006-0265-6

Saein AF, Saen RF (2012) Assessment of the site effect vulnerability within urban regions by data envelopment analysis: a case study in Iran. Comput Geosci 48:280–288

Samela C, Troy TJ, Manfreda S (2017) Geomorphic classifiers for flood-prone areas delineation for data-scarce environments. Adv Water Resour 102:13–28

Sanders BF, Schubert JE (2019) PRIMo: parallel raster inundation model. Adv Water Resour 126:79–95

Sanyal J, Lu XX (2006) GIS-based flood hazard mapping at different administrative scales: a case study in Gangetic West Bengal, India. Singap J Trop Geogr 27:207–220

Seenath A, Wilson M, Miller K (2016) Hydrodynamic versus GIS modelling for coastal flood vulnerability assessment: which is better for guiding coastal management? Ocean Coast Manag 120:99–109

Seppänen H, Luokkala P, Zhang Z, Torkki P, Virrantaus K (2018) Critical infrastructure vulnerability—a method for identifying the infrastructure service failure interdependencies. Int J Crit Infrastruct Prot 22:25–38

Shahapure SS, Eldho TI, Rao EP (2010) Coastal urban flood simulation using FEM, GIS and remote sensing. Water Resour Manag 24:3615–3640. https://doi.org/10.1007/s11269-010-9623-y

Shastri H, Paul S, Ghosh S, Karmakar S (2015) Impacts of urbanization on Indian summer monsoon rainfall extremes. J Geophys Res Atmos 120(2):496–516

Shen Y, Morsy MM, Huxley C, Tahvildari N, Goodall JL (2019) Flood risk assessment and increased resilience for coastal urban watersheds under the combined impact of storm tide and heavy rainfall. J Hydrol 579:124159

Sherly MA, Karmakar S, Parthasarathy D, Chan T, Rau C (2015) Disaster vulnerability mapping for a densely populated coastal urban area: an application to Mumbai, India. Ann Assoc Am Geogr 105:1198–1220. https://doi.org/10.1080/00045608.2015.1072792

Sherly MA, Karmakar S, Chan T, Rau C (2016) Design rainfall framework using multivariate parametric-nonparametric approach. J Hydrol Eng 21(1):04015049

Sherly MA (2016) Urban flood risk mapping of a coastal megacity—an application to Mumbai, India. PhD Thesis, Indian Institute of Technology Bombay, India, and Monash University, Australia

Shiau J-T, Chen C-N, Tsai C-T (2011) Physiographic drainage-inundation model based flooding vulnerability assessment. Water Resour Manag 26:1307–1323

Simões NE, Ochoa-Rodríguez S, Wang L-P, Pina RD, Marques AS, Onof C, Leitão JP (2015) Stochastic urban Pluvial flood hazard maps based upon a spatial-temporal rainfall generator. Water 7:3396. https://doi.org/10.3390/w7073396

Simonović SP (2012) Floods in a changing climate: risk management. Cambridge University Press

Sivapalan M, Blöschl G (1998) Transformation of point rainfall to areal rainfall: intensity-duration-frequency curves. J Hydrol 204:150–167. https://doi.org/10.1016/s0022-1694(97)00117-0

Slovic P (1987) Perception of risk. Science 236:280–285

Smith A, Bates PD, Wing O, Sampson C, Quinn N, Neal J (2019) New estimates of flood exposure in developing countries using high-resolution population data. Nat Commun 10(1):1–7

Sun D, Yang H, Guan D, Yang M, Wu J, Yuan F et al (2018) The effects of land use change on soil infiltration capacity in China: a meta-analysis. Sci Total Environ 626:1394–1401

Te Linde AH, Bubeck P, Dekkers JEC, De Moel H, Aerts JCJH (2011) Future flood risk estimates along the river Rhine. Nat Hazard 11(2):459

Teng J, Jakeman AJ, Vaze J, Croke BF, Dutta D, Kim S (2017) Flood inundation modelling: a review of methods, recent advances and uncertainty analysis. Environ Model Softw 90:201–216

Thouret J-C, Enjolras G, Martelli K, Santoni O, Luque JA, Nagata M, Arguedas A, Macedo L (2013) Combining criteria for delineating lahar- and flash-flood-prone hazard and risk zones for the city of Arequipa, Peru. Nat Hazards Earth Syst Sci 13:339–360

Tingsanchali T, Karim F (2010) Flood-hazard assessment and risk-based zoning of a tropical flood plain: case study of the Yom River, Thailand. Hydrol Sci J 55:145–161

Toonen WH, Munoz SE, Cohen KM, Macklin MG (2020) High-resolution sedimentary Paleoflood records in Alluvial River environments: a review of recent methodological advances and application to flood hazard assessment. In: Palaeohydrology. Springer, Cham, pp 213–228

Trenberth KE, Fasullo JT, Shepherd TG (2015) Attribution of climate extreme events. Nat Clim Chang 5:725–730. https://doi.org/10.1038/NCLIMATE2657

Trenberth K, Jones P, Ambenje P, Bojariu R, Easterling D, Tank AK, Parker D, Rahimzadeh F, Renwick J, Rusticucci M, Soden B, Zhai P (2007) Observations: surface and atmospheric climate change. In: Solomon S, Qin D, Manning M, Chen Z, Marquis M, Averyt KB, Tignor M, Miller HL (eds) Climate change 2007: the physical science basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, chap. 3. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA

Turner BL, Kasperson RE, Matson PA, McCarthy JJ, Corell RW, Christensen L, Eckley N, Kasperson JX, Luers A, Martello ML et al (2003) A framework for vulnerability analysis in sustainability science. Proc Natl Acad Sci USA 100:8074–8079

Tyrna B, Assmann A, Fritsch K, Johann G (2018) Large-scale high-resolution pluvial flood hazard mapping using the raster-based hydrodynamic two-dimensional model FloodAreaHPC. J Flood Risk Manag 11:S1024–S1037

UN/ISDR (2004) Living with risk: a global review of disaster reduction initiatives, 2004 version, vol 1, New York and Geneva, 2004

UNDESA (2015) World urbanization prospects: The 2014 revision, Tech. Rep. ST/ESA/SER.A/352, United Nations, Department of Economic and Social Affairs, Population Division, New York, USA

UNDHA (1992) Internationally agreed glossary of basic terms related to disaster management, United Nations, United Nations Department of Humanitarian Affairs

USDA (2001) Stream corridor restoration principles, processes, and practices, Part 653 of the national engineering handbook. The Federal Interagency Stream Restoration Working Group, Washington D.C., USA

USBR (1998) Downstream hazard classification guidelines. ACER Technical Memorandum 11. Denver, Colorado

Verstraten L, Wasko C, Ashford G, Sharma A (2019) Sensitivity of Australian roof drainage structures to design rainfall variability and climatic change. Build Environ 161:106230

Vojinovic Z, Abbott MB (2012) Flood risk and social justice—from quantitative to qualitative flood risk assessment and mitigation, Urban hydroinformatics series. IWA Publishing, London

Vojinovic Z, Hammond M, Golub D, Hirunsalee S, Weesakul S, Meesuk V, Medina N, Sanchez A, Kumara S, Abbott M (2015) Holistic approach to flood risk assessment in areas with cultural heritage: a practical application in Ayutthaya, Thailand. Nat Hazards 81:589–616

Wahl T, Jain S, Bender J, Meyers SD, Luther ME (2015) Increasing risk of compound flooding from storm surge and rainfall for major US cities. Nat Clim Chang 5:1093–1097. https://doi.org/10.1038/nclimate273610.1038/nclimate2736. http://www.nature.com/nclimate/journal/v5/n12/abs/nclimate2736.html{#}supplementary-information

Wang X, Kinsland G, Poudel D, Fenech A (2019) Urban flood prediction under heavy precipitation. J Hydrol 577:123984

Wei Y-M, Fan Y, Lu C, Tsai H-T (2004) The assessment of vulnerability to natural disasters in China by using the DEA method. Environ Impact Assess Rev 24:427–439. https://doi.org/10.1016/j.eiar.2003.12.003

Wenzel HG (2013) Rainfall for urban stormwater design, in urban stormwater hydrology. American Geophysical Union, Washington, D. C.

Werren G, Reynard E, Lane SN, Balin D (2015) Flood hazard assessment and mapping in semi-arid piedmont areas: a case study in Beni Mellal Morocco. Nat Hazards 81:481–511. https://doi.org/10.1007/s11069-015-2092-0

Wilby RL, Keenan R (2012) Adapting to flood risk under climate change. Prog Phys Geogr 36:348–378. https://doi.org/10.1177/0309133312438908

Winsemius HC, Aerts JCJH, van Beek LPH, Bierkens MFP, Bouwman A, Jongman B, Kwadijk JCJ, Ligtvoet W, Lucas PL, van Vuuren DP, Ward PJ (2015) Global drivers of future river flood risk. Nat Clim Chang. Advance online publication. http://doi.org/10.1038/nclimate289310.1038/nclimate2893. http://www.nature.com/nclimate/journal/vaop/ncurrent/abs/nclimate2893.html{#}supplementary-information

Wisner B, Blaikie P, Cannon T, Davis I (2004) At risk: natural hazards, 2nd edn. People's vulnerability and disaster, Routledge, London

WMO (2008) Urban flood risk management: a tool for integrated flood management, flood management tools series, APFM Technical Document 11, World Meteorological Organisation

Wu SY, Yarnal B, Fisher A (2002) Vulnerability of coastal communities to sea-level rise: a case study of Cape May County, New Jersy, USA. Clim Res 22:255–270. https://doi.org/10.3354/cr022255

Xu X, Wang YC, Kalcic M, Muenich RL, Yang YE, Scavia D (2019) Evaluating the impact of climate change on fluvial flood risk in a mixed-use watershed. Environ Model Softw 122:104031

Yalcin E (2019) Two-dimensional hydrodynamic modelling for urban flood risk assessment using unmanned aerial vehicle imagery: a case study of Kirsehir, Turkey. J Flood Risk Manag 12:e12499

Zhang N, Alipour A (2019) Integrated framework for risk and resilience assessment of the road network under inland flooding. Transp Res Rec 2673(12):182–190

Zhang L, Singh VP (2007) Gumbel-Hougaard copula for trivariate rainfall frequency analysis. J Hydrol Eng 12:409–419

Zhou Z, Wu WB (2009) Local linear quantile estimation for nonstationary time series. Ann Stat 37(5B):2696–2729

Zhou X, Bai Z, Yang Y (2017) Linking trends in urban extreme rainfall to urban flooding in China. Int J Climatol 37(13):4586–4593

Zhou Y, Shen D, Huang N, Guo Y, Zhang T, Zhang Y (2019) Urban flood risk assessment using storm characteristic parameters sensitive to catchment-specific drainage system. Sci Total Environ 659:1362–1369

Chapter 6
A Survey on Disaster: Understanding the After-Effects of Super-Cyclone Amphan, the Helping Hand of Social Media

Soham Poddar, Mainack Mondal, Saptarshi Ghosh, and Arnab Jana

1 Introduction

Super-cyclonic storm "Amphan" hit Eastern India, specifically the state of West Bengal, Odisha and parts of Bangladesh in May 2020. Amphan was a very powerful tropical cyclone—technically, a super cyclone (CAT 5) (Balasubramanian and Chalamalla 2020)—that caused widespread damage.[1] In fact, CNN[2] reported that Amphan-caused damages amount to around US $13 billion, which makes it the costliest cyclone ever recorded in the North Indian Ocean. The cyclone made landfall in West Bengal on May 20, 2020.

The meteorological offices in India gave early warning of the development of Amphan. Consequently, state as well as central governments made an effort prior, during and after this natural disaster to contain the devastation. However, it is not well understood how, from a collective societal point of view Amphan affected the lives of *normal* citizens, and if novel digital mediums like online social media platforms (e.g., Facebook, WhatsApp, Twitter) helped the citizens to cope better with this disaster. Note that *cyclone Amphan happened at a time when the state of West Bengal (and the whole of India) was under strict lockdown restrictions due to the COVID-19 pandemic*. Since physical movement of people was severely restricted, digital platforms such as online social media are likely to have played an especially important role in coordinating relief efforts.

[1] https://www.bbc.com/news/world-asia-52734259

[2] https://tinyurl.com/CNN-amphan

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P. Banerji and A. Jana (eds.), *Advances in Urban Design and Engineering*, Design Science and Innovation, https://doi.org/10.1007/978-981-19-0412-7_6

Thus, in this work, we attempted to understand this collective view via self-reported data from a sample of Amphan-affected population who resides in West Bengal, one of the worst affected states due to Amphan. Specifically, we conducted an *online survey* to get an estimate of the damages and impact of the cyclone on people. In this report, we will present our insights gained from the survey.

Some of the key takeaways from the survey are listed below. Details can be found in later sections.

- People were most affected due to disruption of services such as electricity, phone and internet than due to physical damages like uprooting of trees (this observation might have been affected by (i) the COVID19-induced lockdown which meant most people were indoors and (ii) the bias in our survey participants towards students and academicians residing in urban areas).
- Among the two most popular electric suppliers in West Bengal, it seems that CESC managed to restore a significantly higher fraction of connections (over 60%) within a day after the cyclone, as compared to WBSEDCL. However, for both suppliers, there were a comparable fraction of hard-to-repair connections whose restoration took more than 4 days.
- Among the popular phone service providers, Jio seems to have performed the best, with about 52% of the connections being disrupted, compared to almost 89% of Vodafone connections and 79% of Airtel connections being disrupted.
- The districts of Howrah and South 24 Parganas seem to have been the most affected, with very high fractions of participants saying they were severely affected by multiple factors associated with the cyclone. Though, it is to be noted that our sample sizes from these two districts are relatively small.
- It is seen that Online Social Media (OSM) is being used by the affected population in several important ways, including inquiring about safety of others, informing others of one's own safety, organizing donation campaigns, and so on. However, the authorities are *not* using OSM sufficiently to connect to people, which should be considered by the authorities for the future. There will always be the risk of fake news/biased opinions spreading through OSM (as also observed to some extent after Amphan), but the benefits of mass communication through social media clearly outweigh the downsides.
- Participants have given mixed ratings to the preparedness of the authorities in dealing with the disaster—the number of people who opined that the authorities were highly prepared to deal with the disaster almost equals the number of people who felt that the authorities were poorly prepared. We observed that people tend to give higher ratings to the authorities if they received helpful responses from the authorities, and if their services were restored earlier.

The insights obtained from this study can help the authorities to better understand the evolving information needs of people and to improve how they connect with people during disaster situations in future.

Organization of the Chapter: The rest of this chapter is organized as follows. We discuss some related work in Sect. 2, followed by the description of our survey methodology in Sect. 3. We then analyze the responses to the survey in subsequent

sections, starting with the demographics of the participants in Sect. 4. We then get an estimate of the damages caused by the cyclone to various localities and districts (Sect. 5), followed by how much the damages affected the people (Sect. 6). Then we discuss the use of OSM platforms by the people affected by the cyclone (Sect. 7). We also analyze how well the authorities were prepared to deal with the crisis (Sect. 8). Further, we discuss some implications/takeaways from the survey that can help better handling of disasters in future (Sect. 9). We conclude the study in Sect. 10.

2 Related Work

Studies on Similar Disasters: The frequency of super-cyclones has been predicted to have increased in recent past due to climate change and other man-made interventions, and this phenomenon has been studied across the globe (Nott and Hayne 2001; McCabe et al. 2001). These events pose serious threat to public health, livelihood and civil infrastructure in general (Majra and Gur 2009; Iwasaki et al. 2009). In this context, researches have pointed towards the growing needs of the adaptive capabilities of developing nations towards these extreme events especially with the surge in frequency and intensity (Mirza 2003). Several studies have also been conducted accessing the vulnerabilities in the process of disaster management in India (Kawyitri and Shekhar 2020; Mazumdar and Paul 2016; Yadav and Barve 2017).

Importance of Participation of Population During Disasters: The public opinion towards authorities during a disaster has been studied previously in O'Sullivan et al. (2012), OECD (2013), Eiser et al. 2012). Such studies have shown that proper communication in both directions (authorities and the public) is important in helping to prepare the population before a disaster (Grothmann and Reusswig 2006), which can greatly reduce the damages caused (Mahdavian et al. 2020; Ardaya et al. 2017). How the authorities choose to communicate can also affect the co-operation of the people with them (Coombs 1995). This brings forward the importance of participation of the local population on matters related to disaster risk mitigation, and the importance of authorities to communicate effectively with them. Especially in the context of developing nations like India, the importance of public participation in disaster management and planning for short-term crisis management and long-term risk management has been ascertained (Bhattacharyya 2015; Kala 2014; Raju and Becker 2013). Studies have shown that public communication during disaster plays a crucial role in mitigation of the effects of disasters (Diwanji et al. 2020; Doyle et al. 2019). This can be done in several ways, ranging from traditional television/radio broadcasts to the emerging use of online social media.

Use of Social Media in Disaster Mitigation: Online social media has been found to be an effective method of communication with the population during disasters over one-way communication channels (Saroj and Pal 2020; Houston et al. 2015; Alexander 2014; Gao et al. 2011). Firstly, social media can be used to raise disaster awareness for increasing preparedness of the population (Anson et al. 2017; Rogstadius et al. 2013). Social media can also be used in estimating the demand and supply

scenarios of infrastructure, emergency supply of food, water and medicine (Reuter and Kaufhold 2018a; Kryvasheyeu et al. 2016; Imran et al. 2013; Cameron et al. 2012). Quite a few studies focus on mitigation of the after-effects in post-disaster phases (Kankanamge et al. 2020; Kim and Hastak 2018; Basu et al. 2017), while some studies are based on monitoring and assessment of the crisis as a whole (Shan et al. 2019). Research has been done to use social media as a platform to connect people to help each other during disasters (Li et al. 2019; Purohit et al. 2014). Some progress has been made in integrating the data from authorities with that from social media to better help disaster management (Schempp et al. 2019). Social media such as Whatsapp are also known to be used by responding authorities for coordinating relief efforts (Resource Mapping During a Natural Disaster: A Case Study on the 2015 Nepal Earthquake 2017).

A surge of posts on social media occur during any major events including disasters, which cover a variety of topics such as reporting of first-hand information or seeking of help/information from officials (Stowe et al. 2016). However, people often make posts relating the event which are not relevant to the process of disaster mitigation. The challenge lies in extracting useful information from the huge amount of social media posts being made and several researches have been conducted in this regard (De Albuquerque et al. 2015; Middleton et al. 2013; Kumar et al. 2011). Another major challenge in the process of utilizing social media is the spread of misinformation/fake news, which causes panic among the population and deters authorities from effective disaster mitigation (Kwanda and Lin 2020; Krishnan and Chen 2018).

3 Survey Methodology

We deployed the survey on May 30, 2020, i.e., 10 days after the cyclone. We chose to wait for 10 days after the cyclone due to several reasons—(i) the internet connectivity of many people was disrupted by the cyclone for several days (as will be evident from the results of the survey discussed in later sections). Since our survey would be conducted online, we wanted to ensure that internet connectivity would be restored for most people and (ii) to allow people time to recuperate from the effects of the cyclone.

The survey was disseminated through mailing lists of a few educational institutes in and around Kolkata, West Bengal, and through social media posts by the authors. Consequently, as can be seen in Sect. 4, most of the participants of the survey were students and faculty members of educational institutes in and around Kolkata. We collected data using our survey over a duration of 2 weeks, i.e., between May 30 and June 16, 2020. In total, 201 participants responded to the survey.

As part of the survey, a participant was mostly asked about the effects of the cyclone in his/her "locality", which was described as the region approximately within 500 meters in all directions from the participant's home.[3] Among the participants,

[3] The exact questions asked during the survey are listed in the Appendix.

Table 1 Gender distribution of survey participants and people in West Bengal. The gender ratio of the participants is slightly biased towards males

	Male (%)	Female (%)
Survey participants	58.2	41.8
Population of West Bengal (WB)	51.3	48.7

90.6% said they were themselves in the locality for which they were answering during the cyclone, while the rest were responding on behalf of others who were in affected localities.

Note that *cyclone Amphan occurred during the COVID-19 pandemic, when West Bengal (and the whole of India) was under strict lockdown protocols*. This exceptional situation might have affected some of the observations in the survey. For instance, our survey indicates that people were much more adversely affected by factors such as disruption to phone and Internet services, than by physical damages such as uprooting of trees and waterlogging in their locality (as detailed in later sections)—the difference between the effects may have been larger due to the fact that the lockdown forced a lot of people to work from home, without venturing out into streets. However, it is also possible that the authorities required more time to repair the damages (e.g., remove uprooted trees, repair damaged electricity cables) due to the ongoing pandemic (and resultant lockdown), than they would have under normal circumstances. Also note that our online mode of survey deployment was the only feasible option during a nation-wide lockdown (as opposed to approaching citizens' offline).

4 Demographics of Participants

In this section, we study the demographics of the 201 participants who responded to the survey, in terms of their gender distribution, age distribution and occupation distribution. We also compare the distribution of the participants with the overall population distribution of the state of West Bengal, to check how representative our set of participants is of the overall population of the state.

Gender Distribution: Table 1 shows the distribution of gender of the survey participants.[4] We also compare it to the distribution of gender in the overall population of the state of West Bengal according to 2011 census 2011.[5] As we can see, the gender ratio of the survey participants is slightly biased towards males, with males consisting of 58% of the participants compared to 51% in overall population of West Bengal.

[4] We also had "Others" as an option (apart from "Male" and "Female") in our survey. However, no participant selected it.

[5] www.census2011.co.in/census/state/west+bengal.html

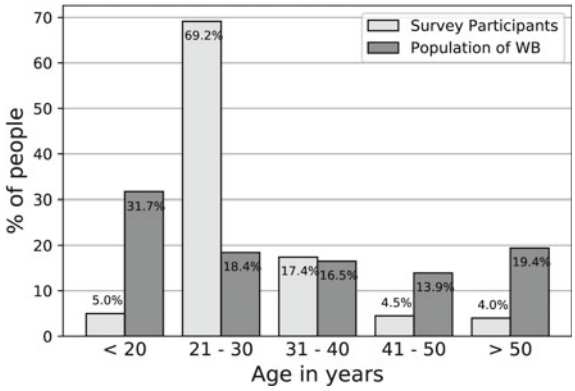


Fig. 1 Age distribution of survey participants and the overall population of West Bengal (WB). Our sample is heavily biased towards the age group between 21 and 40

Age distribution: Fig. 1 presents the age distribution of our participants. We again compare the age distribution to that of the overall population of West Bengal according to the 2011 census.[6]

Evidently, the age distribution of our participants is heavily biased towards people aged between 21 and 30 years (69% among survey participants, compared to 18% in WB population). In fact, 85% of the survey participants are aged between 21 and 40 years (compared to 35% in WB). This bias towards younger participants is mainly a result of our methodology of distributing the survey via mailing lists of educational institutions, whereby the survey was mostly taken by university students. However, this might even be beneficial for our study since people in this age group are generally well aware of the situation in the localities and their families. In fact, 90% of the participants in this age-group were themselves in the localities for which they reported the damages.

Occupation distribution: The distribution of occupation of the participants is given in Fig. 2. Our sample is biased towards more students, teachers and engineers, with students making up about 53% of our sample. As in the case of age distribution, this bias stemmed from our recruitment procedure that relied heavily on the students and faculty members of educational institutes, and users of social media, who are more likely to use the internet (and take our survey).

Geographical distribution: During the survey, participants were asked to state the pin code of their locality. Responses were obtained from a total of 124 distinct pin codes. We mapped the pin codes to the various districts of West Bengal. The distribution of the pin codes among the districts of West Bengal is shown in Fig. 3a. According to the Wikipedia,[7] and the newspaper "Hindustan Times",[8] the districts North 24 Paraganas (N24P), South 24 Parganas (S24P), Kolkata (KOL), Hooghly (HGLY) and Howrah (HWH) were the ones mostly affected by cyclone Amphan. These are also the five districts from where most of the responses were received.

[6] http://statisticstimes.com/demographics/population-of-west-bengal.php

[7] https://en.wikipedia.org/wiki/Cyclone_Amphan

[8] https://tinyurl.com/HT-amphan

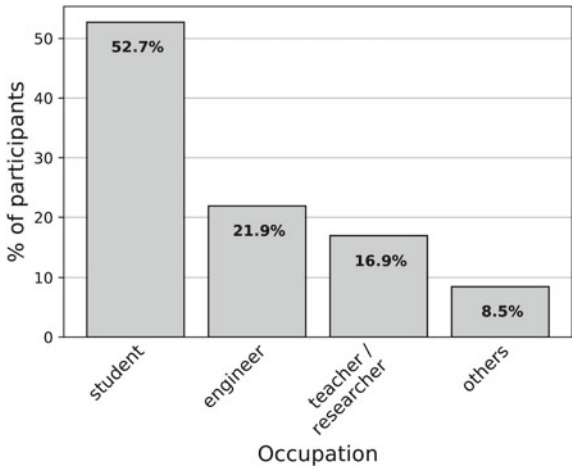


Fig. 2 Occupation distribution of survey participants. The participants are mostly students

We have considered these top five districts individually and grouped the rest as "Others", as in Fig. 3b. It can be noted that, although the majority of the survey participants were from urban areas, some of them were from semi-urban areas.

Summary of Section

We found that our sample population is biased towards a younger population (age group of 21–40), and towards students. This bias is inherent in our recruitment procedure (via email list of educational institutions, social media).

However, we note that this biased population is still suitable for our study due to two reasons: First, our sample covers a wide range of cyclone-affected localities and provides a wide coverage over age groups as well as gender. Moreover, this bias might even facilitate parts of our exploration—one of the aims of this study is to understand the perceptions about digital media usage during disasters; since our survey respondents are well versed with digital media usage, it is possible to gain valuable insights about this aspect from the survey (see Sect. 7).

5 Measuring Extent of Damages

In this section, we study the damages caused by the cyclone to the various localities of the participants. We first analyze the physical damages caused to the localities (for example, damages to trees and buildings) in Sect. 5.1, followed by an analysis of how services like electricity supply were disrupted in Sect. 5.2.

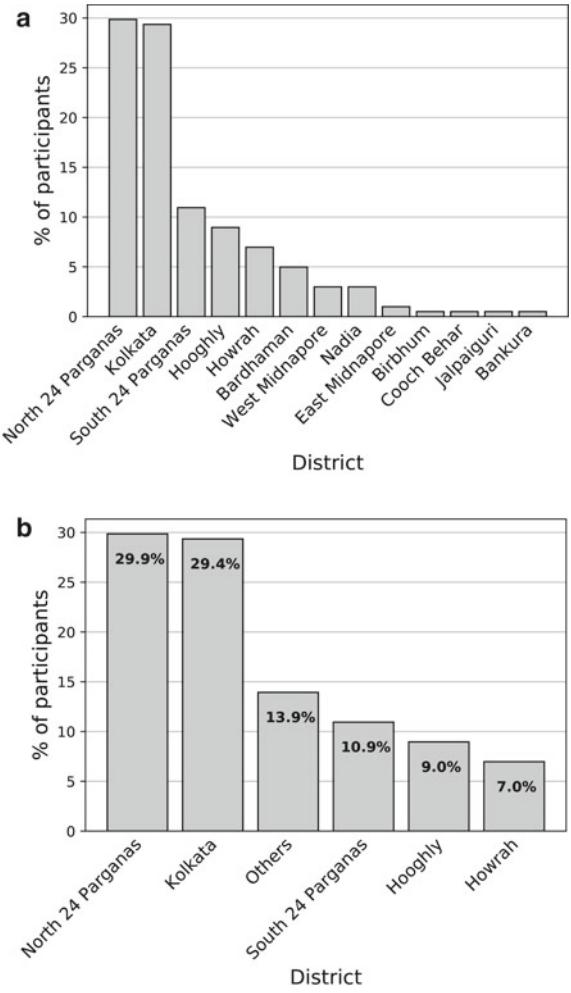


Fig. 3 Geographical distribution of survey participants. Most of the participants were from N24P and KOL. **a**: Distribution of participants among all districts in WB. **b**: Considering the top five districts and grouped rest as "Others"

5.1 Physical Damages to Localities

We asked participants to give an estimate of the damages caused by Amphan to their localities in terms of (i) number of trees uprooted, (ii) number of buildings damaged, (iii) number of days for which one's locality was waterlogged. We had specified that "locality" refers to the region approximately within 500 m in all directions from the participant's home. The distribution of responses by the participants is shown in Fig. 4. We have also calculated the district-wise distribution of heavily damaged localities, and tabulated them in Table 2.

Trees uprooted: The number of trees that were uprooted or seriously damaged by the cyclone is shown in Fig. 4a. Uprooting of trees was prevalent in a large majority

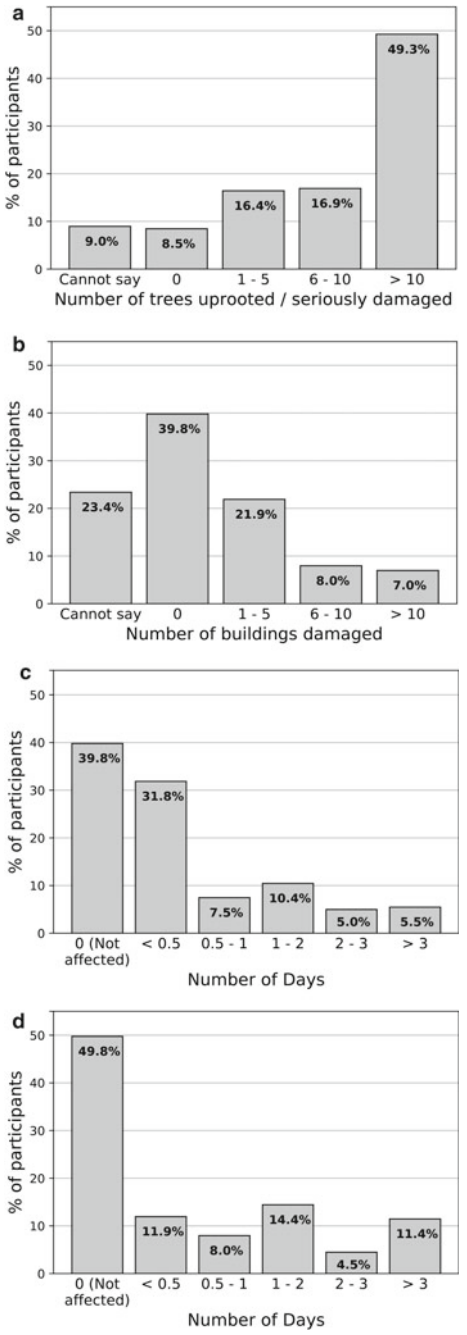


Fig. 4 Measuring the extent of damages in the localities of the survey participants. A lot of trees were damaged in many localities, but there was not much damage to buildings in the localities of the participants (mostly urban). Waterlogging and disruption to drinking water supply have also been relatively less. **a**: Number of trees uprooted in participants' locality. **b**: Number of Buildings damaged in participants' locality. **c**: Number of days for which participants' locality was waterlogged. **d**: Number of days for which participants' locality faced disruption of supply of drinking water

Table 2 Distribution of heavy damages to different districts, where "heavy damage" is as described in the first column

Participants who said their locality was damaged heavily in terms of:	N24P (60) (%)	KOL (59) (%)	S24P (22) (%)	HGLY (18) (%)	HWH (14) (%)	Others (28) (%)
Trees uprooted (More than five trees)	65.0	66.1	86.4	**88.9**	85.7	28.6
Buildings damaged (More than five buildings)	10.0	13.6	18.2	**27.8**	21.4	14.3
Waterlogging (More than 1 day)	21.7	27.1	18.2	5.6	**35.7**	10.7
Drinking water supply disrupted (More than 1 day)	35.0	22.0	27.0	**44.4**	42.9	21.4
Electricity supply disrupted (More than 1 day)	56.7	25.4	**81.8**	61.1	64.3	28.6
Phone service disrupted (More than 1 day)	61.7	72.9	**81.8**	61.1	64.3	25
Internet service disrupted (More than 1 day)	68.3	88.1	81.8	83.3	**100**	25

The percentages represent the fraction of participants from that district who said their localities were damaged heavily. The numbers in brackets below each of the district names represent the count of participants from that district. The highest percentage in each row is highlighted in boldface. Note that "Others" refer to all the districts that were not affected much by cyclone Amphan.

of localities. In 66.2% of the localities, more than five trees were uprooted. In 49.3% localities, more than 10 trees were uprooted.

The district-wise distribution of heavy damage to trees is given in the first row of Table 2. As expected, damages to trees affected the other districts ("Others") quite less (28.6% participants reported more than five trees uprooted), whereas for each

of the five districts that were most affected by the cyclone, over 65% of participants reported more than five trees uprooted. The fractions are especially high in South 24 Paraganas, Hooghly and Howrah, where more than 85% of participants from these districts reported more than five trees uprooted in their locality.

Buildings damaged: The number of buildings damaged in Fig. 4b. Damages to buildings were relatively less in the localities of our survey participants. Only in 15% of the localities, more than five buildings were damaged. From Table 2, we see that the fraction of participants who reported more than five buildings damaged is 10% in North 24 Paraganas, 13.6% in Kolkata, slightly more (27.8%) in Hooghly. These low fractions are somewhat expected due to these being urban areas.

Waterlogging: The distribution of the duration for which the localities were waterlogged is shown in Fig. 4c. About 21% of all localities of the participants faced waterlogging issues for more than 1 day. As seen in Table 2, waterlogging affected Howrah the most (35.7% of participants reported waterlogging for more than one day) and Hooghly the least (5.6% participants reported waterlogging for more than one day).

The relatively low severity of waterlogging in some localities indicates good drainage facilities in those localities. The areas where waterlogging was more severe could have improper drainage that tends to flood even with normal rains. In fact, 31.2% of the survey participants said that their locality was waterlogged due to cyclone Amphan but is not usually waterlogged during normal rainfall. Whereas, 23.8% of participants said that their locality gets regularly flooded every time there is heavy rainfall. The authorities should attempt to improve the drainage facilities in these localities.

5.2 Disruption of Services

We asked the participants if their drinking water, electricity, phone and internet services had been disrupted due to the cyclone Amphan, and if so, how long it took for these services to be restored back. We now analyze the disruption of various services.

Disruption of drinking water supply: The duration for which the supply of drinking water was disrupted is given in Fig. 4d. About 30.3% of the participants faced problems with drinking water supply beyond one day. The district-wise distribution is given in Table 2. Drinking water problems were faced by all districts more or less evenly, with Hooghly and Howrah facing the most problems, with 44.4% and 42.9% of the participants from these districts saying they faced irregular drinking water supply beyond one day.

It can be noted that disruption of drinking water supply may be correlated with electricity services being hampered for a long time (as discussed below), which rendered electric water pumps inoperable.

Disruption of electricity supply: There are two primary electricity supply providers in West Bengal—(i) CESC that primarily supplies Kolkata and parts

of Howrah and other districts neighboring Kolkata and (ii) WBSEB/WBSEDCL that supplies the other regions. In total 91 of our survey participants reported they were supplied by CESC, and 106 participants reported they were supplied by WBSEDCL/WBSEB (while only 4 reported some other supplier).

In total, as many as 89.1% of our survey participants reported disruption of electricity in their locality. Specifically, 82.4% out of the 91 participants supplied by CESC and 95.3% out of the 106 participants supplied by WBSEDCL/WBSEB faced disruption of electricity supply. Thus, it seems that people supplied by WBSEDCL/WBSEB were disrupted more than those by CESC (95.3% versus 82.4%).

The distribution of time taken for restoration of electricity supply is given in Fig. 5. The overall trends are given in Fig. 5a whereas Fig. 5b gives a comparison between the two major electricity suppliers CESC and WBSEDCL/WBSEB. In case of CESC, the majority of the connections were restored within a day (61%), whereas WBSEDCL/WBSEB took longer to restore supplies. However, for both providers, a considerable fraction of connections took longer than 3 days to restore (21.4% for CESC, and 27.6% for WBSEDCL/WBSEB).

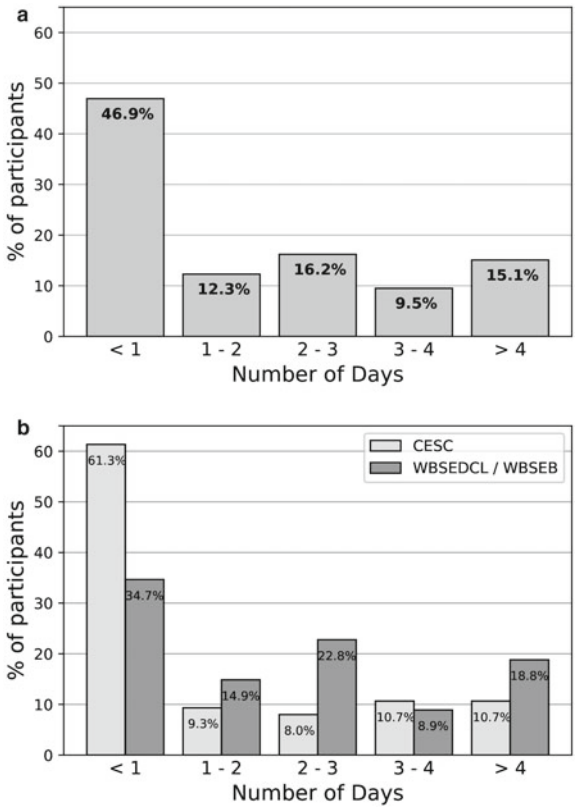


Fig. 5 Time taken (in days) for restoration of electricity supply. We present (**a**) overall results, and (**b**) a comparison between the two major electricity suppliers—CESC and WBSEB/WBSEDCL. The percentages in the bar charts are calculated based on the number of participants for whom services were disrupted (91 participants supplied by CESC, and 106 by WBSEDCL/WBSEB; 82.4% and 95.3% participants respectively faced disruption for them). **a**: Number of days taken for restoration of electricity (for all 201 participants). **b**: Comparison of electricity restoration time between CESC and WBSEDCL/WBSEB

The district-wise distribution of disruption of electric supply is given in Table 2. As we can see, a significantly less number of participants from Kolkata (25.4%) faced disruption beyond 1 day. The "Others" were not affected too much by the cyclone, hence most of the participants from these regions had electricity restored in under a day. However, the districts of North 24 Parganas, South 24 Parganas, Hooghly and Howrah saw heavy disruption of electricity services.

It can be noted that a large majority of electricity connections of Kolkata and Howrah are supplied by CESC. There is a huge difference in the fraction of connections in these two districts that were disrupted for more than a day—25.4% for Kolkata and 64.3% for Howrah. This difference indicates that CESC may have prioritized fixing connections in Kolkata since it is a major city.

We had also asked the participants (who said they faced disruption of electricity supply) *if their locality had some public utility whose operation could have been disrupted due to lack of electricity*. About 11.7% of participants answered there were *hospitals/nursing homes* in their localities, 26.1% said there were *water pumping stations*, and as many as 67.8% of participants said there were *mobile towers* in their locality. The mobile towers not getting electricity supply for long could have depleted their backup power source, which led to further disruption of phone and internet services (as discussed below). The same goes for the water pumping stations, whose disruption could have led to unavailability of drinking water in certain localities for a long duration.

Disruption of phone and Internet Services: Next we asked about the disruptions to phone and internet services. For the phone connections, we asked survey participants to mark which service providers they used, and which of them were disrupted, and how long it took for at least one service to be restored. For internet connections, we asked which media they used to access the internet (like mobile internet or broadband), and if they faced disruption of internet services.

It can be noted that there are four primary mobile service providers in the state of West Bengal—Vodafone, Airtel, BSNL and Jio. Out of the 201 survey participants, 114, 103, 53, and 132, respectively, reported using these services. Note that many participants reported to be using more than one mobile service providers simultaneously. For internet connectivity, there are two popular choices—mobile internet (used by 168 participants) and broadband internet (used by 111 participants). Again, several participants reported to be using both.

Table 3 Number of participants who avail different network providers for phone and percentage of participants who experienced disrupted phone services

Network Provider	Total	Disrupted (%)
Overall	201	85.1
Vodafone	114	88.6
Airtel	103	78.6
BSNL	53	66.0
Jio	132	52.2

Table 4 Number of participants who avail internet via different technologies, and percentage of participants who experienced disrupted internet services

Internet technology	Total	Disrupted (%)
Overall	201	88.6
Mobile	168	89.9
Broadband	111	90.1

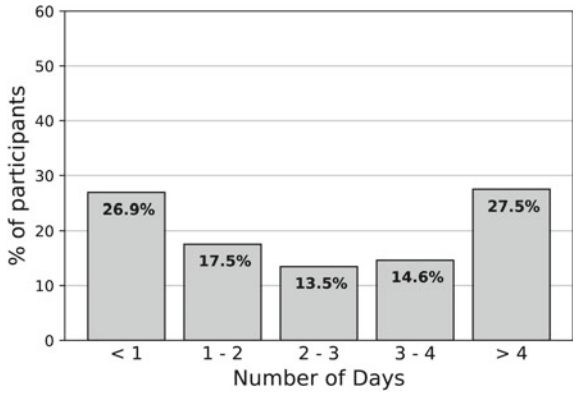


Fig. 6 Time taken for phone services to be restored

Table 3 shows the fraction of mobile connections that were disrupted. Overall, a huge number (85%) of phone connections seem to have been disrupted, with even more (88.6%) internet connections being disrupted. Among phone service providers, Vodafone seems to have been disrupted the most (88%), followed by Airtel (78.6%), while Jio connections were disrupted quite less relatively (52%). These observations in our survey corroborate with reports in the news media. For instance, The Indian Express reported[9] on May 22, 2020 (i.e., 2 days after the cyclone)—"indianexpress.com reached out to some people in Kolkata, and most of them told us that only Jio and BSNL services are working somewhat decently, whereas, Vodafone and Airtel services are not working at all".

Table 4 shows the fraction of disrupted internet connections. Internet connections were also heavily disrupted, where close to 90% of both mobile internet connections as well as Broadband Internet connections were disrupted.

The distribution of *restoration times* of the phone services is given in Fig. 6 where it is seen that a large fraction of phone connections (42.1%) took more than 3 days to be restored. The distribution of restoration time of internet services is given is Fig. 7, and a significant fraction of them (57.8%) took more than 3 days to be restored.

The district-wise distributions of phone and internet connections that were disrupted for more than a day are shown in Table 2. It seems the phone and internet services were disrupted for over a day for a large majority of participants in all the five districts that were mostly affected by Amphan. The districts of Kolkata, South 24 Parganas and Howrah (especially for internet service disruption) seem to have

[9] https://tinyurl.com/IE-amphan

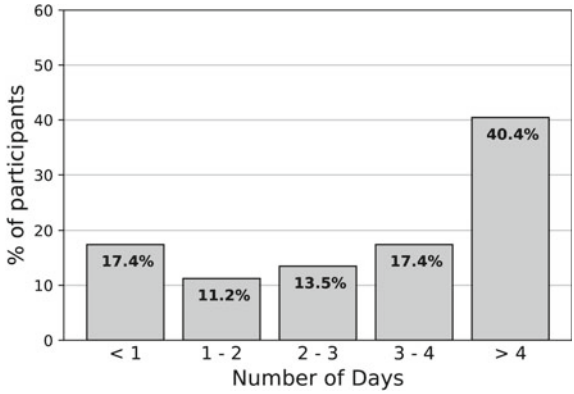


Fig. 7 Time taken for internet services to be restored. Note that restoration of internet services took more time than restoration of phone services, for a substantial fraction of participants

been severely affected (though our sample size from Howrah and South 24 Parganas is quite small).

It can be noted that phone connections were disrupted slightly less than internet connections. Several participants indicated that, even though they could not access the internet through their mobile connections, they could use their phones for calling (especially the ones using the service provider Jio).

Summary of Section

The major physical damage (in the localities covered by our survey participants) was uprooting of trees, whereas the damage to buildings seemed less (since most of the participants were from urban areas). There was not too much damage in terms of waterlogging and disruption of supply of drinking water, even though some participants faced disruption of drinking water supply beyond 3 days. The district of Hooghly seems to have faced the most damage; however, the number of participants from here is quite less.

Importantly, a huge fraction of participants faced disruption of electricity, phone and internet services; even worse, a huge fraction of these services took more than 3 days to be restored (this delay in restoration could have been higher due to the ongoing COVID19-induced lockdown). Among the two most popular electricity suppliers, it seems that CESC managed to restore a significantly higher fraction of connections within a day after the cyclone, as compared to WBSEDCL. Among the popular phone service providers, Jio seems to have faced relatively less disruption.

6 Effect of These Damages on the Population

In this section, we attempt to study how severely the population was affected by the damages caused to their localities. We considered the seven factors discussed in Sect. 5 and tried to find to what extent the participants were affected by each factor.

To this end, for each of the seven factors, we asked participants to rate the extent to which they/their family were affected, on a *Likert scale* of 1–5, where level "1" indicates "not affected at all", and level "5" indicates "extremely severely affected". The distributions of the responses for all seven factors are shown in Fig. 8a–g.

We consider a participant to be *"severely affected"* if he/she selected levels 4 or 5 on the Likert scale. We have sorted the factors based on the decreasing order of number of people saying that they were severely affected by a certain factor. We also calculated which factors affected people severely (participants who selected levels 4 and 5) from each of the districts, and have tabulated the district-wise distributions in Table 5.

Electricity, phone, internet and drinking water services: A staggering 72.8% of the participants were severely affected (i.e., selected levels 4 or 5 on the Likert scale) by disruption of internet services (see Fig. 8a). As many as 67.3% of the participants were severely affected by disruption in phone services (Fig. 8b), while 48.5% of the participants were severely affected by disruption of electricity supply (Fig. 8c).

There can be two potential factors leading to such high fractions of people getting severely affected by disruptions of these services. First, as stated earlier, the cyclone occurred during the COVID19-induced lockdown which forced a lot of people to work from home. Second, our sample population mostly consisted of students, faculty and engineers (as given in Sect. 4). These services were particularly crucial for our sample population while working from home. These two factors might explain why the disruption severely affected so many of the survey participants.

The district-wise distribution of these participants is given in the first three rows of Table 5. It seems that people from Howrah and South 24 Parganas were most severely affected overall (though the number of participants from these districts is only 14 and 22, respectively).

Also 24.7% of the participants were severely affected by drinking water shortage (Fig. 4d), with the highest fraction being from Howrah.

Physical damages to localities: For the three physical damage factors (uprooting of trees, damage to buildings, and waterlogging), the number of people severely affected follows the same pattern as the amount of damages caused. Figure 8d shows that 30.3% of the participants were severely affected due to uprooting of trees. Figure 8f shows that not too many (16.3%) were affected severely by water-logging and even fewer (10%) by damages to buildings as shown in Fig. 8g. The probable reason for these low fractions is that the participants were from urban areas mostly.

The district-wise distribution of these participants is given in Table 5. Uprooting of trees seems to have affected people more or less equally from all the districts, except for South 24 paraganas where a lot more people (50%) seem to have been affected, which is expected because of the huge amount of trees present in this district. Waterlogging seems to have been a problem mostly in Kolkata, North 24 Paraganas and Howrah. North 24 Paraganas seems to be most affected by damage to buildings, but still only a few participants (10) said they were affected severely.

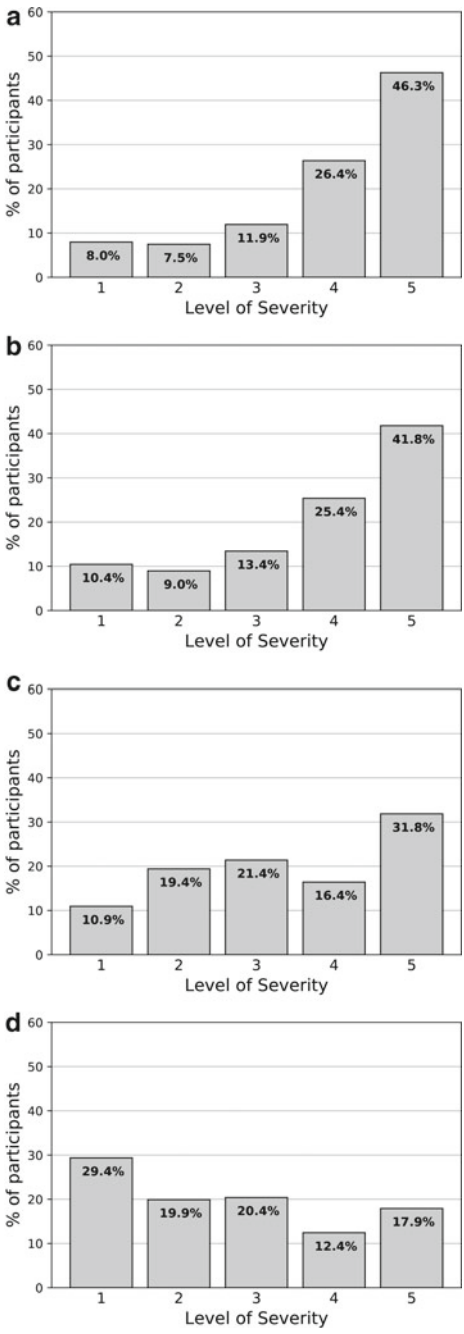
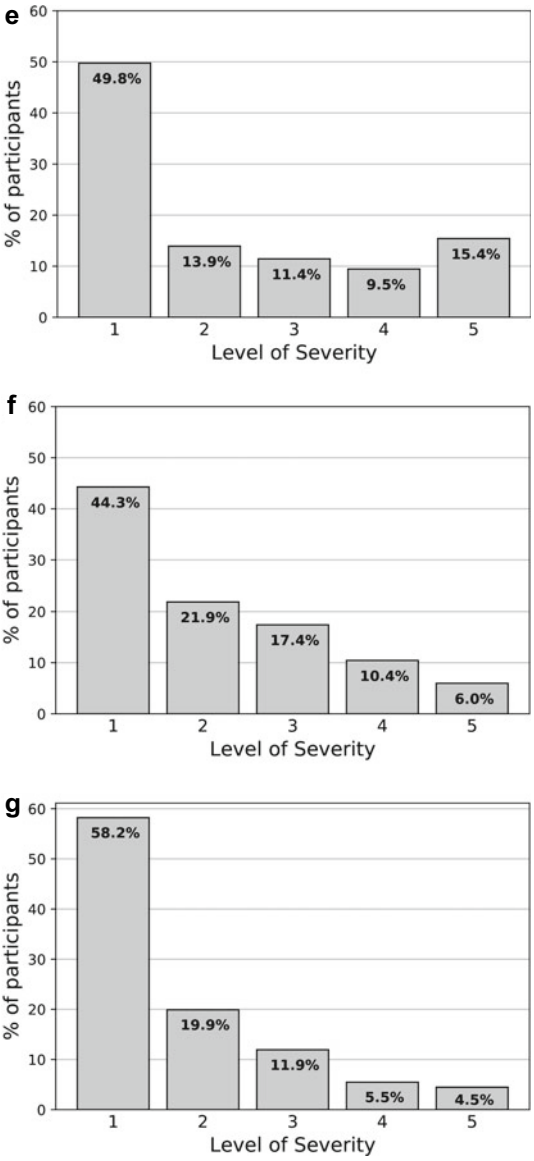


Fig. 8 Severity of participants affected by disruption of various factors on a scale of 1 (least severe) to 5 (most severe). Participants were affected much more by disruption of services than physical damages to their localities. **a**: Self-reported severity for disruption of internet services. **b**: Self-reported severity for disruption of phone services. **c**: Self-reported severity for disruption of electricity supply. **d**: Self-reported severity for uprooting of trees. **e**: Self-reported severity for disruption of supply of drinking water. **f**: Self-reported severity for to waterlogging. **g**: Self-reported severity for damages to buildings

Fig. 8 (continued)



Summary of Section

The population was affected much more by disruption of electricity, phone and internet services than by physical damages such as uprooting of trees and water-logging (which may be because of the COVID19-induced lockdown and the bias in our survey population). All districts seem to have been more or less equally affected due to disruption of internet and phone services (except for "Others" which were

Table 5 Distribution of participants who were severely affected (i.e., selected one of the highest two levels 4 or 5 on Likert scale of being affected) by various factors, across the different districts

Participants who said they were heavily affected (levels 4 and 5) due to	Overall (201) (%)	N24P (60) (%)	KOL (59) (%)	S24P (22) (%)	HGLY (18) (%)	HWH (14)(%)	Others (28) (%)
Disruption of internet connectivity	72.8	81.7	69.5	86.4	77.8	**100**	32.1
Disruption of phone connectivity	67.3	73.3	67.8	**86.4**	72.2	78.6	28.6
Disruption of electricity supply	48.5	60.6	27.1	77.3	50.0	**78.6**	28.6
Uprooting of trees	30.0	33.3	23.7	**50.0**	33.3	35.7	17.9
Disruption of drinking water supply	24.7	30.0	20.3	31.8	22.2	**42.9**	10.7
Waterlogging/flooding	16.3	20.0	**22.0**	9.1	11.1	21.4	3.6
Damage to buildings	9.9	**16.7**	6.8	9.1	5.6	7.1	7.1

The percentages represent the fraction of participants who were severely affected from that district. The numbers in brackets below each of the headers represent the count of participants from that district. The highest percentage in each row is highlighted in boldface. The seven factors (rows) are arranged in decreasing order of the overall fraction of participants who said they were severely affected by a certain factor (second column).

anyway affected less by the cyclone). South 24 Paraganas and Howrah seem to have been affected more by disruption of electricity supply. Participants from South 24 Paraganas seem to have been affected significantly more due to uprooting of trees, whereas Kolkata and North 24 Paraganas seem to have been affected more due to waterlogging.

7 Impact of Social Media

Online Social Media (OSM) is being increasingly used in post-disaster times both within India and abroad (Nazer et al. 2017; Imran et al. 2015; Niles et al. 2019; Reuter and Kaufhold 2018b). In this section, we analyze the impact of OSM on people during the days immediately after the Amphan cyclone. We also try to analyze how effective the authorities were in utilizing social media to reach people during the disaster.

OSM usage of participants in general: Out of the total of 201 survey participants, 198 said that they use social media, and the frequency of usage is as given in Fig. 9. Our survey participants mostly consist of people who frequently use social media, with 90.5% participants using social media every day. This high social media usage is expected as our survey population is biased towards people who frequently use social media and are thus more likely to respond to our survey (as discussed in Sect. 4).

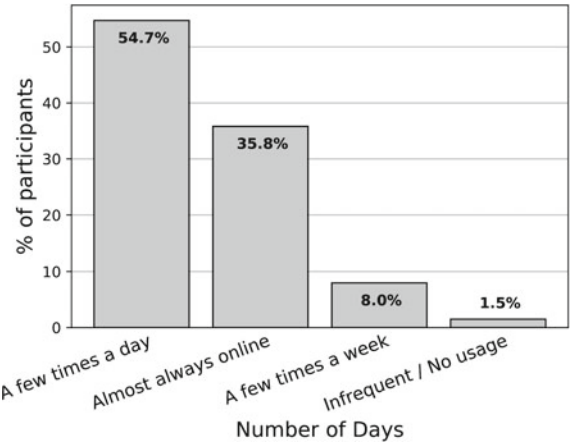


Fig. 9 Frequency of social media usage of our participants

Table 6 Different social media used by participants

Twitter (%)	Instagram (%)	Facebook (%)	Whatsapp (%)
22.9	46.8	85.1	95.5

We also asked the participants that social media apps/sites they use, with a lot of them using Facebook and Whatsapp as shown in Table 6.

OSM usage of participants within 7 days after Amphan: We asked three primary questions to the survey participants to find out the impact of social media during and after the disaster—(i) whether they posted any information related to cyclone Amphan on OSM, (ii) whether they received any useful information related to Amphan from OSM and (iii) whether they observed any undesirable/harmful information related to Amphan on OSM. All these questions specified that the participants should consider a time window of *7 days after the cyclone* while answering these questions (e.g., whether they had posted/received any information relevant to Amphan from OSM within 7 days after the cyclone).

In each of the three questions described previously, we had also kept an option stating "I did not use social media within 7 days after Amphan". A total of 22 participants selected this option for all three questions. We tried to find the reasons for these people not using social media. Two potential reasons could be (i) they are generally infrequent users of OSM, or (ii) their internet/electricity services were disrupted after the cyclone, thus preventing them from using OSM. It is interesting to see that, out of the 22 participants who did not use OSM in 7 days after Amphan, most of them (81.8%) are frequent users of OSM. Among them, about 72.7% faced internet connection problems and 63.6% faced electricity problems beyond 2 days after the cyclone, which might have been the reason for them not being able to use social media. It is difficult to guess why the rest did not use OSM for those few days. It is possible that they were recuperating from the effects of the cyclone and/or the COVID pandemic.

The rest 179 (89%) of our survey participants used OSM during the period of 7 days after Amphan. We refer to these participants as "active users". In the rest of this section, we analyze the information posted/received by these active users on OSM over the 7 days immediately after cyclone Amphan.

Information posted on social media: We first asked *if the participants themselves had posted information related to Amphan on social media* during the 7 days immediately after the cyclone. The responses have been tabulated in Table 7. Quite a lot of the participants (46.4% of the active users) used social media but did not post anything related to Amphan. However, the rest actually posted various information related to Amphan on OSM, e.g., described the situation in their locality (14% of active users), or posted images of damages in their locality (20.1%), posted their opinion on issues related to Amphan (13.4%), and so on. An important usage of OSM seems to be that a sizable fraction of people are using OSM to inquire about safety of others (27.9% of the active users) and to inform others about their own safety (26.8%). The use of OSM for inquiring about safety of others and informing others of one's own safety has been observed during other disaster events as well (Reuter and Kaufhold 2018b). Around 15.6% people also posted information to help others. A small fraction of participants (5.6%) specifically connected to social media accounts of the Government agencies or service providers and asked for help.

Useful information received from social media: We then asked *what kind of useful information they received from OSM related to Amphan*. The responses are summarized in Table 8. Among the participants who used social media within 7 days after Amphan, 18.4% did not get any useful information related to Amphan. The rest 81% of participants received various useful information, including 33% of them receiving useful updates from government and/or service providers. As many as 43% of active participants received information about safety of others, 31.3% received important updates from their own locality, and 49.2% received important updates from other regions. We also asked the participants to briefly describe some social media posts which they felt contained important information on Amphan. Some of the responses by the participants are shown in Table 10. From this table, we observe another important usage of OSM in organizing online donation campaigns.

These numbers show that OSM is more popularly used to consume information than produce information. Also, it can be noted that the engagement by the authorities is quite low after the cyclone, as compared to before the cyclone—while 62.7% of all the survey participants received advance warning *before* the cyclone via OSM, only 29.4% received useful updates from authorities in the 1-week period *after* the cyclone. This big difference between the two fractions shows that Government and other authorities can use social media to reach out to more people after a disaster, as shown also shown in studies (Nazer et al. 2017; Imran et al. 2015). Especially, online social media is even more beneficial since the authorities can do both—broadcast information to everyone, and engage with personal user accounts individually—which is not possible with traditional media like television or newspapers.

Harmful/undesirable information received from social media: Finally, we also asked if the participants observed any undesirable/harmful content on social media, which are known to often circulate on social media after a crisis (Zubiaga et al.

Table 7 Experience of posting information on online social media (OSM), as reported by the survey participants

Experience with posting information on OSM by participants	#	%	% active
Connected to Government accounts/NGOs/service providers and asked for help	10	5.0	5.6
Posted my opinion on issues related to Amphan	24	11.9	13.4
Generally described the situation in my locality	25	12.4	14.0
Posted information that can help others (e.g., helpline numbers)	28	13.9	15.6
Posted images of the damages in my locality	36	17.9	20.1
Informed others about safety of myself/my family	48	23.9	26.8
Inquired about safety of others	50	24.9	27.9
I used social media, but did not post any information related to Amphan	83	41.3	46.4

"#" (%) represents the number (percentage) of participants. "% active" is the fraction of participants who said they were active on social media within the 7 days following Amphan. The rows are ordered in increasing number of participants.

Table 8 Information received by the participants from social media

Experience with information received by our participants from OSM	#	%	% active
I used social media, but did not receive any useful information related to Amphan	33	16.4	18.4
Received important updates from my own locality	56	27.9	31.3
Received useful updates from Government accounts/NGOs/service providers	59	29.4	33.0
Received information about safety of others	77	38.3	43.0
Received important updates from other regions	88	43.8	49.2
Received advance warning about the cyclone (from social media)	126	62.7	70.4

The columns are same as that in Table 7. The rows are ordered in increasing number of participants.

2018; Rajdev et al. 2015). The responses to our question are summarized in Table 9. Among the participants who used social media within 7 days after Amphan, 48% said they observed some undesirable/harmful posts—19.6% said they observed fake news/rumors, 21.2% said they saw too much useless posts, 34.1% observed too much of political arguments, and 7.8% saw too much of superstitious/religious posts. We also asked the participants to briefly describe some social media posts that they thought had a negative impact on the situation. Some of their responses are shown in Table 11.

Summary of Section

As discussed earlier, our sample of survey participants is biased towards frequent social media users; but this bias actually makes the analysis in this section more credible. We found that people use OSM in many different ways in the aftermath of the disaster. Importantly, out of the "active" survey participants who used OSM during the

Table 9 Undesirable/harmful content observed by participants on social media

Experience of undesirable/harmful information on OSM	#	%	% active
Observed too much of religious/superstitious posts	14	7.0%	7.8%
Observed many posts about other regions, but not enough coverage of my locality	30	14.9%	16.8%
Observed fake news/rumours	35	17.4%	19.6%
Observed too much useless posts	38	18.9%	21.2%
Observed too much of political arguments	61	30.3%	34.1%
I used social media, but did not observe any negative effect of social media	86	42.8%	48.0%

The columns are same as that of Table 7. The rows are ordered in increasing number of participants.

7 days immediately after Amphan, 81.6% said they received some useful information related to Amphan from OSM, while 52% said they observed undesirable/harmful content on OSM. Hence, *a much larger fraction of users (who actively use social media) seem to find useful information* via *OSM, than the fraction of users who find OSM propagating harmful content*.

Also, our study indicates that Government agencies and service providers should engage more with people via OSM in the aftermath of a disaster, to give them localized and personalized updates on the situation.

8 Preparedness of Authorities

In this section, we study how vigilant the authorities (including government and private service providers) were to mitigate the damages caused by the cyclone.

Warning people about the cyclone in advance: We asked the participants if they had received advance warning about the cyclone, and if so, via which medium. The responses are given in Table 12. The authorities were effective in informing a large majority of people via news media (94.5%), but relatively less through direct communication (31.3%). A large fraction (62.7%) also received warning from social media.

In fact, one of our participants from a remote region of West Bengal commented—"The Govt. of West Bengal warned us through SMS that those who were not staying in *pukka* houses should find some place safe and stay there for the next few days. It also specifically warned residents near coastal areas". Hence, the authorities were very much effective in warning people about the cyclone.

Responses received from authorities after the cyclone: We asked the participants if they had tried to contact any of the authorities for assistance immediately after the cyclone. About half of the participants said that they did *not* attempt to contact any authority. To the other half of the participants (who tried to contact authorities

Table 10 Sample responses (excerpts) by participants when asked to describe "social media posts that you found to contain important information on Amphan"

Category	Responses
Situational information	– Updates on the speed and movement of the cyclone
	– Updates on the measures taken by the State and Central Government
Useful contacts	– Essential phone numbers for connecting CESC, Water Department, Government of WB Facebook Page, etc
	– Instagram and WhatsApp stories with helpline nos and CM relief fund donation details
	– I came across phone numbers where I could address my problems regarding the disruption of electricity, and NGOs helping the needy
Attempts to collect donations and relief	– I could see many relief activities going in social media and people posting activity pictures and asking for donation to help more. This is a very positive thing I have seen
	– Social media prompted to help bring in donation drives from people much faster than other media in these conditions
Inquiring about safety of others/self	– Social media gave more important updates since TV was not working, and even with less internet connectivity, at least text communication was to some extent helped to assure about relatives
	– On Facebook there appeared a button after the cyclone to mark whether I was safe during the cyclone which helps my friends to know about my situation after the cyclone
Other benefits of social media	– The hashtags (#PrayForBengal, #FightBackbengal, etc.) expressing togetherness of Bengal were influencing enough
	– I feel that the posts, stating the devastating condition of worst-hit area Sundarban due to Amphan are helpful in reality. Many can contribute to the funds that are shared through social media (generally Facebook)

Table 11 Sample responses (excerpts) by participants when asked to describe "social media posts that you think hindered/worsened the situation"

Responses
– Posts vilifying little efforts of people trying to donate from selling artwork, trolling unnecessarily for difference of opinions, fake news about politics around relief work, etc. But overall negative effect was less than positive
– Fake news and propaganda by political parties
– The posts that tried to add a political angle even to a natural disaster like Amphan
– Negativity spreading regarding Electricity disruption

Table 12 Communication medium through which our participants received warning about the cyclone

Medium of communication	%
Did not receive any warning	2.0
Via communication from Government (SMS/phone/email)	31.3
Via announcements on news media (TV, newspaper)	94.5
Via word of mouth from friends and relatives	36.8
Via social media (Facebook/Twitter/Whatsapp)	62.7

for help), we asked whether they received helpful responses from the authorities. This is the distribution of their responses:

- Could not contact authorities (or no response): 53%
- Could contact but did not receive helpful response: 12%
- Could contact and received helpful response: 35%

It is alarming that as much as 65% of the participants who tried to contact authorities could not actually contact them or did not get any helpful response. This high fraction may be because (i) the cyclone damaged the helplines as well and (ii) due to the ongoing lockdown situation, the authorities could deploy a reduced number of personnel (compared to non-pandemic situations). Overall, these statistics show that authorities should improve their responsiveness after a disaster.

Rating the preparedness of authorities: Finally, we asked the participants to rate the preparedness of the authorities serving their localities on a Likert scale of 1–10, where level "1" means "authorities were not prepared at all" and level "10" means "authorities were excellently prepared".

The distribution of the ratings by our survey participants is shown in Fig. 10. The mean preparedness rating (averaged across all participants) is 5.25, while the median preparedness rating (across all participants) is 5.0.

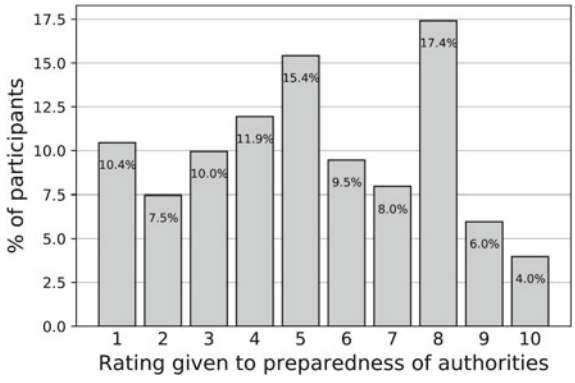


Fig. 10 Preparedness of authorities as perceived by our participants

Table 13 Rating given to authorities (eg, government, service providers) on their preparedness

Participants who said authorities were	N24P (60) (%)	KOL (59) (%)	S24P (22) (%)	HGLY (18) (%)	HWH (14) (%)	Others (28)
Highly Prepared (Rating ≥ 8)	40.0	20.3	18.2	11.1	21.4	35.7
Poorly Prepared (Rating ≤ 3)	23.3	37.3	27.3	27.8	28.6	17.9

The numbers in brackets below each of the headers represent the actual count of participants from that district.

We consider the authorities to be *highly prepared* (from the point of view of a participant) if they were rated greater than or equal to 8. On the other hand, we consider the authorities to be *poorly prepared* (from the point of view of a participant) if they were rated less than or equal to 3. Out of the 201 participants, almost an equal number said authorities were highly prepared (55 participants) and authorities were poorly prepared (56 participants).

Table 13 shows the district-wise fractions of participants (i) who said authorities were highly prepared and (ii) who said authorities were poorly prepared. Interestingly, across all districts, there are both participants who said authorities were highly prepared, as well as participants who said authorities were poorly prepared. The authorities seem to have been best prepared in North 24 Paraganas—40% of the participants from this district said authorities were highly prepared, and much fewer participants (23.3%) said authorities were poorly prepared. On the contrary, in Kolkata, only 20.3% said authorities were highly prepared but 37.3% said authorities were poorly prepared. Apart from North 24 Paraganas and "Others" (districts that were not affected much by the cyclone), in all other districts, a larger fraction of participants felt the authorities were poorly prepared (as compared to the fraction who felt authorities were highly prepared).

Note that the preparedness of the authorities was most probably hampered by the ongoing COVID19-induced lockdown, which made it difficult for the authorities to deploy sufficient manpower in many regions.

Reasons for good and bad ratings: We wanted to identify some probable factors that could have affected the preparedness ratings given by participants. Obviously, the actual reason behind a participant's rating can only be found through personal interaction. Since such interaction was not feasible, we checked if some specific factors are correlated with the ratings given by participants.

Our hypothesis is that a person's rating of the preparedness of authorities can be affected by factors such as whether he/she received helpful responses from the authorities, how long he/she had to tolerate disruptions in electricity/phone/internet services, and so on. We now investigate these hypotheses.

Table 14 shows the correlation between the preparedness rating given by a participant, and whether the said participant received helpful responses from the authorities. We see that 72% of the participants who received helpful responses said that the authorities were highly prepared, while 88.9% of those who did not receive any helpful response said that the authorities were poorly prepared. These figures seem to corroborate our hypothesis that participants who received helpful responses would

Table 14 Response received from authorities versus rating given to preparedness of authorities

Among those who tried to contact authorities	People saying authorities were	
	Highly prepared	Poorly prepared
Total count	25	36
Received helpful response	**72.0%**	11.1%
Received no/unhelpful response	28%	**88.9%**

Total count consists of only the participants who tried to contact the authorities.

tend to say authorities were highly prepared, whereas those who did not receive helpful responses, would tend to say that the authorities were poorly prepared.

Similarly, Tables 15, 16 and 17, respectively, show the correlation between the preparedness ratings given by participants, and the time taken for restoration of electricity supply, phone services, and internet services for those participants. All the three tables showed a common trend (that agrees to our hypothesis)—people who faced disruption of these services for less than 1 day mostly opined that the authorities were highly prepared (fractions shown in blue-colored text). Whereas, people facing disruption of these services for more than 2 days have mostly said authorities were poorly prepared (fractions shown in red-colored text).

Table 15 Time for restoration of electricity supply versus rating given to preparedness of authorities

Among those facing disruption, electricity supply was restored in	People saying authorities were	
	Highly prepared	Poorly prepared
Total count	49	51
Less than 1 day	**57.2%**	45.1%
Between 1 and 2 days	16.3%	5.9%
More than 2 days	26.5%	**49.0%**

Total count consists of only the participants who faced disruption in electricity supply.

Table 16 Time for restoration of phone connection versus rating given to preparedness of authorities

Among those facing disruption, phone connection was restored in	People saying authorities were	
	Highly prepared	Poorly prepared
Total count	44	49
Less than 1 day	**45.5%**	20.4%
Between 1 and 2 days	29.5%	8.2%
More than 2 days	25.0%	**71.4%**

Total count consists of only the participants who faced disruption in phone services.

Table 17 Time for restoration of internet connection versus rating given to preparedness of authorities

Among those facing disruption, internet connection was restored in	People saying authorities were	
	Highly prepared	Poorly prepared
Total count	46	50
Less than 1 day	**30.4%**	8.0%
Between 1 and 2 days	17.4%	4.0%
More than 2 days	52.2%	**88.0%**

Total count consists of only the participants who faced disruption in internet services.

Summary of Section

While the authorities did a very creditable job of warning people of the cyclone in advance, the performance of the authorities *after* the cyclone was not equally impressive. A large majority of people who tried to contact authorities for help after the cyclone either could *not* contact the authorities or did not get helpful responses from the authorities. Regarding preparedness of authorities, an equal number of participants rated the authorities to be highly prepared and poorly prepared to deal with the effects of the cyclone. Notably, in four out of the five districts that were majorly affected by cyclone Amphan, more people judged the authorities to be poorly prepared. These overall poor preparedness ratings of authorities seem to be correlated with factors such as whether participants received helpful responses, or how long it took for restoration of essential services.

9 Implications

Finally, in this section, we present our synthesis on how, taking lessons from this disaster, the authorities can better handle future disasters. Specifically, we present our insights across two fronts. First, as part of the survey, we asked the participants—"*If you have any suggestions that will help to better prepare for future disaster events, please list them here*"; we will present our findings from the participant's responses to this question. Second, we will discuss how our survey results strongly indicate the efficacy (as well as pitfalls) of using social media to help people in the times of disaster.

9.1 Suggestions to Better Prepare for Future Disasters

We identify a few key themes from the general responses of the participants when asked to give suggestions that will help to better prepare for future disaster events.

We present those themes as well as a few verbatim user responses in Table 18. Specifically, the participants expressed ideas to better handle future disasters in terms of the after-effects.

Continuous maintenance: Our participants pointed out ways to minimize damage due to uprooting of trees via continuous maintenance (e.g., cutting and trimming the trees regularly).

Advance planning to employ more resources: The participants opined that, since a major disaster like Amphan can be expected to disrupt services such as electricity, mobile and internet, the authorities need to have a better "preparedness planning" so that more manpower and backup infrastructures can be quickly called upon to ensure functioning of these services. For instance, power back generators can be kept ready, and army personnel can be kept prepared to help with cleaning uprooted trees. In fact, similar suggestions also came up while solving the problem with lack of drinking water and food in certain areas (e.g., "*water should be kept in store from beforehand in adequate amount*").

Improving co-ordination: An important point that was mentioned was the improvement of co-ordination among various authorities (e.g., between municipality and electricity supplier), e.g., "*Need to have synchronized effort all the related departments and Govt Agencies*". It seems that lack of such co-ordination really hindered the efforts of the authorities. For example one participant mentioned that "*Before restoring electricity supply, it should be checked whether the locality is still waterlogged. The waterlogging resulted in "electric fires" on several electricity poles when power supply was restored.*" So, more information sharing between different authorities (e.g., those who are helping with solving water-logging and those who are fixing affected electrical lines) in crucial for a swifter response.

We note that most of the suggestions discussed above were a direct response (from the participants) to the situation at hand and aimed at addressing the specific problems faced by them in-spite of the best efforts of authorities. Additionally, we further analyzed communication between the authorities and citizens via novel mediums like social media—an avenue that helped some people to avert the worst in this disaster and could be further improved by developing more systematic mechanisms for communication.

9.2 Utility of Social Media in Post-disaster Scenario

We note in Table 18 that some participants pointed out the value of communication between authorities and affected populace. One participant mentioned that *"A toll free number should be given prior to such natural calamity and a quick response team must be on standby in every locality"*. However, given the huge spread of the affected area and the rarity of such disaster events, such a centralized approach might be too costly to build for authorities. To that end, our data, however, point out a few very interesting observations on how to improve the efficacy of two-way communication between authorities and affected citizens.

Table 18 Sample responses (excerpts) by participants when asked to give "suggestions that will help to better prepare for future disaster events"

Themes	Responses from participants
Uprooting of trees	– Army must be kept ready to take care of the cleaning of uprooted trees.
	– The trees in localities could be trimmed before so that uprooting can be avoided.
	– Trees are not regularly cut and maintained. No pruning is done even before the monsoons. If regularly cut and pruned they would, even if uprooted, caused less damage.
Electricity, mobile, Internet supplies	– Electricity dept should be more adequate and engage more people when the workload is so huge.
	– Have power backup generators ready.
	– Using underground cables for power distribution in clustered places like here in Kolkata. Using underground optical fibre for data transmission.
	– Targeting electricity to mobile towers and communication mediums so that news can travel and authorities can be contacted and people can be helped out.
	– Before restoring electricity supply, it should be checked whether the locality is still waterlogged. The waterlogging resulted in "electric fires" on several electricity poles when power supply was restored.
	– If main line electric supply wire take down from electric post before storm came then electric supply does not damage that much.
Drinking water and food	– I think proper drinking water should be kept in store from beforehand in adequate amount, so that it can be supplied to people lacking drinking water, later in a systematic manner.
	– Those who are severely affected by the cyclone need to be served with food for at least a few days.
	– Drinking water tankers should be ready to supply after disaster.
General disaster response	– Frequent mock drills within the disaster response teams and frequent maintenance of the tools/machines used by them.
	– Need to have synchronised effort all the related departments and Govt Agencies
	– The Corporation, electric supply and other authorities should be well prepared before with lots of manpower and equipment for disaster.

(continued)

Table 18 (continued)

Themes	Responses from participants
	– It'll be better that if we can provide an idea to those people who are staying in village about the severeness of the storm on the basis of the estimated speed, so that they can take preparation in a much better way. Not only do's. Tell the reason why to do..
	– Improve drainage system, increase forest more specifically Sundarban, make concrete structures in safe distance from the sea.
	– When is such natural calamity is forecasted, I feel the roadside dwellers or homeless people and animals must be shifted to nearby schools, colleges, or any vacant and safe buildings so that they don't face the nature's wrath and be safe.
	– A toll free number should be given prior to such natural calamity and a quick response team must be on standby in every locality

The increasing reach of social media: Recall that Table 12 identified that traditional broadcast mediums such as newspaper and television fared the best in warning people of the impending disaster—94% of our participants received advance warning through these mass communication mediums. However, these mediums have two problems—they are costly, and they provide one-way communication (i.e., they do not provide any simple way for the common people to reach the authorities with their questions or concerns). On the other hand, online social media (OSM) can reach the populace at a minimal fraction of the cost, and also provides a simple way for citizens to reach authorities (i.e., two-way communication). One key finding from Table 12 is that, as many as 62.7% of the participants received warning via OSM, which is second only to the mass communication mediums. Additionally, even though Amphan led to severe disruption of Internet connectivity, more than 80% of our survey participants received useful information about Amphan via social media in the 7 days after the cyclone (as seen from Table 8). In fact, a major utility of social media seems to be in inquiring about safety of friends/relatives and informing others about one's own safety (as reported by 30%–40% of the participants). These numbers underline the increasing outreach of this medium, at least among the urban population who are conversant with use of such novel mediums.

Lowering the cost of disseminating and receiving information: OSM provides a *low-cost* and *real-time* medium for the authorities to reach the citizens, as well as for the citizens to express their worries to the right people. Furthermore, OSM can often help (due to the low cost and ubiquity of mobile Internet) to receive information about the affected remote places which are often *not covered* by traditional mediums. For instance, one participant mentioned that *"I feel that the (social media) posts, stating the devastating condition of worst-hit area Sundarban (a remote region in West Bengal) due to Amphan are helpful in reality. Many can contribute to the funds*

which are shared through social media". So, our results identify that developing mechanisms to timely disseminate information on easily-accessible social media can tremendously help the affected populace to cope up with their loss.

It can be noted that recent research works have developed mechanisms for using digital media in spite of disruptions in internet connectivity (Paul et al. 2020, 2019). Such mechanisms can be set up during major disasters to ensure connectivity among the people, which will increase the access to social media and other digital media in post-disaster scenarios.

Enabling citizens to get responses from authorities: We note from Table 14 that the event of receiving responses to Amphan-related queries is highly positively correlated with the favorable perception of people about preparedness of authorities. However, it is very hard for people to receive responses to their queries via traditional mechanisms like phone. To that end, our survey results demonstrate a need for authorities to be more proactive in reaching out and answering queries to help the affected populace via digital media (including social media). To this end, novel Artificial Intelligence (AI)-driven chatbots may provide a scalable and automated way to pave this two-way communication during or after future disasters.

Facilitating trustworthy and useful news on OSMs: OSM have a severe pitfall today—often, they are *not* a reliable medium to connect with general populace due to misinformation, abuse and in general, lack of trustworthy information (Rajdev et al. 2015). Additionally, there is often lot of "conversational chatter" on OSM (such as political propaganda) which does not help post-disaster relief operations, and in fact, obscures the critical information. Table 11 identified some types of misinformation that worsen the situation. Often such misinformation (e.g., rumors) is just a side-effect of lack of good, authentic information. Thus, we strongly prescribe the authorities to disseminate more useful information from trustworthy official accounts to drown such misinformation. Additionally, recent AI-based techniques can be employed to extract critical information from social media that would help post-disaster relief operations (Basu et al. 2019; Dutt et al. 2019; Rudra et al. 2015), as well as to identify and counter rumors and other misinformation (Rajdev et al. 2015; Rudra et al. 2018). Thus, creating AI-based automated systems to aggregate useful information from OSM and disseminate trustworthy information on OSM will quite possibly help people to better cope with natural disasters in future.

10 Conclusion

In this report, we analyzed the responses to an online survey (by 201 participants) to get insights about the damages caused by the super-cyclone Amphan, and its impact on people. We saw that our participants were severely affected by disruption of internet, phone and electric services. In fact, more than 40% of our participants responded that these services took more than 4 days to be restored. We also found that people have rated the authorities highly if they were responsive and vigilant enough to repair the damages caused within a day. Furthermore, our exploration

revealed that communication (or lack there-of) between the authorities and affected citizens strongly influenced public perceptions about preparedness of the authorities. Then we synthesized our findings into policy implications for better handling future disasters. The survey results strongly suggest that authorities can better handle such situations using social media and AI-driven techniques over digital mediums that are low-cost, personalized alternatives of traditional communication media.

This study points towards the current extent of damages such as uprooting of trees and consequent disruption of electricity and telecommunication services, damage of buildings and needless to mention, waterlogging. While preparedness of the authority post-disaster is important, the extent of damage mapping that could be assessed through the OSM data especially in cases of developing nations could be valuable for building resilience through adaptive measures. Studies pointed out that there could be relationships between trees, cyclones and house damage (Van der Sommen et al. 2018). The future studies could look into the scenarios and sensitivity of planning and design of resilient urbanscapes. Additionally this study points towards the importance of the ability of people to reach out to the authority during and post-disaster; which instills confidence among the people at large. The current analysis of the perception of the people would aid the local disaster management teams to prepare for warning modules together with aid responses as well.

As stated earlier, some of the observations from the survey can be affected by the ongoing COVID19-induced lockdown situation, as well as by the bias of our survey participants towards students residing in urban areas. As a result, some of the micro-level findings might not generalize in another sample and another time. However, we believe that the broad findings (e.g., communication from authorities is a necessary aspect, how people use social media during a disaster, what affects people the most) should generalize across various disaster events.

We believe that this work will pave the way forward in better understanding of the impact of disasters like Amphan on the general populace, and also help to build novel mechanisms for authorities to cope with the after-effects of such disasters.

Acknowledgements We sincerely thank all the participants who gave their valuable time in responding to the survey. We also acknowledge Abhisek Dash, Shalmoli Ghosh, Shounak Paul and Paheli Bhattacharya (all from IIT Kharagpur) for their constructive suggestions and help in designing the survey. We especially thank Moumita Basu (of UEM Kolkata) for her insights on the survey design, as well as for her valuable help in disseminating the survey widely. This research is partially funded by the Sponsored Research and Industrial Consultancy (SRIC) unit, IIT Kharagpur, through the project "Building Information Systems for Emergency Relief and Preparedness".

Survey Questionnaire

We state below the exact questions asked in the survey.

Some details about you and your locality

In this survey, you will be asked questions about the effect of cyclone Amphan on your LOCALITY. For purpose of this survey, consider your "locality" to be the region within approx. 500 m from your home in all directions.

PIN code of your locality: ___.

A more specific identifier for your locality (e.g., street name, specific name of area): ___.

Were you yourself in the said locality during the cyclone, or are you filling in the survey on behalf of someone else who was in that locality (e.g., your family or relatives)? I was myself in the said locality during cyclone Amphan ○ I am filling in the survey on behalf of someone else who was in that locality ○ Other ___.

What is your age group? < 20 years ○ 21–30 years ○ 31–40 years ○ 41–50 years ○ > 50 years ○ Would prefer not to say ○

What is your gender? Male ○ Female ○ Other ○ Would prefer not to say ○

What is your occupation? (E.g., student, teacher, businessman, doctor, engineer, software professional, …) ___.

Before the cyclone

How did you receive advance warning about cyclone Amphan? You can select one or more options. Did not receive any advance warning ○ Via announcements on news media (TV/newspaper/radio) ○ Via social media (e.g., Facebook/Twitter/WhatsApp) ○ Via word of mouth from friends/relatives ○ Via specific communication from Government (SMS/WhatsApp/phone/email, etc.) ○ Others ○

Were any services disrupted even BEFORE cyclone Amphan struck your locality? You can select one or more options. No service was disrupted before the cyclone ○ Electricity was disrupted ○ Mobile connectivity was disrupted ○

Were you asked to evacuate your locality before the cyclone struck? Yes ○ No ○ Cannot say ○

Damage in your locality due to Amphan

Approximately how many trees were uprooted/seriously damaged in your locality due to Amphan? Cannot say ○ No tree was uprooted/seriously damaged in my locality ○ Between 1 and 5 trees ○ Between 6 and 10 trees ○ More than 10 trees ○

Approximately how many buildings were damaged in your locality due to Amphan? Assume "damaged" means anything more severe than breaking of glass windows. Cannot say ○ No building was damaged in my locality ○ Between 1 and 5 buildings ○ Between 6 and 10 buildings ○ More than 10 buildings ○

Approximately for how long was your locality waterlogged/flooded due to Amphan? My locality was not waterlogged ○ Less than 6 h ○ Between 6 and 12 h ○ Between 12 h and 1 day ○ Between 1 and 2 days ○ Between 2 and 3 days ○ Between 3 and 4 days ○ More than 4 days ○ My locality is still waterlogged ○

Approximately for how long was drinking water supply irregular in your locality? Drinking water supply was not affected in my locality ○ Less than 6 h ○ Between 6 and 12 h ○ Between 12 h and 1 day ○ Between 1 and 2 days ○ Between 2 and 3 days

○ Between 3 and 4 days ○ More than 4 days ○ Drinking water supply not regular till now ○

Disruption of Electricity

Which electricity supplier are you served by? CESC ○ WBSEDCL/WBSEB ○ Other ○

Was electricity disrupted in your locality due to cyclone Amphan? Yes ○ No ○ Cannot say ○

Approximately how long after the cyclone did normal electricity service resume in your locality? Within 6 h ○ Between 6 and 12 h ○ Between 12 h and 1 day ○ Between 1 and 2 days ○ Between 2 and 3 days ○ Between 3 and 4 days ○ More than 4 days ○ Normal electricity service not resumed till now ○

Were electric poles/cables/transformers damaged in your locality due to the cyclone? Yes ○ No ○ Cannot say ○

Are there any PUBLIC UTILITIES in your locality, whose operations were hampered due to disruption in electricity? You can choose one or more options. No public utility in my locality ○ Hospital/nursing home ○ Water pumping station ○ Mobile tower ○ Other ○

Disruption in phone connectivity

Which phone service provider do you use? You can select more than one option, e.g., if you or your family members use multiple service providers. Airtel mobile ○ BSNL mobile ○ Jio mobile ○ Vodafone mobile ○ Landline phone ○ Other ○

Was phone connectivity disrupted in your locality due to Amphan? Yes ○ No ○ Cannot say ○

Which of these phone services were disrupted? You can select one or more options. Airtel mobile ○ BSNL mobile ○ Jio mobile ○ Vodafone mobile ○ Landline phone ○ Other ○

Approximately how long after the cyclone did normal phone connectivity resume in your locality? [In case different services resumed at different times, please specify for that phone service which resumed the earliest] Within 6 h ○ Between 6 and 12 h ○ Between 12 h and 1 day ○ Between 1 and 2 days ○ Between 2 and 3 days ○ Between 3 and 4 days ○ More than 4 days ○ Normal phone connectivity not resumed till now ○

Disruption in internet connectivity

How do you connect to the internet? You can select one or more options. Through mobile phone ○ Through landline ○ Cable internet ○ Other ○

Was internet connectivity disrupted in your locality due to Amphan? Yes ○ No ○ Cannot say ○

Approximately how long after the cyclone did normal internet connectivity resume in your location? Within 6 h ○ Between 6 and 12 h ○ Between 12 h and 1 day ○ Between 1 and 2 days ○ Between 2 and 3 days ○ Between 3 and 4 days ○ More than 4 days ○ Normal internet connectivity not resumed till now ○

How much were YOU/YOUR FAMILY affected by the cyclone?

We are stating below some possible aspects of damage. In the context of each aspect, please rate how much you or your family were affected in the scale of 1–5. Here, 1 indicates "I/my family was not affected at all" and 5 indicates "I/my family was extremely severely affected".

Uprooting of trees: 1 ○ 2 ○ 3 ○ 4 ○ 5 ○
Damage to buildings: 1 ○ 2 ○ 3 ○ 4 ○ 5 ○
Waterlogging/flooding: 1 ○ 2 ○ 3 ○ 4 ○ 5 ○
Disruption of electric supply: 1 ○ 2 ○ 3 ○ 4 ○ 5 ○
Disruption of phone connectivity: 1 ○ 2 ○ 3 ○ 4 ○ 5 ○
Disruption of internet connectivity: 1 ○ 2 ○ 3 ○ 4 ○ 5 ○
Unavailability of drinking water: 1 ○ 2 ○ 3 ○ 4 ○ 5 ○

Other questions about your locality

Was there any agitation in or around your locality after the Amphan cyclone, to protest against non-availability of essential supplies (e.g., electricity, water)? Yes ○ No ○ Cannot say ○

Which of the following is true regarding waterlogging/flooding in your locality?

○ My locality gets regularly flooded during heavy rains and was also flooded due to Amphan.

○ My locality does NOT usually get flooded but was flooded due to Amphan.

○ My locality did not get flooded due to Amphan.

If you or your locality faced any other problems due to the cyclone Amphan, please list them here. ___.

Use of social media

NORMALLY, how frequently do you use social media (i.e., visit sites like Facebook, Twitter, WhatsApp, Instagram, etc.)? Almost always online ○ A few times a day ○ A few times a week ○ A few times a month ○ I do not use social media ○

In general, which social media sites do you use? You can select one or more options. Twitter ○ WhatsApp ○ Facebook ○ Instagram ○ Other ___.

Have you POSTED any information related to Amphan on social media, within 7 days after the cyclone? You can select one or more options.

○ I did not use social media within 7 days after Amphan.

○ I used social media, but did not post any information related to Amphan.

○ Generally described the situation in my locality.

○ Posted images of the damages in my locality.

○ Connected to Government accounts/NGOs/service providers and asked for help.

○ Inquired about safety of others.

○ Posted information that can help others (e.g., helpline numbers, assured safety of others in my region).

○ Informed others about safety of myself/my family.

○ Posted my opinion on issues related to Amphan.

○ Other ___.

Have you RECEIVED any useful information related to Amphan from social media, within 7 days after the cyclone? You can select one or more options.

○ I did not use social media within 7 days after Amphan.

○ I used social media, but did not receive any useful information related to Amphan.

○ Received important updates from my own locality.

○ Received important updates from other regions.

○ Received useful updates from Government accounts/NGOs/service providers.

○ Received information about safety of others.

○ Other ___.

Please describe (in a few sentences) some social media posts that you found to contain important information on Amphan. You can also mention some keywords indicating the type of important posts, or give examples of important posts. ___.

Did social media hinder/worsen the situation related to Amphan in any way? You can select one or more options.

○ I did not use social media within 7 days after Amphan.

○ I used social media, but did not observe any negative effect of social media.

○ Observed fake news/rumors.

○ Observed too much useless posts.

○ Observed too much of political arguments.

○ Observed too much of religious/superstitious posts.

○ Observed many posts about other regions, but not enough coverage of my locality.

○ Other ___.

Please describe (in a few sentences) some social media posts that you think hindered/worsened the situation. ___.

Preparedness of authorities

Were the authorities in your locality (e.g., municipality, electric suppliers, mobile/internet suppliers) prepared to deal with such a disaster situation? Please rate their preparedness in the scale of 1–10, where 1 indicates "Not prepared at all" and 10 indicates "Excellently prepared".

1 ○ 2 ○ 3 ○ 4 ○ 5 ○ 6 ○ 7 ○ 8 ○ 9 ○ 10 ○

When authorities in your locality/helpline numbers were contacted for reporting problems, were the responses helpful?

○ We did not try to contact any local authority/helpline number.

○ We tried to contact authorities, but could not reach them/did not get any response.

○ We could contact the authorities, but their responses were NOT helpful.

○ We could contact the authorities and received helpful responses.

○ Other ___.

If you have any suggestions that will help to better prepare for future disaster events, please list them here. Your suggestions can be general, or specific to your locality. ___.

Any other information

Please let us know in the text box below if you wish to share any other information about your experiences of cyclone Amphan. E.g., If you wish to give more details about some of your responses in this survey. Or, if you would like to inform about specific social media accounts whose posts you found important or harmful, etc. Specifically, we aim to understand the problems faced after a natural disaster and how digital platforms like social media can help/hinder coping with such disasters. PLEASE CLICK THE "SUBMIT" BUTTON BELOW TO COMPLETE THE SURVEY. _____.

References

Alexander DE (2014) Social media in disaster risk reduction and crisis management. Sci Eng Ethics 20(3):717–733

Anson S, Watson H, Wadhwa K, Metz K (2017) Analysing social media data for disaster preparedness: understanding the opportunities and barriers faced by humanitarian actors. Int J Disaster Risk Reduct 21:131–139

Ardaya AB, Evers M, Ribbe L (2017) What influences disaster risk perception? intervention measures, flood and landslide risk perception of the population living in flood risk areas in Rio de Janeiro State, Brazil. Int J Disaster Risk Reduct 25:227–237

Balasubramanian S, Chalamalla VK (2020) Super cyclone amphan: a dynamical case study. CoRR/2007.02982. https://arxiv.org/abs/2007.02982

Basu M, Ghosh S, Jana A, Bandyopadhyay S, Singh R (2017) Resource mapping during a natural disaster: a case study on the 2015 Nepal Earthquake. Int J Disaster Risk Reduct 24:24–31

Basu M, Shandilya A, Khosla P, Ghosh K, Ghosh S (2019) Extracting resource needs and availabilities from microblogs for aiding post-disaster relief operations. IEEE Trans Comput Soc Syst 6(3):604–618

Bhattacharyya R (2015) Administrative planning and political response to a post-disaster reconstruction: a study of Aila (Cyclone)-devastated gosaba block in West Bengal (India). In: Strategic disaster risk management in Asia. Springer, pp 115–128

Cameron MA, Power R, Robinson B, Yin J (2012) Emergency situation awareness from twitter for crisis management. In: Proceedings of the 21st international conference on world wide web, pp 695–698

Coombs WT (1995) Choosing the right words: the development of guidelines for the selection of the 'appropriate' crisis-response strategies. Manag Commun Q 8(4):447–476

De Albuquerque JP, Herfort B, Brenning A, Zipf A (2015) A geographic approach for combining social media and authoritative data towards identifying useful information for disaster management. Int J Geograph Inf Sci 29(4):667–89

Diwanji VS, Arpan L, Ulak MB, Hou JJ, Ozguven EE, Arghandeh R (2020) Understanding citizens communication channel preferences during natural disasters: a synchronicity-based, mixed-methods exploration using survey and geospatial analysis. Int J Disaster Risk Reduct 47:101646

Doyle EEH, Johnston DM, Smith R, Paton D (2019) Communicating model uncertainty for natural hazards: a qualitative systematic thematic review. Int J Disaster Risk Reduct 33:449–476

Dutt R, Basu M, Ghosh K, Ghosh S (2019) Utilizing microblogs for assisting post-disaster relief operations via matching resource needs and availabilities. Inf Process Manage 56(5):1680–1697

Eiser JR, Bostrom A, Burton I, Johnston DM, McClure J, Paton D, Van Der Pligt J, White MP (2012) Risk interpretation and action: a conceptual framework for responses to natural hazards. Int J Disaster Risk Reduct 1:5–16

Gao H, Barbier G, Goolsby R (2011) Harnessing the crowdsourcing power of social media for disaster relief. IEEE Intell Syst 26(3):10–14

Grothmann T, Reusswig F (2006) People at risk of flooding: why some residents take precautionary action while others do not. Nat Hazards 38(1):101–120

Houston JB, Hawthorne J, Perreault MF, Park EH, Hode MG, Halliwell MR, Turner McGowen SE et al (2015) Social media and disasters: a functional framework for social media use in disaster planning, response, and research. Disasters 39(1):1–22

Imran M, Castillo C, Diaz F, Vieweg S (2015) Processing social media messages in mass emergency: a survey. ACM Comput Surv 47(4). https://doi.org/10.1145/2771588

Imran M, Elbassuoni S, Castillo C, Diaz F, Meier P (2013) Extracting information nuggets from disaster-related messages in social media. In: Iscram

Iwasaki S, Razafindrabe BHN, Shaw R (2009) Fishery livelihoods and adaptation to climate change: a case study of Chilika Lagoon, India. Mitig Adapt Strat Glob Change 14(4):339–355

Kala CP (2014) Deluge, disaster and development in Uttarakhand Himalayan region of India: challenges and lessons for disaster management. Int J Disaster Risk Reduct 8:143–152

Kankanamge N, Yigitcanlar T, Goonetilleke A, Kamruzzaman Md (2020) Determining disaster severity through social media analysis: testing the methodology with South East Queensland Flood Tweets. Int J Disaster Risk Reduct 42:101360

Kawyitri N, Shekhar A (2020) Assessing vulnerability and capacity of Bhubaneswar as a progressive smart-city: an empirical case study of fani cyclone impact on the city. Int J Disaster Risk Reduct 101986

Kim J, Hastak M (2018) Social network analysis: characteristics of online social networks after a disaster. Int J Inf Manage 38(1):86–96

Krishnan S, Chen M (2018) Identifying tweets with fake news. In: 2018 IEEE international conference on information reuse and integration (Iri). IEEE, 460–464

Kryvasheyeu Y, Chen H, Obradovich N, Moro E, Van Hentenryck P, Fowler J, Cebrian M (2016) Rapid assessment of disaster damage using social media activity. Sci Adv 2(3):e1500779

Kumar S, Barbier G, Abbasi M, Liu H (2011) Tweettracker: an analysis tool for humanitarian and disaster relief. In: Proceedings of the international aaai conference on web and social media, vol 5, p 1

Kwanda FA, Lin TTC (2020) Fake news practices in Indonesian newsrooms during and after the Palu earthquake: a hierarchy-of-influences approach. Inf Commun Soc 23(6):849–866

Li J, Stephens KK, Zhu Y, Murthy D (2019) Using social media to call for help in hurricane harvey: bonding emotion, culture, and community relationships. Int J Disaster Risk Reduct 38:101212

Mahdavian F, Wiens M, Platt S, Schultmann F (2020) Risk behaviour and people's attitude towards public authorities–a survey of 2007 Uk and 2013 German Floods. Int J Disaster Risk Reduct 49:101685

Majra JP, Gur A (2009) Climate change and health: why should india be concerned? Indian J Occupat Environ Med 13(1):11

Mazumdar J, Paul SK (2016) Socioeconomic and infrastructural vulnerability indices for cyclones in the Eastern Coastal States of India. Nat Hazards 82(3):1621–1643

McCabe GJ, Clark MP, Serreze MC (2001) Trends in Northern Hemisphere surface cyclone frequency and intensity. J Clim 14(12):2763–2768

Middleton SE, Middleton L, Modafferi S (2013) Real-time crisis mapping of natural disasters using social media. IEEE Intell Syst 29(2):9–17

Monirul Qader Mirza M (2003) Climate change and extreme weather events: can developing countries adapt? Climate Policy 3(3):233–248

Nazer TH, Xue G, Ji Y, Liu H (2017) Intelligent disaster response via social media analysis: a survey. SIGKDD Explor Newsl 19(1):46–59. https://doi.org/10.1145/3137597.3137602

Niles MT, Emery BF, Reagan AJ, Sheridan Dodds P, Danforth CM (2019) Social media usage patterns during natural hazards. PLoS One 14(2)

Nott J, Hayne M (2001) High frequency of 'super-cyclones' along the great barrier reef over the past 5,000 years. Nature 413(6855):508–512

OECD, OECD. 2013. "Trust in Government, Policy Effectiveness and the Governance Agenda." *Government at a Glance* 2013.

O'Sullivan JJ, Bradford RA, Bonaiuto M, De Dominicis S, Rotko P, Aaltonen J, Waylen K, Langan SJ (2012) Enhancing flood resilience through improved risk communications. Nat Hazard 12(7):2271–2282

Paul PS, Chandra Ghosh B, Ghosh A, Saha S, Nandi S, Chakraborty S (2020) Disaster Strikes! Internet Blackout! What's the Fate of Crisis Mapping? In: Proceedings of ACM international conference on human-computer interaction with mobile devices and services (Mobilehci).

Paul PS, Mehta N, Kumar Das A, Agarwal S, Saha S, Nandi S (2019) SURAKSHIT: a smartphone-based application for 'localized' GIS data aggregation in absence of internet. In: Proceedings of the international conference on distributed computing and networking (ICDCN), pp 393–396

Purohit H, Hampton A, Bhatt S, Shalin VL, Sheth AP, Flach JM (2014) Identifying Seekers and Suppliers in Social Media Communities to Support Crisis Coordination. Computer Supported Cooperative Work (CSCW) 23(4):513–545

Rajdev M, Lee K, Lee K, Lee K (2015) Fake and spam messages: detecting misinformation during natural disasters on social media. In: Proceedings of Ieee/Wic/Acm international conference on web intelligence and intelligent agent technology (Wi-Iat), pp 17–20

Raju E, Becker P (2013) Multi-organisational coordination for disaster recovery: the story of post-tsunami Tamil Nadu, India. Int J Disaster Risk Reduct 4:82–91

.Resource Mapping During a Natural Disaster: A Case Study on the 2015 Nepal Earthquake (2017) Int J Disaster Risk Reduct 24:24–31

Reuter C, Kaufhold M-A (2018) Fifteen years of social media in emergencies: a retrospective review and future directions for crisis informatics. J Contingenc Crisis Manag 26(1):41–57

Reuter C, Kaufhold M-A (2018) Fifteen years of social media in emergencies: a retrospective review and future directions for crisis informatics. J Contingenc Crisis Manag 26:41–57

Rogstadius J, Vukovic M, Teixeira CA, Kostakos V, Karapanos E, Laredo JA (2013) Crisistracker: crowdsourced social media curation for disaster awareness. IBM J Res Dev 57(5):1–4

Rudra K, Ghosh S, Goyal P, Ganguly N, Ghosh S (2015) Extracting situational information from microblogs during disaster events: a classification-summarization approach. In: Proceedings of the ACM CIKM, Melbourne

Rudra K, Sharma A, Ganguly N, Ghosh S (2018) Characterizing and countering communal microblogs during disaster events. IEEE Trans Comput Social Syst 5(2):403–417. https://doi.org/10.1109/TCSS.2018.2802942

Saroj A, Pal S (2020) Use of social media in crisis management: a survey. . Int J Disaster Risk Reduct 101584

Schempp T, Zhang H, Schmidt A, Hong M, Akerkar R (2019) A framework to integrate social media and authoritative data for disaster relief detection and distribution optimization. Int J Disaster Risk Reduct 39:101143

Shan S, Zhao F, Wei Y, Liu M (2019) Disaster management 2.0: a real-time disaster damage assessment model based on mobile social media data—a case study of Weibo (Chinese Twitter). Saf Sci 115:393–413

Stowe K, Michael P, Martha P, Leysia P, Anderson KM (2016) Identifying and categorizing disaster-related tweets. In: Proceedings of the fourth international workshop on natural language processing for social media, pp 1–6

Van der Sommen FJ, Pearson DM, Boggs GS (2018) Analysis of the interrelationship between houses, trees and damage in a cyclone affected city: can landscape design and planning utilising trees minimise cyclone impact? Int J Disaster Risk Reduct 28:701–710

Yadav DK, Barve A (2017) Analysis of socioeconomic vulnerability for cyclone-affected communities in coastal Odisha, India. Int J Disaster Risk Reduct 22:387–396

Zubiaga A, Ahmet A, Kalina B, Maria L, Rob P (2018) Detection and resolution of rumours in social media: a survey. ACM Comput Surv 51(2). https://doi.org/10.1145/3161603

Chapter 7
Challenges of Data-Driven Decision Models: Implications for Developers and for Public Policy Decision-Makers

Sónia Teixeira, José Coelho Rodrigues, Bruno Veloso, and João Gama

1 Introduction

Data-driven decision systems have led to social change and disruptive changes to public administration (Citron 2007). These adaptive systems, due to their learning capability, reduce the intervention of humans, being a support in Public Policy decision-making or even being the decision-maker, depending on the context. The use of such systems has benefits for society, for example bringing comfort or allowing faster problem solving, in many cases with better decisions than humans (Bellamy et al. 2019). However, this technology does not always decide correctly or without inaccuracies (Bellamy et al. 2019). Data-driven decision systems can reproduce Bias, eventually generating injustices and discrimination. These problems achieve higher relevance and discomfort in areas such as health or justice (Lecher 2018). Presently, research about Bias has made considerable progress, such as, in mitigating algorithm

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P. Banerji and A. Jana (eds.), *Advances in Urban Design and Engineering*, Design Science and Innovation, https://doi.org/10.1007/978-981-19-0412-7_7

biases[1] at specific levels of algorithms, or in creating tools for providing Bias detection in the data introduced at the system[2], general frameworks for helping to explore ethical issues (Aydemir and Dalpiaz 2018), some of which considering the disparity of impact (Lipton et al. 2017). On the other hand, as the decisions of these algorithms are not always correct, trying to understand and sometimes demonstrate (for example, in court) how a problem occurs, such as the existence of Bias and its consequences, such as injustice, reinforces the need for being able to explain (Explainability) what happens in the system, namely the decisions made by the algorithms (Brauneis and Goodman 2017). The lack of transparency of systems does not always result from companies deliberately avoiding transparency, but rather from the complexity of the algorithm (Chouldechova 2017). Transparency raises yet another issue, namely data-driven decision systems used by organizations providing services of public interest (such as in Public Administration), which are mostly created by private entities, which leads to further challenges. Another dimension is the Accuracy of the system. One of the phases of the data mining process is model evaluation, which does not always really reveal how trustable the model is. With this background, and considering the importance of this topic to society, as well as its complexity, the purpose of this work is to understand the position of Bias, Explainability and Accuracy in the Cross-Industry Standard Process for Data Mining (CRISP-DM) and the Public Policy (PP) processes (how are they addressed in CRISP-DM and PP processes), particularly looking to identify at which stages of these processes are each of the three dimensions addressed. Furthermore, this work intends to make a comparison between these processes and identify whether a parallel might be possible to consider between them. In order to do that, documents listed in the "Law and Policy Reading" list, published by the AI Now Research Institute from New York University, and related to these topics are analyzed. We used methods of different qualitative approaches (Content Analysis, Coding and Cross-Case Analysis).

This paper aims to contribute (i) to the identification of the three risk dimensions in Artificial Intelligence (AI)—Bias, Explainability, and Accuracy—from which Ethical issues may emerge, throughout the Data Mining process and the Public Policy process; (ii) to the comparison of both processes regarding to these three dimensions; (iii) to Public Policymakers and developers in their decision-making processes that involve the evaluation of AI tools.

Overall, this document is structured as follows. Section 2 presents the most important characteristics for Public Policy and their importance on ethical problems which arise from data-driven decision models and the Public Policy process. Data Mining process and the risks of data-driven decision models related to our study are also presented in this section. Section 3 presents the data source selected. Section 4 presents an overview of the path and approaches followed to reach our goals. Section 5 presents the analysis for understanding the data selected, the position of the Bias, Explainability, and Accuracy through the CRISP-DM and PP processes, a compar-

[1] https://aif360.mybluemix.net/?cm_mc_uid=42643015043715552375663&cm_mc_sid_50200000=24341351557649842548.

[2] https://dsapp.uchicago.edu/home/resources/opensource/.

ative study between the phases of the different processes, and the discussion of the results. In Sect. 6, some final remarks are presented.

2 Background

This section provides the conceptual background to the work performed. It starts by presenting the policy-making process and the most important characteristics of a Public Policy, with special focus on the importance of ethical issues that arise from data-driven decision models. Then, the processes of Data Mining are presented, followed by the risks of data-driven decision models.

2.1 Public Policy and Policy-Making Process

Policy is defined as designating the behavior of a particular actor or group of actors, it is developed by the government or other official entity, and its purpose is oriented toward a social problem or matter of concern (Anderson 2003). Public policies affect and are affected by several factors, which also influence the policy-making process. These factors include: experience, expertise and judgment, available resources, values, habit, and traditions that are affected by the policy, pressure groups and consultants, and other contingencies (De Marchi et al. 2016). In the case of problems that raise ethical issues (such as the three dimensions under consideration in this work), the judgments, the values, and the pragmatics and contingencies are the three factors that most influence the need for Public Policy in this field. The Public Policy process consists of five phases: (i) Problem Identification and Agenda Setting, (ii) Proposal Formulation, (iii) Selection/Adoption of proposal to implement, (iv) Implementation of the proposal, and (v) Evaluation of the implementation (Anderson 2003). The Public Policy Process is presented in Fig. 1.

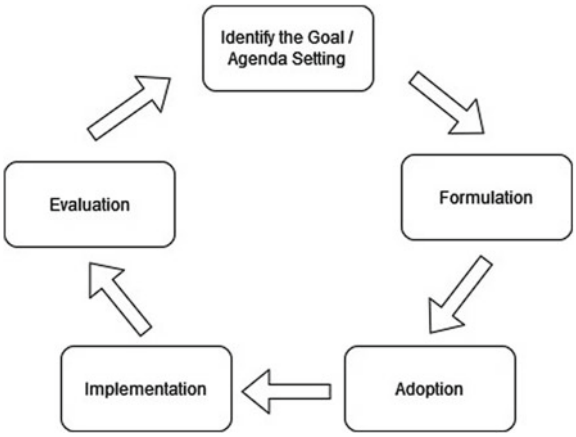


Fig. 1 Public policy process (considering the description at Anderson (2003))

The phases of the process consist of:

- *Problem Identification/Agenda Setting* is the first phase of the process and consists of identifying and defining the problems to be considered for the formulation of Public Policies (Anderson 2003).
- The following phase, *Formulation*, is the elaboration of proposals, options or alternatives to solve or improve the problem identified in the first phase (Anderson 2003).
- Once the proposal has been formulated, it is necessary to decide which of the proposed alternatives should be implemented, who is eligible to implement it, and what are the requirements, *Selection/Adoption* phase. There is always the alternative of not taking any action (Anderson 2003).
- The *Implementation* phase focus on implementing or applying the adopted Policies, taking into account the course of Policy Administration (Anderson 2003).
- The final phase, *Evaluation*, determine whether the Policy being implemented is achieving its stated goals and its consequences are identified (for example, whether someone is favored or is in disadvantaged by any action taken) (Anderson 2003).

At *Helping researchers become policy entrepreneurs* by Young and Mendizabel (2009), the authors consider the existence of six phases in the PP process. This is due to a subdivision of the first phase. The *Multi Streams Framework* from Kingdon presents not-so-linear processes (Perry and Kingdon 1985), where it is included in the Public Policy process the three aspects that lead to windows of opportunity, for later Public Policy-makers to act. As our focus relies on understanding where are the three risk dimensions (Bias, Explainability, and Accuracy) addressed in the PP process, and what are the contributions of addressing those risks to the development of Public Policies, the Public Policy process considered in the analysis is the process proposed by Anderson (2003). In order to do that, it is subdividing the first phase, since with more phases it will be possible to make a more thorough identification of where, along the process, each risk is addressed. The phases of the Public Policy Process and their relationship with the three dimensions are presented in Table 1.

2.2 Data Mining Process

With the growth of Data Mining, it became necessary to find patterns that could represent the process used to extract knowledge from the data. The three processes most commonly referred to in the literature that describe the steps of Data Mining applications are KDD (Knowledge Discovery in Databases), SEMMA (Sample, Explore, Modify, Model, Assess), and CRISP-DM (CRoss-Industry Standard Process for Data Mining) (Azevedo and Santos 2008).

The Data Mining process used as reference for comparison with the Public Policy process was the CRISP-DM process, as it was found to be the most relevant process used in the literature, and the specificity of its phases allows for an almost direct

Fig. 2 CRISP-DM overview process (Chapman et al. 2000)

comparison with the Public Policy process previously mentioned (at Sect. 2.1). The CRISP-DM process comprises six steps in its process (Chapman et al. 2000). The CRISP-DM process is presented in Fig. 2.

The phases of CRISP-DM process consist of:

- In the first phase, it is necessary to understand the business perspective and goals in order to define the Data Mining problem, this step is called *Business Understanding* (Wirth and Hipp 2000).
- Then, *Data Understanding* step, it is necessary to collect the data, identify its quality problems, as well as explore the data to develop a new hypothesis (Wirth and Hipp 2000).
- Next, in the *Data Preparation* step, the data is processed, and all the activities of the following steps will be performed (Wirth and Hipp 2000).
- The *Modeling* phase consists of selecting the techniques to be applied and calibrating the optimal values (Wirth and Hipp 2000).
- Next, the evaluation of the model(s) is performed, as well as steps that allow reaching the goal identified in the first stage, in a phase called *Evaluation* (Wirth and Hipp 2000).
- Finally, the *Deployment* phase is necessary to organize the knowledge obtained so that it has value for the client (Wirth and Hipp 2000).

The CRISP-DM Business Understanding stage is not considered by us as specific from business, once any problem needs to understand its context and goals, also with Public Policy this is necessary. For that reason it was decided to maintain the Business Understanding phase in the analysis, since it will be important for the processes comparison.

2.3 Risks of Data-Driven Decision Models

In the field of Artificial Intelligence, the biggest challenges are the issue of discrimination and the need for explanation about which leads to a decision by the machine. These problems are complex to solve and achieve particular relevance for Public Policy. Artificial Intelligence, namely data-driven decision models, increasingly incorporate learning mechanisms. Different types of algorithms applied to the most varied areas, in particular in the public domain, bring several concerns. They have characteristics that make them increasingly adaptable, without the need for human intervention. The development, application and use of these algorithms to support decision-making can have negative consequences, such as injustice and social discrimination replicated by the algorithm or inaccurate or incorrect results, in which identification might be hampered by the lack of transparency of the procedure performed. The report refers to Bias, Explainability and Accuracy as "risks around the underlying methodology". Advances in algorithmic capabilities are only a small part of data-driven decision model development, the other larger and more important part is the quality of data so that the full potential of the model can be revealed. Attention to risks around inaccuracies is important because accuracy is compromised in the presence of Bias and may even lead to incorrect decisions. This means that the risk of Bias is another dimension to be taken into account. The report states that Bias can occur "in different points and aspects", for example, in the data itself, in the way that data is processed and optimized, and in the form of interpretation Bias. As a manifestation of these types of Bias, social discrimination may occur. Another risk, highlighted by the entry into force of the General Data Protection Regulation (GDPR) was Explainability, due to the right to the explanation stipulated at GDPR. Terms such as Accountability, Transparency, and Opacity are linked to Explainability, although with distinct particularities. Explainability is intended, in a way, to reduce the risk that decisions are unknown and increase the possibility of correcting the decision if an incorrect decision occurs. This facilitates introducing a change of established practices[3]. Hence, people should know the provenance of the decision that has consequences for their lives.

3 Data Source

In order to understand when and how the dimensions (Bias, Explainability, and Accuracy) are addressed in each process, and whether any of the dimensions is a priority in order to contribute to goals of algorithm governance strategy, the documents at the "Law and Policy Readings" list[4] from the AI Now Institute is analyzed. AI Now

[3] https://irgc.epfl.ch/issues/projects-cybersecurity/the-governance-of-decision-making-algorithms/.

[4] https://docs.google.com/spreadsheets/d/1qtNGMB46GOwbkJUdVV9RPUNHbNkK9XW8rln48lAeEks/edit#gid=0.

Institute is an interdisciplinary research institute, founded in 2017, that studies the social implications of Artificial Intelligence. The research focus of the AI Now Institute is distributed in four areas: Rights and Liberties, Labor and Automation, Bias and Inclusion, and Safety and Critical Infrastructure. Most of the documents considered for this study are centered in the lines Bias and Inclusion (responsible for "researches issues of fairness, looking at how Bias is defined and by whom, and the different impacts of AI and related technologies on diverse populations"), and Safety and Critical Infrastructure responsible for study "ways in which AI and related technologies are being applied within" health, infrastructures, power grid, risk posed by errors "domains and aims to understand possibilities for safe and responsible AI integration"[5]. Policy-makers, advocates, academics, litigators, and other experts, have contributed with suggestions of readings that they found most useful in their work[6]. The reading list, accessed on 10th of August 2019, includes documents labeled in six types of readings: news and magazine articles (8), paper journals (73), books (15), papers from centers (12), cases (24), and statutes (36). Each type of reading has categories for a specific article or document. For example, papers classified in data source as from "centers" are distributed among General/Background subject, Criminal Justice, Public Health, and Public Benefits. The documents classified as news and magazine articles, journal papers, papers from centers and documents involve court cases were considered for our document selection, and used in our analysis. Considering the four types of labels, mentioned in the previous sentence, 44 are classified as Criminal Justice subject, 29 as General/Background, 15 as Other, 11 as Public health, 8 as Finance, 4 as Education and 4 as Public Benefits, and 2 as Employment. Among the journal papers, only 24 out of 73 are not published in Law Journals. The analysis also has three articles which are not in the AI Now Law and Policy Reading list, although they have been recently suggested to be part of the list. The papers are *Algorithmic Bias in Autonomous Systems* (Danks et al. 2017), and applications of Machine Learning to Administrative Government and support Policy Decision-Making as *Cyber Hate Speech on Twitter: An Application of Machine Classification and Statistical Modeling for Policy and Decision-Making* (Burnap and Williams 2015) and *Trade-offs in Accuracy and Efficiency in Supervised Learning Methods* (Collingwood and Wilkerson 2012). The selection of relevant documents from this data source is the source for the several analyzes, for which we have proposed to contribute.

4 Methodology

To achieve our research purpose, we started by identifying the existing Public Policy (PP) and Data Mining (DM) reference processes, adopted for this study (at Sect. 2). Then, through online searches, the data source that best fits the analysis

[5] https://ainowinstitute.org/.

[6] https://medium.com/@AINowInstitute/ai-now-law-and-policy-reading-list-641368f09228.

of the three risk dimensions from which social and ethical problems may emerge (at Sect. 3) is selected. After this, by reading the documents presented in the data source, the relevant documents for the analysis were selected. The criteria for selection were to have an AI background, to address a topic of public interest, and to be aligned with the three risk dimensions considered in this work. The next step is focused on understanding the representativeness of the topics under study in the documents selected for analysis. For that, an analysis of the content (Flick et al. 2004) of these selected documents was made. In the first analysis, the abstracts of these documents were considered using the word frequency count approach (Word Cloud), making it possible to understand their representativeness (at Sect. 5.1). After that, in order to deepen the content analysis, we applied an unsupervised machine learning pipeline, for topic modeling (Zou and Hou 2014), to all the content of the selected documents in order to confirm if the three risk dimensions under analysis were represented in the distribution of the topics. The result visualization of this application is also presented in the form of a Word Cloud. As mentioned earlier, we start this study to analyze three dimensions of risk in the data-driven decision models (at Sect. 2.3), which are concepts and ideas that we look for in the text of the selected documents (Saldana 2009). Considering this, the three dimensions were identified along the process of CRISP-DM and PP with the Coding approach. Once the Bias, Explainability, and Accuracy dimensions were located along the DM and PP processes, it was possible to compare both processes, cases, looking for similarities and differences between the positions of the three risk dimensions, considering the order of the phases of the processes. This is performed using Cross-Case Analysis (Mathison 2005). After this will be presented the position, considering our approach of the analyzed papers, for Bias, Explainability, and Accuracy along the CRISP-DM and PP processes (Fig. 3).

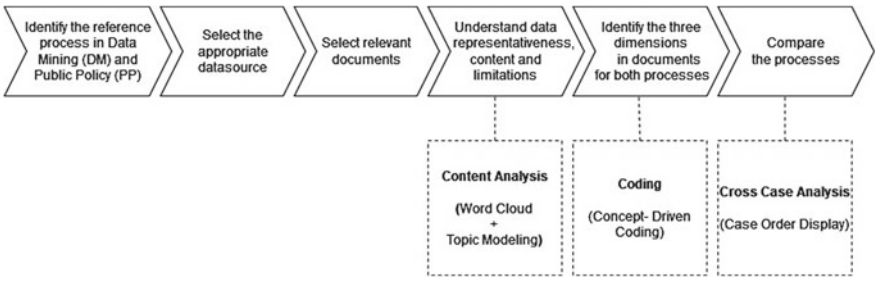


Fig. 3 Methodology overview

5 Results and Discussion

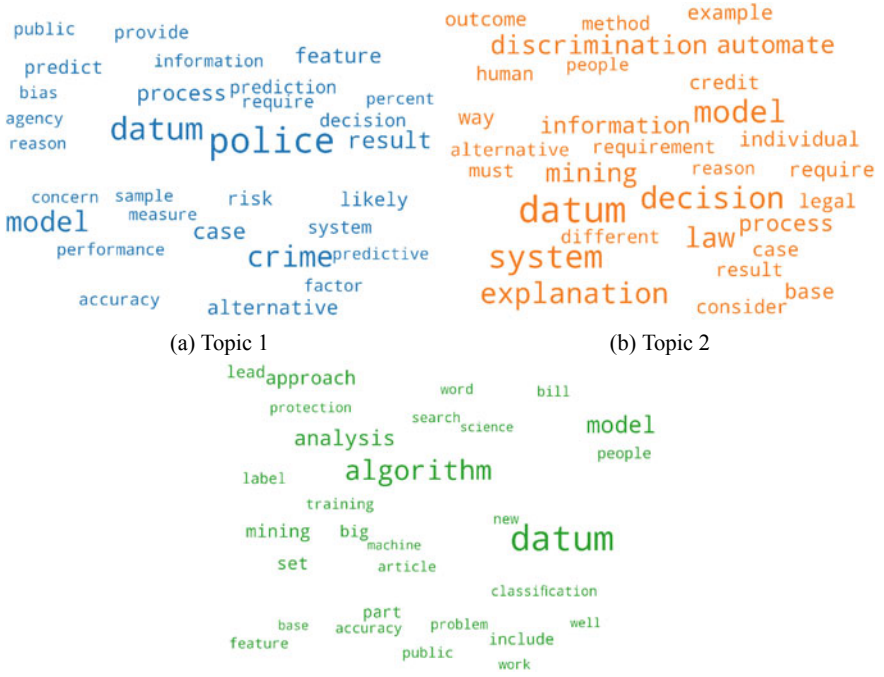
This section presents the analysis for understanding the data selected, for situating the Bias, Explainability, and Accuracy at CRISP-DM and PP processes, for the comparative study, and the discussion of the results.

5.1 Representativeness of the Documents Selected

This subsection addresses, in some way, the representativeness of the selected documents, considering the number of words from their abstracts. The documents selected for analysis of the positioning of Bias, Explainability, and Accuracy, in the CRISP-DM and PP processes, were analyzed by detecting the most relevant words, in order to understand if their representativeness was in accordance with the goal of the study. The representativeness study was performed through the visualization tool *Jason Davies World Cloud Generator* (Davies 2012). The abstracts of all selected articles were introduced into the tool. The word count options were also selected, as the option 100 for the number of words. After this procedure, the result presented in Fig. 4 was obtained. The words: Biases, Bias, Explanation, Predictive, AI, Algorithms, Decisions, Intelligence, Artificial, Society, Risk, Policy, Fairness, Accuracy, Decision-making, Accountability, and Social are the representatives of the selected papers, however, the most highlighted are Systems and Data.

In order to deepen the representativeness of the selected documents, we applied an unsupervised machine learning pipeline to extract the topics from the selected

Fig. 4 Most frequent words in the abstract of the documents selected



(a) Topic 1

(b) Topic 2

(c) Topic 3

Fig. 5 Topic modeling

documents. The goal is to prove that the expert's opinion about the representativeness of documents with three dimensions risk under analysis is coincident with the result of a probabilistic model that extracts the topics and own words automatically in a reproducible way. For this analysis, we use R and all the document's content was considered. The pipeline has four steps: (i) load the data, i.e., we download all the pdfs and store them in a folder; (ii) data pre-processing, i.e., we remove the punctuation, remove stop words, form bigrams, trigrams, and lemmatization; (iii) use the Latent Dirichlet Allocation (LDA) to model the documents (Zou and Hou 2014); and (iv) data visualization using a word cloud. The LDA model has the following parameters: (num_topics = 3, random_state = 100, update_every = 1, chunksize = 1, passes = 1, alpha = 'symmetric', iterations = 500, per_word_topics = True). In order to perform this, the Prabhakaran (2018) was followed. The results in Fig. 5 clearly show the formation of three Topics which include the words: Bias, Explanation, and Accuracy.

5.2 Position of Dimensions in Processes

As mentioned previously, in Sect. 2, more specifically at Public Policy and Policy-Making Process and Data Mining Process subsections, the Public Policy and Data Mining processes, respectively, comprise an orderly sequence of steps inherent in each process, steps with specific activities whose purpose is to achieve the initially defined goal, either in the form of software or system (in the case of CRISP-DM) or in the form of Public Policy (in the case of the PP process). This subsection situates the position of the three risk dimensions: Bias, Explainability, and Accuracy, along CRISP-DM and PP processes, which are presented in Table 1. The dimensions were allocated to a specific stage of the process, either CRISP-DM or PP, whenever the dimension was addressed in the document under analysis. This occurs always, even whether or not it was approached slightly, as in the case of news and magazine articles or papers in which the focus was not technical but with a social and informative perspective. On the documents analyzed, the report of examples of situations where Bias occurred, Opacity, Explainability, and Transparency of the algorithms was predominant. Thus, as noted in Table 1, from a Public Policy perspective, these studies are centered on the first two phases, comprising a window of opportunity. That is, it corresponds to the identification of the goals for the formulation of Public Policies. The only case considered as Policy Formulation is an paper that presents alternative suggestions in the form of laws. At the Implementation stage, the two Artificial Intelligence application documents are included which intend to solve any detected public interest problem or that intended to be automated. With the exception of Accuracy, the remaining risk dimensions such as Bias and Explainability are in the first stage of the PP process. The presence of the metrics used for model evaluation, such as Accuracy, in the Artificial Intelligence process, highlights the application character of the articles allocated in the implementation stage of the Public Policy process. It is relevant to mention that in the Agenda Setting phase, we considered the documents which presented suggestions or alternatives to a problem. However, they were not considered in the Formulation step because they did not present a well-defined action. In the CRISP-DM process, the position of the Bias, Explainability and Accuracy dimensions is distributed. The description of discrimination considering the risk of Bias essentially addresses the source of data. In the Data Understanding phase, the most allocated dimension is Bias, with four of these articles also reporting Accuracy problems and two referring to all dimensions. In these cases, their allocation was made in the Data Understanding phase. The Data Understanding phase includes approaches that refer to Bias due to variable elimination. Cases allocated in the Data Preparation phase include Bias from, for example, features construction. The documents allocated to the Modeling phase raise issues of Opacity, Explainability, and Transparency, their focus are the models used. When the focus of document is given to the impact of Opacity, Explainability the document is also allocated to the Deployment phase. In the Evaluation stage, documents were allocated that somehow express concern in the evaluation of the models and their interpretation. For its part in the Evaluation phase, the most allocated dimension is that of Accuracy. There are no dimensions allocated to the Business Understanding phase.

Table 1 Bias, explainability and accuracy at CRISP-DM and PP processes

Dimensions of risk	Document title	*CRISP-DM process*						*Public Policy process*					
		Business understanding	Data understanding	Data preparation	Modeling	Evaluation	Deployment	Identify the goal	Agenda Setting	Policy formulation	Adoption	Implementation	Policy evaluation
E	Accountability of AI Under the Law: The Role of Explanation						x	x					
E	How the Machine 'Thinks': Understanding Opacity in Machine Learning Algorithms				x			x					
AB	Algorithmic Transparency for the Smart City		x	x		x			x				
B	Building a Better HAL 9000: Algorithms, the Market, and the Need to Prevent the Engraining of Bias		x					x					
B	Artificial Intelligence Policy: A Primer and Roadmap		x				x	x					
B	How Algorithms Discriminate Based on Data They Lack: Challenges, Solutions, and Policy Implications		x					x					
ABE	Machine Learning for Policymakers What It Is and Why It Matters		x	x	x	x		x					
EB	Algorithmic Accountability: A Primer		x		x		x		x				
B	Unfairness By Algorithm: Distilling the Harms of Automated Decision-Making		x						x				
B	Public Scrutiny of Automated Decisions: Early Lessons and Emerging Methods		x				x		x				
B	Stuck in a Pattern: Early Evidence on "Predictive Policing" and Civil Right		x				x	x					
ABE	A case study of Algorithm-assisted Decision Making in child Maltreatment Hotline Screening Decisions		x		x	x	x	x					
EB	Why New York City's High School Admissions Process only Works most of the Time		x		x		x	x					
B	Foretelling the Future: A Critical Perspective on the Use of Predictive Analytics in Child Welfare		x				x	x					
E	What Happens when an Algorithm cuts your Health Care				x		x	x					
E	The Broken Promises of Choice in New York City Schools			x			x	x					
B	To Predict and Serve?		x				x	x					
B	Governmental Data Mining and its Alternatives		x					x					
B	Automated Decision-Making and Big Data: Concerns for People With Mental Illness		x				x	x					
AB	The Accuracy, Fairness, and Limits of Predicting Recidivism		x			x	x	x					
B	Disparate Impact in Big Data Policing		x				x			x			
E	Predictive Risk Modelling to Prevent Child Maltreatment and Other Adverse Outcomes for Service Users: Inside the 'Black Box' of Machine Learning			x	x		x	x					
E	The Intuitive Appeal of Explainable Machines				x			x					
AB	Standards of Fairness for Disparate Impact Assessment of Big Data Algorithms					x	x	x					
B	Algorithmic Bias in Autonomous Systems		x	x	x		x	x					
A	Trade-offs in Accuracy and Efficiency in Supervised Learning Methods					x						x	
A	Cyber Hate Speech on Twitter: An Application of Machine Classification and Statistical Modeling for Policy and Decision Making					x						x	

Legend: E - Explainability/Opacity/Transparency; B - Bias; A - Accuracy; AB - Accuracy and Bias; EB - Explainability and Bias; ABE - Accuracy, Bias and Explainability

5.3 CRISP-DM and PP Processes Comparison

This subsection covers the comparison of CRISP-DM and PP processes. The comparison is made at the level of the process phases and the position of the dimensions within each of the processes. The CRISP-DM and PP process has different tasks or activities between its steps. However, its principle is similar. In both the cases, the starting point is problem identification, then a selection is made of what is relevant to its resolution or what can be considered and the diagnosis of the situation (Business Understanding at CRISP-DM and Agenda Setting at PP). Once this situation is diagnosed, it becomes relevant to give consistency to the problem alternatives, Data Understanding (CRISP-DM) and Formulation (PP) phase. In the next step, having this sequence, the decision for one of the proposed alternatives for resolution comes naturally in order to adopt the best strategy (PP), the same happens in the Data Preparation phase where techniques are used to use the data or features which represent well the problem with reduced information loss (CRISP-DM). Also, the next step has parallelism between both processes, because what is intended with the Implementation (PP) or Modeling (CRISP-DM) is to carry out/apply what has an effect on solving the problem, and according to their specificity's and goals, previously defined. Also the last phase presents a parallelism between processes, even more evident than in some of the previous phases. That happens because the aim of Evaluation (CRISP-DM) and Evaluation (PP) phase is to evaluate the measures and strategies adopted according to the goals and context. Table 2 compares the two processes phases. Table 3 presents the position of the dimensions along the CRISP-DM process and the Public Policy process. Concerns about Bias throughout the CRISP-DM process are not the same type, for that reason their resolution needs are different. Explainability issues focus on the Data Preparation and Modeling phases, that is, the data transformation and modeling part. The Accuracy dimension focuses on the model evaluation stage. The early stages of the Public Policy process are those that include the Bias and Explainability dimensions. The phase Identify the Goal/Agenda Setting was split in our analysis, considering the level of detail presented in the documents. The Accuracy dimension arises in the Evaluation.

Table 2 Processes phases comparison

CRISP-DM process	Public Policy process
Business understanding	Identify the goal
Business understanding	Agenda setting
Data understanding	Formulation
Data preparation	Adoption
Modeling	Implementation
Evaluation	Policy evaluation
Deployment	

Table 3 Dimensions in CRISP-DM and PP

Dimensions	CRISP-DM
	Business understanding
Bias	Data understanding
Explainability and bias	Data preparation
	Modeling
Accuracy and bias	Evaluation
Bias	Deployment
Dimensions	**Public Policy process**
Bias and explainability	Identify the goal
	Agenda setting
Bias	Formulation
	Adoption
	Implementation
Accuracy	Evaluation

6 Conclusion

In the analysis performed, regardless of whether the articles focus on Public Policy, technology, application or overview, they relate to the process of Public Policy essentially in the first two steps, Identify the Goal/Agenda Setting and Formulation. At the intersection of the dimensions under study (Bias, Explainability, and Accuracy) with the steps of the CRISP-DM process to situate their position through the processes (Table 1), it was possible to observe that the documents analyzed on Bias are the ones that cover more phases of the Data Mining (DM) process. This is essentially due to a paper proposing a taxonomy for Bias (Danks et al. 2017). Bias has a higher incidence in the Data Understanding phase, i.e., problems with data Bias are a concern in the phase. In the case of Explainability, the Modeling phase is relevant, nine of the documents that address Explainability (in a broader sense including relations with Opacity and Transparency) focus on this DM process stage. However, two papers also mention the way features were constructed as a concern for Transparency, which is represented at the Data Preparation phase of CRISP-DM, understandably, because the model selected is the focus of development to lead to Explainability. Accuracy is more present in the Evaluation phase. The documents considered in the Evaluation stage are related to technology, with technology that can be useful to evaluate the measures adopted in the field of Public Administration. In a comparison perspective, the CRISP-DM and PP processes have different tasks or activities between their steps. However, their principles are quite similar. Although there is a proximity between the processes, evidenced in the analysis, the same does not occur in the positioning of the study of the three dimensions (Table 2 and 3). This reveals that there are different current stages of development of the two processes. However, on the one hand, the emergence of Public Policies in this area arises, at this moment, from necessity and future prevention. The identification

and positioning of the three dimensions along the Data Mining process (AI domain) and the Public Policy process allows us to contribute to the development of Artificial Intelligence algorithms and the Public Policies, as the positioning of the risks within the phases of those processes allows for more attention to those risk dimensions in the appropriate stage of development. In the case of Artificial Intelligence, this allocation of risks to development phases will allow developers and analysts to quickly identify where the problem occurs, what occurs, and what type of problem it is. The same happens for the Public Policy process, the contribution of risk allocation to its process phases facilitates decision-making for policy-makers involving decision-making about using AI tools. Moreover, there is an interaction between both areas, in the sense that when developing an AI algorithm, developers might be informed about the most relevant risks for the PP that might define the context of the use of that algorithm, and when developing PPs. The decision-maker might also be better informed of the risks that emerge during AI development and the difficulties that might be faced during that process. This is, our analysis bring relevant information to consider when is defined the context of use of an algorithm or of a technology in general, what might be useful for public-policy decison makers and developers. Artificial Intelligence aims at decisions of interest to society (use of the algorithm for PP) and that Public Policies contribute to overcoming risks and social challenges arising from Artificial Intelligence (context defined by PP). For future work, we intend to understand, if any, what is the relationship between the dimensions Bias, Explainability, and Accuracy.

Acknowledgements This work is a result of the project Operation NORTE-08-5369-FSE-000045 supported by Norte Portugal Regional Operational Programme (NORTE 2020), under the PORTUGAL 2020 Partnership Agreement, through the European Social Fund (ESF). Project "Network Science for urban engineering" under the FCT Arrangement/Agreement—Scientific and technological cooperation FCT/ INDIA-2017/2019 Ref: FCT/4755/3/5/2017/S.

References

AI Now Law and Policy Reading List—AI Now Institute—Medium. https://medium.com/@AINowInstitute/ai-now-law-and-policy-reading-list-641368f09228

AI Now Research Institute: AI Now Institute (2017) https://ainowinstitute.org/

AI Now Research Institute: AI Now Law and Policy Reading List—Google Sheets (2017) https://docs.google.com/spreadsheets/d/1qtNGMB46GOwbkJUdVV9RPUNHbNkK9XW8rln48lAeEks/edit#gid=0

Anderson JE (2003) Public policymaking: an introduction. Mifflin Company, Boston, pp 1–34

Aydemir FBBBB, Dalpiaz F (2018) A roadmap for ethics-aware software engineering. In: Proceedings of the international workshop on software fairness—FairWare '18. ACM Press, New York, New York, USA, pp 15–21. https://doi.org/10.1145/3194770.3194778, http://dl.acm.org/citation.cfm?doid=3194770.3194778

Azevedo A, Santos MF (2008) KDD, SEMMA and CRISP-DM: a parallel overview. http://recipp.ipp.pt/bitstream/10400.22/136/3/KDD-CRISP-SEMMA.pdf

Bellamy RK, Dey K, Hind M, Hoffman SC, Houde S, Kannan K, Lohia P, Mehta S, Mojsilovic A, Nagar S, Ramamurthy KN, Richards J, Saha D, Sattigeri P, Singh M, Varshney KR, Zhang Y

(2019) Think your artificial intelligence software is fair? Think again. IEEE Softw 36(4):76–80. https://doi.org/10.1109/MS.2019.2908514

Brauneis R, Goodman EP (2017) Algorithmic transparency for the smart city. SSRN Electron J 103:103–176

Burnap P, Williams ML (2015) Cyber hate speech on twitter: an application of machine classification and statistical modeling for policy and decision making. Policy Internet 7(2):223–242

Center for Data Science and Public Policy: Our Open Source Mission: Code, Data, and other Resources. https://dsapp.uchicago.edu/home/resources/opensource/

Chapman P, Clinton J, Kerber R, Khabaza T, Reinartz T, Shearer C, Wirth R (2000) CRISP-DM 1.0: Step-by-step data mining guide. https://www.semanticscholar.org/paper/CRISP-DM-1.0%3A-Step-by-step-data-mining-guide-Chapman-Clinton/54bad20bbc7938991bf34f86dde0babfbd2d5a72

Chouldechova A (2017) Fair prediction with disparate impact: a study of bias in recidivism prediction instruments, pp 1–6. https://doi.org/10.1089/big.2016.0047, http://arxiv.org/abs/1703.00056, http://arxiv.org/abs/1610.07524

Citron DK (2007) Technological due process. Washington Univ Law Rev 85(6):1249–1313

Collingwood L, Wilkerson J (2012) Tradeoffs in accuracy and efficiency in supervised learning methods. J Inf Technol Polit 9(3):298–318

Danks D, London AJ, Dignum V (2017) Algorithmic bias in autonomous systems. In: Proceedings of the 26th international joint conference on artificial intelligence. IJCAI—international joint conferences on artificial intelligence, pp 4691–4697. http://dl.acm.org/citation.cfm?id=3171944

Davies J (2012) Word cloud generator—Jason Davies. https://www.jasondavies.com/wordcloud/

De Marchi G, Lucertini G, Tsoukiàs A (2016) From evidence-based policy making to policy analytics. Ann Oper Res 236(1):15–38

Flick U, Kardoff EV, Steinke I (2004) A companion to qualitative research. Sage Publications UK. https://books.google.pt/books?hl=pt-PT&lr=&id=6lwPkSo2XW8C&oi=fnd&pg=PP282&dq=content+analysis&ots=Zq_U0nQpMi&sig=BsGhLeZ91wSRsCiaVH2vDDEuSW0&redir_esc=y#v=onepage&q=contentanalysis&f=false

IBM Research Institute: AI Fairness 360 (2018) http://aif360.mybluemix.net/?cm_mc_uid=42643015043715552375663&cm_mc_sid_50200000=24341351557649842548

International Risk Governance Center: The Governance of Decision-Making Algorithms. Tech rep (2018) https://irgc.epfl.ch/issues/projects-cybersecurity/the-governance-of-decision-making-algorithms/

Lecher C (2018) What happens when an algorithm cuts your health care. https://www.theverge.com/2018/3/21/17144260/healthcare-medicaid-algorithm-arkansas-cerebral-palsy

Lipton ZC, Chouldechova A, McAuley J (2017) Does mitigating ML's impact disparity require treatment disparity? Adv Neural Inf Process Syst 2018-Decem:8125–8135. https://arxiv.org/abs/1711.07076

Mathison S (2005) Cross-case analysis. In: Encyclopedia of evaluation. Sage Publications, Inc., 2455 Teller Road, Thousand Oaks California 91320 United States of America. https://doi.org/10.4135/9781412950558.n129, http://methods.sagepub.com/reference/encyclopedia-of-evaluation/n129.xml

Ncr PC, Spss JC, Ncr RK, Spss TK, Daimlerchrysler TR, Spss CS, Daimlerchrysler RW, Chapman P, Clinton JJ, Kerber R, Khabaza TT, Daimlerchrysler TR, Shearer CRH, Daimlerchrysler RW, Reinartz T, Shearer CRH, Wirth R (2000) CRISP-DM 1.0: step-by-step data mining guide. SPSS inc 78:1–78. https://doi.org/10.1017/CBO9781107415324.004, https://www.semanticscholar.org/paper/CRISP-DM-1.0

Perry J, Kingdon JW (1985) Agendas, alternatives, and public policies. J Policy Anal Manage 4(4):621. https://doi.org/10.2307/3323801

Prabhakaran S (2018) Gensim topic modeling—a guide to building best LDA models. https://www.machinelearningplus.com/nlp/topic-modeling-gensim-python/#9createbigramandtrigrammodels

Saldana J (2009) The coding manual for qualitative researchers

Wirth R, Hipp J (2000) CRISP-DM: towards a standard process model for data mining. In: Proceedings of the 4th international conference on the practical application of knowledge discovery and data mining, pp 29–39. https://doi.org/10.1.1.198.5133, http://citeseerx.ist.psu.edu/viewdoc/summary?doi=10.1.1.198.5133

Young J, Mendizabel E (2009) Helping researchers become policy entrepreneurs

Zou C, Hou D (2014) LDA analyzer: a tool for exploring topic models. In: Proceedings—30th international conference on software maintenance and evolution, ICSME 2014. Institute of Electrical and Electronics Engineers Inc., pp 593–596. https://doi.org/10.1109/ICSME.2014.103

Chapter 8
Evolution of Electricity Sector in India: Toward Smart Metering and Sustainable Development

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1 Introduction

Access to electricity is a crucial indicator of human development and has been linked to greater life expectancy at birth, higher per capita GDP, and higher urbanization rates (Niu et al. 2013). Increased electricity consumption has also been linked to better economic growth (Salahuddin et al. 2015), lower unemployment rates (Afolayan et al. 2019), and lower infant mortality rates (Shobande 2020), among other socio-economic indicators. Availability of electricity at the household level, irrespective of it being in urban or rural areas, is one of the significant indicators of the well-being of any society (Ahmad et al. 2014). Access to electricity is often considered a human right (Tully 2006), and providing universal access to the same is a key sustainable development goal (Colglazier 2015). It has also been linked to multiple other Sustainable Development Goals (SDGs) (Brecha 2019). Therefore, providing

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P. Banerji and A. Jana (eds.), *Advances in Urban Design and Engineering*, Design Science and Innovation, https://doi.org/10.1007/978-981-19-0412-7_8

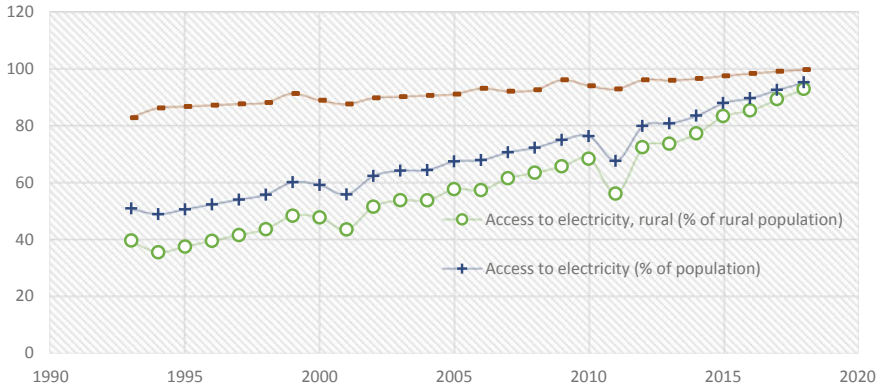

Fig. 1 Improvement in access to electricity (The World Bank, n.d.)

affordable access to electricity to each household is critical for achieving the Sustainable Development Goals (SDGs), the most referred SDG set being the one promoted by the United Nations (UN).

As a developing country with a large urban population, the story of access to electricity in India has been tumultuous. Even four decades after independence, the percentage of rural population with access to electricity was less than 40%, while slightly over 80% of the urban population had access to the same. Although rural electrification rates rose to 85% in 2007, less than 60% of the households had access to electricity (Kemmler 2007). However, a consistent focus on providing electricity access by various planning commissions has resulted in significant improvement in this area. As of 2018, over 95% of India's rural population and nearly 100% of the urban population have access to electricity, as shown in Fig. 1. Rural electrification has continued to improve since then. As of 2019, the government has reported 100% rural electrification and nearly 100% rural household electrification (Singh 2019).

Electricity access is linked to multiple SDGs ranging from those related to good health and well-being to the targets related to climate action. It has been argued that changes in the power sector such as last mile access, renewable-based generation, and smart energy infrastructure can play a key role in achieving multiple SDGs in addition to SDG7, which is directly linked to affordable and clean energy access (IISD 2017).

However, the Indian power sector is yet to face multiple challenges such as the poor financial health of distribution companies (or DISCOMS), high Aggregate Technical & Commercial (AT&C) losses (Dsouza 2019). These include losses due to poor infrastructure and improper instrumentation, commercial losses due to improper billing, ineffective bill collection, theft, and meter tampering (KiranKumar et al. 2013). This work, therefore, studies the impact of legislative and policy interventions on the power sector and metering technology with a focus on sustainable development. The potential consequences of smart metering policy on electricity

access and SDG are explored. An essential intervention in this regard is the introduction of smart metering. While there are studies on the evolution of legislature and policy related to the Indian power sector (Saini 2018; Kumar and Chatterjee 2012), an analysis focusing on metering and the impact of policies on sustainable development goals is yet to be carried out. Since smart metering is in its infancy in India, this study explores the impact of smart metering on sustainable development by comparing it to other countries that have advanced further in this regard.

Major contributions of this work are:

- Discusses the evolution of the impact of energy policy and legislation on the Indian power sector.
- Analyzing the impact of various policy changes on sustainable development of power sector.
- Impact of policy changes on SDGs
- Compares the metering policy in India to those of its global counterparts and identifies potential challenges and solution methods.

This chapter is organized as follows. After a brief introduction to the Indian power sector, the various policies related to the Indian power sector are discussed. As five-year plans have formed the basis of developmental planning in India, the discussion traces the progress of the power sector through these plans. The gradual focus on metering and smart metering technology in planning is also highlighted.

The next sections explore how previous policy changes have impacted sustainable development and SDGs. The need for smart metering to further sustainable development is discussed and the experience of various countries, both developed and developing, are presented. The conclusion presents the summary of the evolution and current scenario of the electricity sector in India, followed by the challenges and opportunities of different interventions in this sector.

2 The Indian Power Sector

The Indian Power sector consists of central and state level bodies functioning in tandem in electricity provision, policy-making, and regulation. In terms of legislation, the power sector falls in the "concurrent list," governed jointly by central and state governments (Shahi 2006). The Ministry of Power, Government of India, has the Central Electricity Authority (CEA), the Bureau of Energy Efficiency (BEE), and the Central Electricity Regulatory Commission (CERC) as administrative bodies. These work on policy formulation, energy efficiency, and determine tariff policies. Besides, various Public Sector Undertakings (PSU) function in the generation, transmission, and distribution. These include the likes of National Thermal Power Corporation (NTPC), National Hydroelectric Power Corporation (NHPC), and Nuclear Power Corporation of India Limited (NPCIL). At the state level, the ministry of power is advised by the policies set by CEA, while the CERC advises the State Electricity Regulatory Commissions (SERCs) on tariff and pricing-related matters.

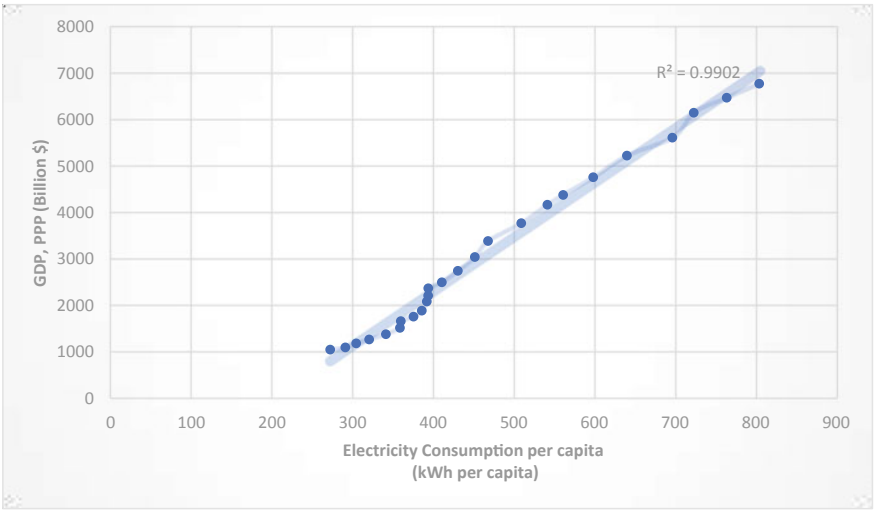

Fig. 2 Growth of electricity sector in India (The World Bank 2020)

The state ministry also controls companies working on Power generation (Genco), Transmission (Transco), and distribution (DISCOM).

Various five-year plans guided the evolution of the Indian power sector since independence; legislations brought into effect have provided a framework for the growth. India had an installed generation capacity of 1362 MW in 1947. As of 2019, at 336 GW, it is the world's third-largest producer of electricity (Central Electricity Authority 2019). As a developing economy, India's electricity consumption is likely to increase, growing at 6.2% per annum till 2030 (Ali 2018).

Figure 2 shows the variation of GDP growth with per capita electricity consumption. A strong positive correlation is observed. In fact, a linear trendline shows an R^2 of 0.99, indicating a significant linear correlation between the two. In essence, the country's economic development is dependent on its ability to provide electricity access to its citizens.

Despite its significant growth and relevance, the Indian Electricity sector faces some critical challenges. For example, the financial performances of distribution companies across India have been unsatisfactory over the years. The sector is also plagued by high AT&C losses, ineffective tariff structures and subsidies, challenges associated with adherence to power purchase agreements, and lack of credible information for decision making (Varghese and Eapen 2016). In addition, the power sector is heavily reliant on fossil fuels, with over 75% of electricity generation coming from conventional power plants (IEA 2019). Over time, various legislative and policy measures have been carried out in the sector to enhance the performance of the sector. The evolution of the Indian power sector through policy is discussed in the next section.

3 Policy-Making and Five-Year Plans

The first planning commission report for the period 1951–1956 discusses electricity on a systemic level. The report presents a review of existing electricity generation systems, mostly in urban areas, catering to industries or urban populations. At the time, electricity generation was from steam (coal-based), hydro, and a small fraction of oil (Planning Commission 1951).

The second plan (1956–61) first assessed the progress made and finds that an 800 MW addition has been made. The larger projects were still in progress. Another achievement noted was the installation of 19,000 miles of sub-transmission and transmission lines of 11 kV and above, effectively doubling the nation's transmission network. By the **third five-year plan (1961–66)**, there was a greater focus on rural electrification. Many of the projects started at the time of the first five-year plan had become operational, and at the beginning of this five-year plan, the installed capacity reached 5700 MW (Planning Commission 1962).

The fourth plan (1969–74) showed a significant lag in installed capacity addition owing to 1962 and 1965 aggression. However, considerable progress was made in interconnecting state grids. Regarding electricity tariff, the plan suggested SEBs to aim at revenues, sufficient to cover operational and maintenance charges, contribution to the general, and depreciation reserves and interest charges on the capital base (Planning Commission 1970). In the second phase of the plan, SEBs were to aim for an overall return of 11%. This was a significant departure from the views of the first five-year plan and in accordance with the observations made by the third five-year plan (Planning Commission 1970). **The fifth five-year plan (1974–78)** did not contain much information on the economics of power generation (Planning Commission 1976). However, **the sixth plan (1980–85)** noted that the SEBs are often at a loss due to improper tariff planning, and the center should take appropriate steps to improve the financial condition of SEBs (Planning Commission 1980). **The seventh commission (1985–90)** report mentioned the need for rural household electrification (as opposed to rural electrification), though there was no mention of electricity pricing or metering (Planning Commission 1985). **The eighth commission** took a similar approach. In both these reports, energy (including traditional heating fuels, oil, natural gas) was treated as a single vertical (Planning Commission 1992). **The Ninth planning commission (1997–2002)** was the first to directly discuss the lack of metering and its side effects on electricity distribution. It also acknowledged that without adequate metering, any measure of T&D loss was at best an estimate, and the effect of theft cannot be adequately understood. This report also suggests privatization of distribution as an option to reduce such losses (Planning Commission 1997).

More significant discussions on metering only started with **the tenth planning commission (2002–07)**. This is primarily due to the introduction of the electricity bill in 2001 (Ministry of Power 2003), which necessitated a national energy policy and mandated the states to set up state electricity regulatory commissions (SERCs).

The commission also mandated 100% metering for all connections and acknowledged that agriculture connections need special focus as most were unmetered (Planning Commission 2002). **The eleventh planning commission** recommended a 3% reduction in technical and commercial losses annually from all distributors and suggested setting up automated metering at all distribution transformers and mapping all consumers geographically. By that stage, the importance of metering for effective distribution was well acknowledged (Planning Commission 2002, 2007). **The twelfth and final five-year plan (2012–17)** noted that the electricity act has failed in many respects as states were reluctant to comply and that state DISCOMS often operated at large losses that couldn't be sustained for long. Various government schemes for aiding state DISCOMS were discussed, including the national electricity fund and the Restructured Accelerated Power Development & Reforms Programme. Also, Time of Day (TOD) metering, load management, energy efficiency, etc., were also discussed (Planning Commission 2012). While the Planning Commissions and NITI Aayog lay out policy directives related to each sector, the implementation of the same happens through appropriate legislation. The focus on smart metering is relatively new, starting with an amendment in 2019.

This legislation is new, and the transition to smart meters is still in its infancy. However, the intent to implement smart metering across the country is clear. It is also likely that prepaid meters will be preferred to improve transparency, billing efficiency, and reduce AT&C losses. The evolution of smart metering in India through various policies and legislative interventions is represented in Fig. 3. An explicit focus on metering is evident from the tenth planning commission period.

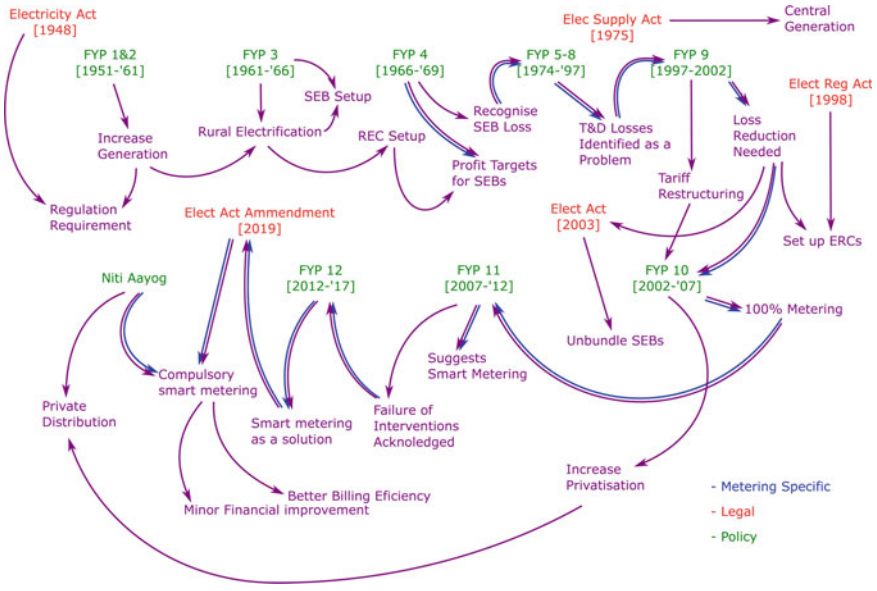

Fig. 3 Evolution of metering in India

Energy Efficiency Services Limited (EESL), a government-owned energy service company, is tasked with the Smart Meter National Programme (Energy Efficiency Services Limited 2020a), which plans to replace over 250 million conventional meters with smart meters. The proposal includes meters that allow for two-way communication (between the utility and meter), software for data acquisition, and management facilities for a remote meter reading. As of 2020, EESL has installed a total of 1.3 million smart meters, primarily in Delhi, Uttar Pradesh, Bihar, and Haryana. The AT& C loss in India at present is close to 20%. This scheme hopes to reduce the losses to below 12% by 2022 and below 10% by 2027 (Zaheeruddin 2014). This is in line with the **Electricity (Amendment) Bill 2020**; it was suggested that a commission be set up to find an electricity tariff reflective of the total cost of generation while establishing contract enforcement authorities and increasing penalties for violations (Ministry of Power 2020).

3.1 The Evolution of the National Grid

Another key change implemented through the planning commission is related to the evolution of the national electricity grid. As generation increased, the grid expanded to facilitate power transmission, and the **second planning commission report** (Planning Commission 1956) noted a 100% increase in grid coverage during the term of the first five-year plan. The target set by the second planning commission was to double the grid length during its term. The commission also suggested interconnections grids across state lines wherever beneficial, thus effectively introducing the possibility of a grid spanning states. **The third commission** further built on this concept, suggesting a super-grid in the Southern region, linking up Andhra Pradesh, Mysore, Madras, and Kerala power systems along with interconnecting grids in various other states, with the aim of eventually forming super grids (Planning Commission 1962). By the end of the third plan, the national power sector was effectively constituted of five major grids, namely the Northern, Eastern, Southern, Western, and North-Eastern grids (Planning Commission 1970). Therefore, **the fourth plan** recommended setting up central load dispatching stations in each region, thereby allowing for effective integration of these regional grids into a national grid (Planning Commission 1970). Eventually, the National Power Transmission Company (POWERGRID) was established in 1989, and large-scale national grid integration commenced. By 1991, the eastern and north-eastern grids were connected. **The ninth five-year plan (1997–2002)** focused on integrating various regional grids into a national grid (Planning Commission 1997). In 2003, the western grid was synchronized with the eastern and north-eastern grid system. During the term of the ninth Plan, the Indian Electricity Grid Code (IEGC) was established by the CERC to facilitate smooth operations of a national grid (Power Grid Corporation of India 2006). By 2006, all but the southern grid was integrated and synchronized. During the term of **the twelfth five-year plan (2012–2017)**, a national synchronized grid was achieved as per the One nation One Grid policy when the southern grid was integrated into the rest of the grids in

2014. The **twelfth** plan also introduced the idea of smart grids and smart metering, which would address the problem of losses to a great extent. NITI Aayog, which has since replaced the Planning Commission, has highlighted the need for smart metering, smart grids, and privatizing distribution. The widespread deployment of smart meters would be an exciting phase in India's metering policy when viewed in relation to the smart grid initiative.

4 Analyzing the Impact of Various Policies on Sustainable Development

The major policy interventions related to the Indian power sector have already been discussed. The next step is to understand the impact of these interventions in the power sector. Since the focus of this work is on sustainability and SDGs, various characteristics such as renewable generation, efficient energy utilization, etc., are discussed. These measurable parameters are then linked to sustainable development goals to assess the implication of policy changes on SDGs.

4.1 Effect on Generation, Access to Electricity, and Losses

The policy interventions and legislation discussed have had corresponding effects on the Indian power sector. One key advantage of appropriate metering is the reduction in Transmission and Distribution (T&D) losses as it reduces the non-technical component of T&D losses due to unethical billing practices and theft (Khazaee et al. 2017). The data on T&D losses in India is shown in Fig. 4. There is a sudden increase in T&D losses reported from 1997 to 2002. This has been attributed to the success of the regulatory process, including the setting up of the SERCs and CERC during the term of the 9th five-year plan, supported by the 1998 amendment of the electricity act (Garg et al. 2003). The losses peaked in 2002 immediately after the introduction of the 2001 Electricity Bill, which made electricity metering compulsory and has declined henceforth. During the term of the 10th five-year plan (2002–2007), which tried to implement mandatory metering, the T&D losses continued to decline sharply and continued to do so through the terms of the 11th and 12th five-year plans. A clear correlation between the metering policy and the reduction in T&D losses can be seen here.

However, with the data available, it is not possible to fully establish causation as multiple other regulatory processes such as a nationwide grid interconnection (leading to more high-tension transmission, and hence loss reduction) (Power Grid Corporation of India 2021) as well as various tariff and technology modifications implemented by the SERCs and SEBs were carried out during the same timeframe (Shukla et al. 2004; Hasan and Gaba 2008).

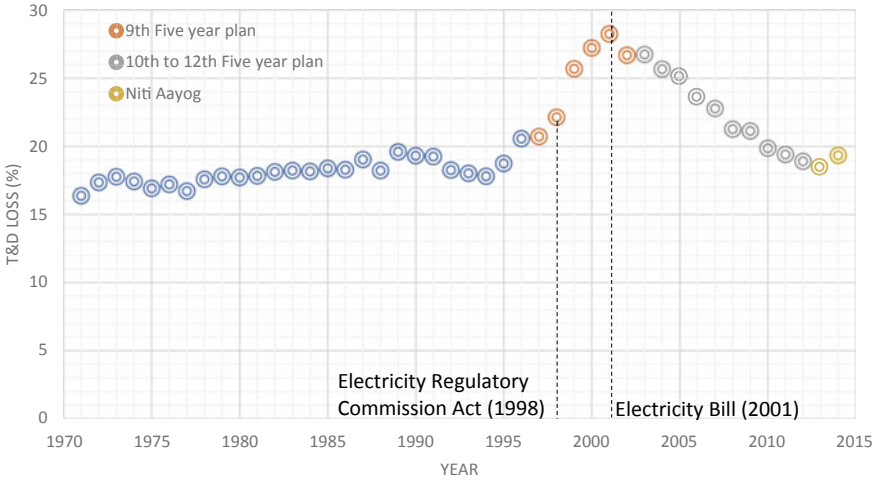

Fig. 4 Variation of T&D loss with time (The World Bank 2020)

In addition to making metering compulsory, the Electricity Act of 2003 also allowed for private sector participation in electricity generation through delicencing and encouraged renewable generation by insisting that at least 10% of the power supplied by suppliers and distributors to the consumers has to be generated using renewable and non-conventional sources of energy. The effects of the same can be observed in Fig. 5. It has also been shown that unbundling electricity utilities can improve the overall technical efficiency of the sector (Malik et al. 2011; Bobde and

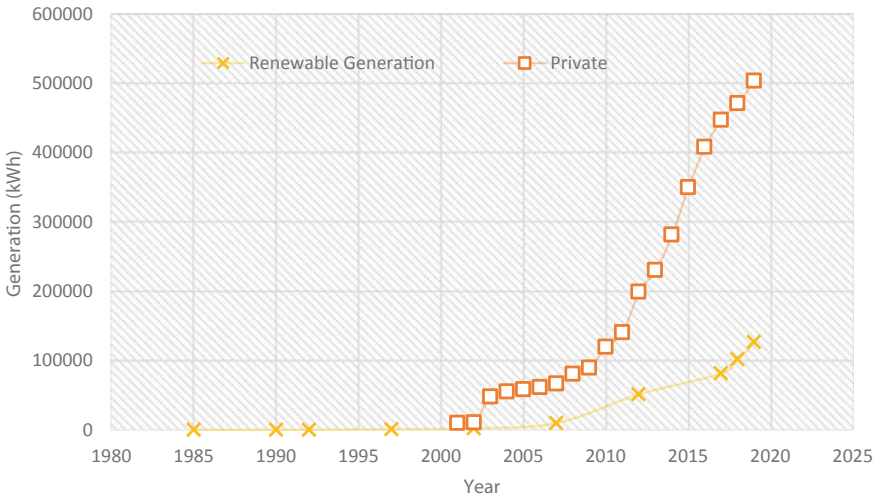

Fig. 5 Variation in Private generation and renewable generation over time (Mhaske 2019)

Tanaka 2020). This factor may also, in some part, contribute to the reduction of T&D losses as the Electricity Act of 2003 also initiated the unbundling process.

The rise in private generation and renewable-based generation is evident after 2003. These figures illustrate that the policies of the planning commission and supporting legislation have reduced T&D losses, improve renewable generation, and increased private participation in the power sector.

4.2 Impact on AT&C Losses

Policy interventions have largely been unsuccessful in improving the health of DISCOMS in India. Figure 6 illustrates the AT&C losses measured in a few selected states over time, and there is a minor reduction in the losses over the same timeframe. This could, at least in part, be attributed to the improvement in T&D losses illustrated in Fig 4.

The data presented above is at a state level for selected states. However, overall, there is an existing need to better the financial performance of DISCOMS across the country, as discussed by planning bodies (Niti Aayog 2019). Multiple interventions such as modifying tariff structures, metering, and payment methods can be employed to make the DISCOM operations more cost-effective. This again highlights a need to focus on better metering for billing efficiency.

4.3 Impact on Sustainable Development Goals

The relationship of these changes to the sustainable development goals is of relevance. The SDG indicator linked to electricity is SDG7, which aims at providing affordable and clean energy to all. This goal is measured by five targets, namely universal access to modern energy, increased global percentage of renewable energy, doubling the improvement in energy efficiency, promoting access, technology, and investments in clean energy, and expanding and upgrading energy services for developing countries. These are measured through six indicators. One indicator measuring universal access to modern energy is access to electricity. The near 100% electricity access achieved by India contributes to this indicator. In addition, providing access to electricity has been linked to a reduction in poverty, as indicated by SDG1 (End poverty in all forms). It improves access to information, which contributes to SDG 9 (Industrial innovation and infrastructure). It has also been linked to reducing violence, contributing to SDG 16 (Peace, justice, and strong institutions).

The focus on renewable energy also contributes to an increased global percentage of renewable energy. India has welcomed financial and technical aid for the development of its renewable sector. Investments in this sector have risen from 500 million in 2000 to over 2 billion in 2016 (SDG Tracker, n.d.). This is primarily due to the delicencing of the power sector as carried out by the Electricity Act of 2003 (Sinha 2011).

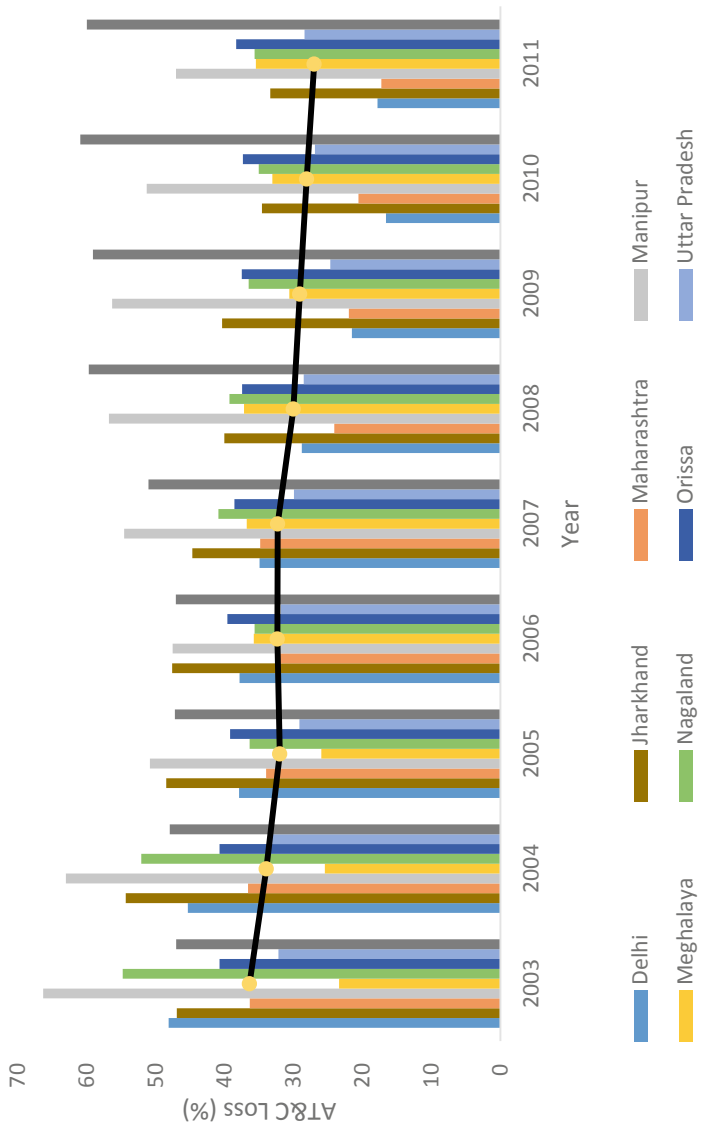

Fig. 6 AT&C losses across states (The World Bank 2020)

Besides, the minimum renewable purchase obligation of 10% imposed by the act also factors in. This reliance on renewable energy also improves air quality and reduces the number of deaths associated with pollution, thereby indirectly contributing to SGG 11 (sustainable cities and communities) and SDG 3 (Good health and well-being). Improved water quality due to reduction in pollution caused by generation aids in achieving SDG 6 (Clean water and sanitation).

The reduction in T&D losses brought about by effective metering and other measures has contributed to a reduction in energy intensity measured in terms of primary energy and GDP. The energy per unit GDP has fallen from 2.3kWh/$ to 1.31 kWh/$ between 1990 and 2015, further contributing to achieving SDG 7 (SDG Tracker, n.d.). Further improvements such as smart metering, especially in urban settings, are likely to contribute to SDG11, aiming to build sustainable cities and communities. More efficient utilization of energy has also been linked to better economic productivity, thereby influencing SDG 8 (Decent work and economic growth) and also contributes to higher agriculture productivity, which is linked to SDG 2 (Zero hunger).

Access to reliable and clean electricity is an integral part of the many sustainable development goals. The 2019 amendment to the Electricity Act necessitates smart metering for all consumers. This is aimed again at reducing the non-technical T&D losses, including theft, meter tampering, and non-payment. Also, smart metering has been linked to greater energy efficiency (Corbett et al. 2018), thus contributing further to SDG 7 (Fonseca et al. 2020). The linkages between SGDs discussed s not extensive, and SDG 7 likely contributes to multiple other SDGs (Fonseca et al. 2020). Smart metering and the energy efficiency associated with it can help achieve the development goals by 2030.

5 Incorporation of Smart Metering

Smart metering has been made compulsory in India in 2019 with the aim of reducing AT&C losses to 10% by 2027. As of now, 1.32 million smart meters have been installed across the country, primarily in Uttar Pradesh, Haryana, Bihar, and New Delhi Municipal Council, Delhi. The states of Andhra Pradesh, Telangana, and Haryana are also in the process of shifting to smart meters (Energy Efficiency Services Limited 2020b). The reports by Energy Efficiency Services Limited show a higher billing efficiency and lower AT&C losses (PTI, The Economic Times 2020). As of 2020, DISCOMS employing smart meters show a billing efficiency of 95%, and the tariff collected per customer has on average increased by 15–20% per month owing to a reduction in theft and improper billing, especially with the implementation of prepaid metering. (The Economic Times 2020).

It is expected that by removing theft and other illegal practices, especially from billing, an ecosystem providing better electricity access to disadvantaged sections of the population can be established (FE Bureau 2019). However, the implementation of smart meters requires significant capital investment, and many DISCOMS,

specifically those with little non-payment problems, are reluctant to invest in the same (Pillay and Jai 2019). Furthermore, the full effect of smart meters can be best realized when the infrastructure associated with them is upgraded to the same standard.

5.1 *Discussions and Comparative Assessment of International Initiatives*

The chapter so far discusses policy developments in India regarding the power sector. The impact of these policies on the power sector is also discussed. This section explores how these policies correlate with changes in other countries, at various stages of development. Broadly, the changes carried out in the electricity sector can be classified as regulatory changes (establishment of CERC and SERCs), restructuring of electricity boards into smaller entities, and allowing for private participation in the sector.

Regarding regulatory changes in India, establishing regulatory bodies at the central and state level resulted in more accurate metering of AT&C losses. However, no significant sector changes have occurred as most utilities continue to run at a loss (Pargal and Ghosh Banerjee 2014; Niti Aayog 2019). Pargal and Ghosh Banerjee (2014) noted that while regulatory bodies existed on central and state level, these were not independent of the respective governments, lacked autonomy, and therefore, had limited effect on transparency and accountability. Similar observations were made by Vivien and Briceño-Garmendia (2010) on Sub-Saharan African countries. The study noted that the performance of state-owned entities in the electricity sector did not perform any better with regulatory agencies unless independent audits were part of the framework. Similarly, (Hanretty and Koop 2013) observed that regulatory independence had a positive effect on the effectiveness of regulatory practices in western European economies. Therefore, it is likely that measures aimed at improving the autonomy of regulatory authorities will enhance their positive impact on the electricity sector.

Restructuring the power sector primarily involved unbundling the state-owned electricity boards. This process has largely been carried out in India. Studies show that unbundling has increased the technical efficiency of generation, transmission, and distribution, especially in smaller states (Bobde and Tanaka 2020). Regarding transmission, there is an overall reduction in technical losses after the implementation of the 2003 Electricity Act, as illustrated in Fig. 4. However, it has also been argued that unbundling does not improve the overall performance of the sector as unbundling brings about regulatory and operational challenges of its own (Pollitt 2008). In India, while an improvement in technical performance can be noted, the economic health of utilities has not improved due to unbundling. The effects of privatization are yet to be felt on a national level as private players are largely limited to cities such as Mumbai, New Delhi, and Kolkata.

With the compulsory metering implemented since the Electricity Act, a decrease in overall T&D losses has been observed. There are several developing and underdeveloped countries with significantly high T&D losses than India. For example, Nepal has reported T&D losses of over 32%, while Libya has over 69%. The policies adopted by India at various stages of development can be of use in these countries (IEA Statistics 2018). Nepal has, in 2017, established an electricity regulatory commission and shifted toward implementing a smart metering policy nationwide. Similarly, most South American countries are shifting toward smart metering policies and developing the necessary infrastructure (Nhede 2018).

The implementation of smart metering in India and similar developing countries is a cost-intensive exercise, and it is useful to look at lessons from more developed economies regarding the effects of smart metering on their electricity sector. Smart metering has been implemented successfully in many countries. For example, Sweden has had 100% smart metering since 2009, Italy records 95% penetration as of 2011, and Finland has over 97% smart metering as of 2013 (Zhou and Brown 2017). Similarly, many EU members are at various stages of metering implementation. Studies on countries with high smart metering penetration show that implementation of smart metering will face institutional barriers, financial barriers, and challenges related to social acceptance. However, these can be overcome by appropriate interventions (Zhou and Brown 2017). The institutional barrier is best overcome by making smart metering compulsory and setting short-term and long-term targets for deployment completion. Similarly, allowing the distribution companies to recover the cost of metering from consumers will help mitigate the financial cost of metering. In cases where the cost was not passed on to consumers (such as Germany), the implementation was less successful. Regarding data privacy, it is observed that while it became a concern in some countries, there has been little public discussion on the topic in others. In most cases (such as with Germany and Finland), governments have implemented the necessary legislation or regulatory measures for data privacy (Zhou and Brown 2017), and in the case of the Netherlands, allowed users a greater degree of control over meter use (Cuijpers and Koops 2013).

Studies have also noted that governments can incentivize private companies through subsidies to develop the technology for smart metering. This, along with providing coherent regulatory frameworks, can help private players implement smart metering technology effectively (Giest 2020). Among smart meters, prepaid meters are of great relevance to India, given that they can reduce theft and avoid the need for meter readings from remote locations. Such meters have been successfully piloted in various parts of the country (Deloitte Touche Tohmatsu India Private Limited 2011). The United Kingdom is the only European country to employ prepaid meters on a significant scale, accounting for 18% of electricity meters in the country. Studies in the UK show that nearly 90% of consumers are happy with their prepaid meters, as it allows them to see their in-home display, use multiple tools to top up the balance, and even avail emergency credit if needed (Dept. of Business, Energy, and Industrial Strategy 2019). Such features may also make prepaid meters more acceptable in India, especially among economically weaker sections of society.

Comparable economies that have implemented prepaid metering include South Africa and Bangladesh. The 4 million prepaid meters installed in South Africa allowed for less billing infrastructure and manpower, thereby reducing the meter reading cost and achieving better revenue recovery. It is reported that prepaid meters helped reduce the profitability gap between richer and poorer customers (Jack and Smith 2016). South Africa also implemented large-scale educational advertisement programs related to smart meters to make customers aware of how to use the technology and regarding problem rectification mechanisms. Customers reported being able to better regulate their energy use once prepaid metering was implemented. Pilot studies on domestic consumers in Bangladesh also produce a similar response (Deloitte Touche Tohmatsu India Private Limited 2011), highlighting the viability of smart metering in developing economies.

6 Conclusion and Policy Implications

This chapter presents an overview of the Indian power sector, analyzing the policy and legislation that shaped this sector. The effects of various interventions have also been discussed in detail. It is seen that there are positive reflections to specific interventions such as the reduction in T&D losses of increased renewable-based generation. However, given the need for efficient energy usage and better billing efficiency, further advancements are necessary.

Recent interventions in terms of compulsory smart metering is a step in this direction. The 2019 amendment to the Electricity Act necessitates smart metering for all consumers. This is aimed again at reducing the non-technical T&D losses, including theft, meter tampering, and non-payment. In addition to the improvement in billing efficiency, smart metering interventions can contribute to energy efficiency and affordability.

As discussed, any improvement in the power sector also influences other sustainable development goals. While the implementation of smart metering can be challenging, it can be mitigated through legislative, policy, and educational interventions, as evidenced by the experiences of countries that have already implemented smart metering. The linkages of SDG 7 to various development goals have already been discussed in this chapter. A summary of interventions and their impact on the power sector and various indicators of SDG 7 is illustrated in Table 1.

There is general agreement that smart metering has been associated with energy savings, better customer experience, and financial gains (Energy Watch 2018). While the implementation is likely to face challenges related to institutional frameworks, the financial cost of installing meters, and the social acceptability of new technology, literature shows that with adequate regulatory interventions such as compulsory metering and time-specific targets, the institutional barriers can be overcome.

Table 1 Impact of interventions

	Focus on improved generation and electrification (1951–1966)	Electricity Regulatory Commission Act (1998)	Electricity Act (2003)	Electricity Act Amendment (2019)
Access to electricity	Yes			
Privatization of DISCOMS			Yes	
Attempt to improve DISCOM health		Yes	Yes	Yes
Private generation			Yes	
Metering		Yes	Yes	Yes
Smart meters				Yes
SDG Indicator 7.1.1 (Access to electricity)	Yes			
SDG Indicator 7.2.1 Renewable energy			Yes	
SDG Indicator 7.3.1 Energy efficiency		Yes	Yes	Yes

Funding The research presented in this paper is part of a research project entitled "What is in a meter? Working towards efficient, socially inclusive and environmentally sensitive energy and water infrastructures in the Global South." The project is funded through the British Academy's Urban Infrastructures of Well-Being Programme 2019, supported under the Global Challenges Research Fund (Reference: UWB190097). The authors wish to acknowledge the British Academy for their support.

References

Afolayan OT, Okodua H, Matthew O, Osabohien R (2019) Reducing unemployment malaise in Nigeria: the role of electricity consumption and human capital development. Int J Energy Econ Policy 9(4):63–73

Ahmad S, Mathai MV, Parayil G (2014) Household electricity access, availability and human well-being: evidence from India. Energy Policy 69:308–315

Ali S (2018) The future of Indian electricity demand: how much, by whom, and under what conditions? Asian Development Bank Institute. think-asia.org/handle/11540/9685. Accessed 30 Jan 2021

Bobde SM, Tanaka M (2020) Structural reforms and technical efficiency in the Indian electricity distribution sector. Asia-Pacific J Oper Res (APJOR) 37(02):1–36

Brecha RJ (2019) Threshold electricity consumption enables multiple sustainable development goals. Sustainability 11(18):5047
Central Electricity Authority (2019) Growth of Electricity Sector in India from 1947–2019. cea.nic.in/reports/others/planning/pdm/growth_2019.pdf. Accessed 30 Jan 2020
Colglazier W (2015) Sustainable development agenda: 2030. Science 349(6252):1048–1050
Corbett J, Wardle K, Chen C (2018) Toward a sustainable modern electricity grid: the effects of smart metering and program investments on demand-side management performance in the US electricity sector 2009–2012. IEEE Trans Eng Manage 65(2):252–263
Cuijpers C, Koops B-J (2013) Smart metering and privacy in Europe: lessons from the Dutch case European data protection: coming of age. Springer, pp 269–293
Deloitte Touche Tohmatsu India Private Limited (2011) Evolving measures for the effective implementation of Prepaid Metering in the country: report to 'Forum of Regulators' on Pre-paid Meter. forumofregulators.gov.in/Data/Reports/Evolving%20measures%20for%20the%20effective%20implementation%20of%20prepaid%20metering%20in%20the%20country.pdf. Accessed 30 Jan 2021
Dept. of Business, Energy, and Industrial Strategy (2019) Smart metering implementation programme a report on progress of the realisation of smart meter consumer benefits. assets.publishing.service.gov.uk. Accessed 30 Jan 2021
Dsouza S (2019) 100% electrification: assessing ground reality. The Brookings Institution. brookings.edu/opinions/100-electrification-assessing-ground-reality/. Accessed 30 Jan 2021
Energy Efficiency Services Limited (2020a) About smart meters. eeslindia.org/content/raj/eesl/en/Programmes/Smart-Meters/about-smart-meters.html. Accessed 30 Jan 2021
Energy Efficiency Services Limited (2020b) Smart Meter National Programme (SMNP). eeslindia.org/smnp.html. Accessed 30 Jan 2021
Energy Watch (2018) Smart meter success stories from around the world. energywatch.com.my/blog/2018/03/19/smart-meter-success-stories-from-around-the-world/. Accessed 30 Jan 2021
FE Bureau (2019) Smart meters help DISCOMS trim losses in Delhi, Meerut. https://www.financialexpress.com/economy/smart-meters-help-DISCOMS-trim-losses-in-delhi-meerut/1659896/ Accessed 30 Jan 2021
Fonseca LM, Domingues JP, Dima AM (2020) Mapping the sustainable development goals relationships. Sustainability 12(8):3359
Garg A, Kabra M, Kacker R (2003) Regulatory Reforms in India: effectiveness, efficiency, and impacts. The Energy and Resources Institute (TERI)
Giest S (2020) Do nudgers need budging? A comparative analysis of European smart meter implementation. Govern Inf Q 37(4):101498
Hanretty C, Koop C (2013) Shall the law set them free? The formal and actual independence of regulatory agencies. Regul Gov 7(2):195–214
Hasan S, Gaba V (2008) Power sector reforms in India: a case study from Delhi. Int J Regul Gov 8(1):31–67
IEA Statistics (2018) Electric power transmission and distribution losses (% of output). data.worldbank.org/indicator/EG.ELC.LOSS.ZS. Accessed 30 Jan 2021
International Energy Agency (IEA) (2019) World Energy Outlook 2019, Annexes; BP Statistical Review of World Energy 2019
IISD (2017) India: Interlinking the SDGs through Electricity Access. sdg.iisd.org/commentary/guest-articles/india-interlinking-the-sdgs-through-electricity-access/. Accessed 30 Jan 2021
Jack BK, Smith G (2016) Charging ahead: prepaid electricity metering in South Africa (No. w22895). National Bureau of Economic Research
Kemmler A (2007) Factors influencing household access to electricity in India. Energy Sustain Dev 11(4):13–20
Khazaee A, Safa HH, Ghasempour M, Delavari H (2017) Distribution loss reduction in residential and commercial pilots by using AMI system. CIRED-Open Access Proc J 2017(1):1711–1714
KiranKumar M, Sairam KV, Santosh R (2013) Methods to reduce aggregate technical and commercial (At&C) losses. Int J Eng Trends Technol 4(5):1501–1505

Kumar A, Chatterjee S (2012) Electricity sector in India: policy and regulation. OUP Catalogue
Malik K, Cropper M, Limonov A, Singh A (2011) Estimating the impact of restructuring on electricity generation efficiency: the case of the Indian thermal power sector (No. w17383). National Bureau of Economic Research
Mhaske P (2019) Growth of electricity sector in India from 1947–2019. Government of India, Ministry of Power, Central Electricity Authority
Ministry of Power (2020) Draft Amendment in the Electricity Act, 2003 to Introduce key Reforms in the Power Sector. pib.gov.in/PressReleasePage.aspx?PRID=1615781. Accessed 30 Jan 2021
Ministry of Power (2003) Electricity Act, 2003. https://powermin.nic.in/en/content/electricity-act-2003. Accessed 30 Jan 2021
Nhede N (2018) Smart grid development in Brazil and other South American countries. smart-energy.com/industry-sectors/policy-regulation/smart-grid-brazil-south-america-frost-sullivan/. Accessed 30 Jan 2021
Niti Aayog (2019) Diagnostic study of the power distribution sector—final report. Niti Aayog, Government of India and CRISIL Infrastructure Advisory, Gurgaon
Niu S, Jia Y, Wang W, He R, Hu L, Liu Y (2013) Electricity consumption and human development level: a comparative analysis based on panel data for 50 countries. Int J Electr Power Energy Syst 53:338–347
Pargal S, Ghosh Banerjee S (2014) More power to India: the challenge of electricity distribution. The World Bank
Pillay A, Jai S (2019) Not all state power distribution cos see financial benefit in smart meters. business-standard.com/article/economy-policy/not-all-state-power-distribution-cos-see-financial-benefit-in-smart-meters-119110601876_1.html. Accessed 30 Jan 2021
Planning Commission (1951) First five year plan. Planning Commission, Government of India, Delhi
Planning Commission (1956) Second five year plan. Planning Commission, Government of India, Delhi
Planning Commission (1962) Third five year plan. Planning Commission, Government of India, New Delhi
Planning Commission (1970) Fourth five year plan. Planning Commission, Government of India, New Delhi
Planning Commission (1976) Fifth five year plan. Planning Commission, Government of India, New Delhi
Planning Commission (1980) Sixth five year plan. Planning Commission, Government of India, New Delhi
Planning Commission (1985) Seventh five year plan. Planning Commission, Government of India, New Delhi
Planning Commission (1992) Eighth five year plan. Planning Commission, Government of India, New Delhi
Planning Commission (1997) Ninth five year plan. Planning Commission, Government of India, New Delhi
Planning Commission (2002) Tenth five year plan. Planning Commission, Government of India, New Delhi
Planning Commission (2007) Eleventh five year plan. Planning Commission, Government of India, New Delhi
Planning Commission (2012) Twelfth five year plan. Planning Commission, Government of India, New Delhi
Pollitt M (2008) The arguments for and against ownership unbundling of energy transmission networks. Energy Policy 36(2):704–713
Power Grid Corporation of India (2021) One nation-one grid: powergrid. Ministry of Power. powergridindia.com/one-nation-one-grid. Accessed 30 Jan 2021
Power Grid Corporation of India (2006) IEGC: powergrid. powergridindia.com/iegc. Accessed 30 Jan 2021

Saini S (2018) Evolution of Indian power sector at a glance. Natl J Multidisc Res Manage 3(1):275–278
Salahuddin M, Gow J, Ozturk I (2015) Is the long-run relationship between economic growth, electricity consumption, carbon dioxide emissions and financial development in Gulf Cooperation Council Countries robust? Renew Sustain Energy Rev 51:317–326
SDG Tracker (nd) Goal 7: affordable and clean energy—SDG tracker. sdg-tracker.org/energy. Accessed 30 Jan 2021
Shahi RV (2006) Indian power sector: challenge and response: compilation of papers presented during 1991–2001. Excel Books India
Shobande OA (2020) The effects of energy use on infant mortality rates in Africa. Environ Sustain Indic 5:100015
Shukla PR, Biswas D, Nag T, Yajnik A, Heller T, Victor DG (2004) Impact of power sector reforms on technology, efficiency and emissions: case study of Andhra Pradesh, India. Program on Energy and Sustainable Development
Singh RK (2019) India to achieve 100% household electrification by March 31, Sustainability Outlook. sustainabilityoutlook.in/news/india-achieve-100-household-electrification-march-31-r-k-singh-763978. Accessed 30 Jan 2021
Sinha A (2011) Renewable energy in India: scope for foreign investment. Alternative Energy eMagazine
The Economic Times (2020) DISCOMS generate 95pc billing efficiency due to smart meters. economictimes.indiatimes.com/industry/energy/power/DISCOMS-generate-95pc-billing-efficiency-due-to-smart-meters/articleshow/75694995.cms?from=mdr. Accessed 30 Jan 2021
The World Bank (2020) Data catalogue: world development indicators. datacatalog.worldbank.org/. Accessed 30 Jan 2021
Tully S (2006) The human right to access electricity. Electr J 19(3):30–39
Varghese G, Eapen LM (2016) Power sector in India-recent challenges and measures undertaken. Asian J Res Bus Econ Manage 6(1):33–46
Vivien F, Briceño-Garmendia C (2010) Africa's infrastructure: a time for transformation. In: Foster V, Briceno-Garmendia C (eds) Africa's infrastructure: a time for transformation, Africa Development Forum, World Bank, Washington DC
Zaheeruddin MM (2014) Smart grid roadmap for India. Adv Res Electr Electron Eng 1(2):30
Zhou S, Brown MA (2017) Smart meter deployment in Europe: a comparative case study on the impacts of national policy schemes. J Clean Prod 144:22–32

Chapter 9
Data-Driven Urban Energy Modeling: Global Trends and India

Chirag Deb

1 Introduction

The rate of urbanism foreseen in the next few decades far supersedes any seen in the known history. By 2050, an additional 2.5 billion people will be living in cities with a majority of this growth taking place in Asia and Africa (Burdett and Rode 2018). Moreover, 80% of the urban infrastructure that will exist in 2050 has yet to be built. The current pathways to urban development are a significant contributor to global emissions. According to the International Energy Agency's Energy Technology Perspectives 2020, the worst consequences of climate change can only be avoided if the global energy system rapidly reduces its emissions ("Energy Technology Perspectives 2020" 2020). Cities are one of the largest energy consumer groups and emitters of greenhouse gases, and therefore, urban areas offer a large potential for reducing energy consumption and emissions (Sola et al. 2020). Cities consume about 75% of global primary energy and emit between 50 and 60% of the world's total greenhouse gases ("Energy|UN-Habitat" 2021). Considering the indirect emissions generated by urban inhabitants, this figure rises to approximately 80%. With increasing electrification and decentralization of urban energy systems involving sectors such as buildings, mobility, and renewable energy sources, there is an immediate need to develop processes and methodologies that are flexible in capturing the complex interactions between these evolving sectors. In this regard, the field of data-driven analytics and modeling has shown extensive promise (Deb and Schlueter 2021). The research in the field of data-driven urban energy modeling is still growing with current publications limited to specific case studies and model development on case-specific datasets. Although generalizing these models is challenging, there is every hope that advancement in urban data collection technologies,

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P. Banerji and A. Jana (eds.), *Advances in Urban Design and Engineering*, Design Science and Innovation, https://doi.org/10.1007/978-981-19-0412-7_9

availability of open data sources and progress in data-driven modeling methodologies will pave way for energy-neutral urban development in the coming decades.

1.1 Research in UBEM and Data-Driven UBEM

Urban Building Energy Modeling or (UBEM) are bottom-up energy models that are used to model entire neighborhoods and cities to understand what future effects comprehensive energy retrofitting programs and energy supply infrastructure may have (Reinhart and Cerezo Davila 2016). UBEM is part of the larger field of exploration called the "urban micro-simulation" which comprises of performance assessment of other urban-related factors such as daylight availability and walkability (Robinson 2011; Perez and Robinson 2012). Recent literature has witnessed a surge in publications related to UBEM when compared to individual building energy modeling. Due to its versatility, UBEM is expected to become a key planning tool for utilities, municipalities, and urban planners. Conventionally, UBEM is based on physics-based thermal modeling of individual buildings wherein heat-balance equations model the thermal behavior and energy consumption. This requires information and data on several aspects such as climate, building type and geometry, construction type and occupancy, and usage schedules. In their review on urban building energy modeling (UBEM) approaches, Ali et al. have broadly categorized the approaches as Top-down and Bottom-up modeling approaches (Ali et al. 2021). According to Kavgic et al., top-down modeling primarily focuses on statistical energy use and historical data (Kavgic et al. 2010). Whereas, the bottom-up approaches provide useful insights to policy makers and are also known as the engineering or simulation methods. These apply simulation techniques using building characteristics, climatic, and system data to calculate the end-use energy consumption. Current research has also witnessed the increased use of measured data to calibrate and even develop data-driven energy models for buildings (Deb et al. 2021; Sigrist et al. 2019). The development in sensing technologies is enabling the increased use of measured data of building factors in modeling approaches (Frei et al. 2020, 2021). At the same time, a number of open source data sets for past and future climate are also becoming available (Crawley et al. 1999). Information on the building geometry and construction is usually obtained by referring to engineering drawings and building plans. This is often a tedious and time-consuming process. In addition, the changes in the building's physical and operational characteristics are seldom captured in building drawings. This has often led to the performance gap, which is the difference between expected (or estimated) and actual (or measured) energy consumption. There are many studies that have documented the performance gap and looked into the contributing factors (Cozza et al. 2020; Mutani and Todeschi 2021). In view of these factors, data-driven UBEM has gained momentum in recent years.

Data-driven UBEM is based on machine learning methods for modeling the energy behavior of neighborhoods and cities using streams of measured data sets. Although UBEM is always based on some form of input data, data-driven UBEM

makes use of measured, time series data of building factors such as energy consumption, occupancy-presence, renewable energy generation, etc. These help in reducing the input assumptions and provide an accurate representation of the urban energy systems. The modeling methodologies include Artificial Neural Networks, Deep Neural Networks, Support Vector Regression, Decision Trees, etc. However, these models are infamous for being governed by the training data sets and are, therefore, limited to specific cases. An important point to note is that UBEM is increasingly being combined with optimization models to derive the best case scenarios (Dias et al. 2019; On the Modelling and Optimization of Urban Energy Fluxes 2009). Such fruitful integration is expected to play a greater role in planning and operating cities in the coming decades. Additionally, the increasing penetration of renewable energy into the urban context opens up opportunities for greater energy integration. At the same time, this introduces new dynamics into the energy systems. To meet these challenges, some researchers have introduced the "Energy Hub" concept wherein an efficient matching of supply and demand of different energy streams using optimization approaches are performed (Bollinger et al. 2018; Wu et al. 2017). The next section presents the existing data-driven urban energy modeling approaches and discusses three case studies in detail.

2 Data-Driven UBEM Approaches

Data-driven modeling approaches are models based on either simulated or measured data from buildings and urban systems. They can be divided into statistical and artificial intelligence methods (Fig. 1). These models can be used for a number of useful purposes including benchmarking, energy demand prediction, forecasting, benchmarking, and classifying buildings (Ahmad et al. 2018; Deb and Lee 2018; Deb et al. 2016, 2018). The two important aspects for data-driven UBEM modeling are:

- the availability (Quality and Quantity) of data, and
- Modeling techniques.

The data requirements vary based on the target of the model. For example, if a model is required to forecast the future energy demand of an entire city without any

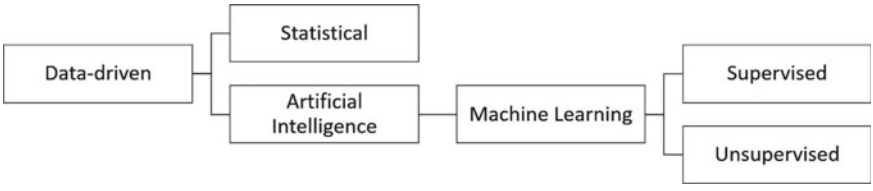

Fig. 1 Data-driven modeling techniques for modeling building energy at urban scale (Ali et al. 2021)

input data on the geometry of the buildings, then the model would need to rely on other data sources, such as the past energy consumption data of the city. The model thus developed could be a univariate time series forecasting model or can be combined with the available climate data to develop a bivariate model, wherein the effect of the climate on energy consumption can be studied. Kazmi et al. have reviewed the existing, open source data sets for residential and commercial buildings (Kazmi et al. 2021). They have noted that detailed data from space conditioning (heating, cooling, ventilation) is limited when compared with electricity data. Additionally, detailed temperature values inside the space are seldom recorded, thereby limiting the usefulness of the data set. The availability of climate data is rather robust and comprises of various open data sources and local weather stations. Since the dependency of the energy demand in buildings on climatic conditions is indispensable, the availability of climate data to develop data-driven models is highly advantageous.

In recent urban energy studies, machine learning algorithms have been widely used compared to traditional statistical techniques. Machine learning models provide the most accurate predictions possible without necessarily establishing the physical basis for the predictions. Nonetheless, these have been found to be extremely beneficial in the prediction and classification of urban energy demand and consumption. There is the widespread application of machine learning in UBEM and some of the main case studies and models have been collated by Ali et al. as seen in the table (Table 1).

However, we take a look into three case studies in detail. The first is a city-scale energy model which has been developed using a relatively smaller sample size. Such data sets are usually obtained or made available by city authorities. Much research has been published that looks into the most relevant features and models using these data sets have been published. The second case study proposed a hybrid approach wherein simulated energy consumption data is combined with measured data and data-driven models are developed using this integration. The third case study proposes an automatic framework to optimize urban design with an UBEM. This study too combines the strengths of simulation and machine learning, wherein the machine learning models are trained on data sets that are results of an optimization algorithm.

2.1 Case Study 1: City-Scale Prediction Model

This research work is published by Kontokosta and Tull (2017). In this study, the authors attempted to develop a data-driven general model that is applicable to analyze the building stock of an entire city. They employ data-driven statistical models to predict the energy use of 1.1 million buildings in New York City using the physical, spatial, and energy use attributes of a subset derived from 23,000 buildings.

The dataset, which is obtained from the New York City Mayor's Office of Sustainability includes detailed information on time series data on energy use by fuel type and source and building occupancy, use, and physical descriptors from 2010 to 2015.

Table 1 Summary of data-driven bottom-up urban building energy modeling studies (Ali et al. 2021)

Projects/paper	Model	Application	Target users	Developer	References
UrbanFootprint	Statistics	Mapping	Urban planners, policy makers	LBNL	The Ultimate Technical Guide to UrbanFootprint (2021)
DUE-B	Classification and Regression Tree	Benchmarking	Policy makers	Urban Informatics Lab	Yang et al. (2018)
CoBAM	Statistics	Energy analysis	Policy makers, practitioners and local communities	EPFL	Zhao et al. (2011)
DUE-S	Residual network model	Energy Analysis	Policy makers	Urban Informatics Lab	Nutkiewicz et al. (2018)
UEUM	k-NN, and ANNs	Energy analysis	Designers, planners, and policy makers	Illinois Institute of Technology	Abbasabadi et al. (2019)
GREEN grading system	XGBoost	Benchmarking	Policy makers	New York University	Papadopoulos and Kontokosta (2019)
Dall'O' et al	Regression	Classification	Local administrators	BEST Politecnico di Milano	Dall'O' et al. (2012)
Pedersen et al	Regression	Load prediction	Urban planners	Norway, NTNU	Pedersen et al. (2008)
Mastrucci et al	Multiple linear regression	Urban planning	Urban planners	CRTE	Mastrucci et al. (2014)
CRECM	Statistical method	Energy Analysis	City policy makers	SCUT	Wang et al. (2020)
Rahman et al	Recurrent neural network	Forecasting	Planning	SSESLab, University of Utah	Rahman et al. (2018)
Robinson et al	Gradient boosting model, Linear regression, SVM	Energy analysis	City planners and policy makers	Georgia Tech	Robinson et al. (2017)

(continued)

Table 1 (continued)

Projects/paper	Model	Application	Target users	Developer	References
Kontokosta et al	Linear regression, random forest, and support vector regression	Energy analysis	Policy makers	New York University	Kontokosta and Tull (2017)
Williams et al	Linear regression, regression trees, and MARS	Energy analysis	Policy makers	TSERI	Williams and Gomez (2016)
Ali et al	Deep Learning	Retrofit analysis	Urban planners and energy policy makers	University College Dublin	Ali et al. (2020)

The energy use is reported by total consumption and by energy use intensities for both site and source energy, while also being normalized for the weather. The data-driven models including Linear regression (OLS), random forest, and support vector regression (SVM) algorithms are first trained on the city's energy benchmarking data and then used to predict electricity and natural gas use for every property in the city. Data for the calendar year 2014 were used in this study.

The results show that the general model produced from the data sample can produce reasonably accurate predictions of energy use across the city at the building scale (Fig. 2). The map of New York City with the predicted electric energy use intensity for each property (Kontokosta and Tull 2017). The easily interpretable OLS model performed best overall, when considering both in-sample and out-of-sample prediction results. The authors also found that building use, size, and morphology emerge as robust predictors of energy use. Additionally, the building type, whether office, retail, or other, impacts electric and natural gas energy use intensity (EUI). They also found that larger buildings are less energy intensive, while taller buildings have higher EUI. The findings create opportunities for data-driven energy policy evaluation in cities. Such models can be used to predict retrofitting and energy savings opportunities at scale and estimate future energy demand based on anticipated changes to future urban development.

2.2 Case Study 2: DUB-S

The Data-driven Urban Energy Simulation (DUE-S) models urban energy use on multiple spatial and temporal scales (Nutkiewicz et al. 2018). DUB-S is a result of

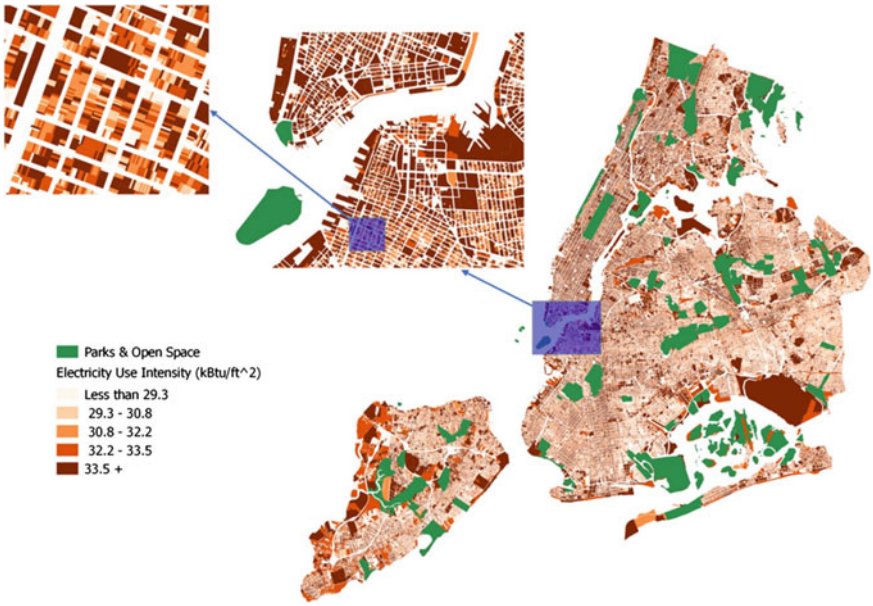

Fig. 2 The map of New York City with the predicted electric energy use intensity for each property (Kontokosta and Tull 2017)

accounting for the inter-building energy dynamics and urban microclimate factors that can have a substantial impact on building energy use. DUB-S integrates a network-based machine learning algorithm (ResNet) with building engineering simulation. Its developers have realized that pure data-driven approaches lack the ability to accurately estimate the energy implications of early-stage design or new retrofits to buildings that are not included in the training dataset. Therefore, the authors present a hybrid model that utilizes simulated time series energy demand data and combines it with measured energy consumption data to train a ResNet model. Here, the inputs are the time series structured data and the output are the measured metered data. These inputs are simulated by using available data sets on building geometry, weather data building physical data. The entire methodological process can be seen in Fig. 3.

This process is applied to a case study consisting of 22 university buildings located in California, USA. The results show that the spring and fall months show a trend in underestimating electricity use while winter and summer ones tend to overestimate. It is also observed that during spring and fall, the variance of the Mean Absolute Percentage Error (MAPE) is smaller than in other months. This indicates that the model performs better when providing a conservative estimation of electricity use.

This study is a fine example of combining simulated and measured data to train and build a machine learning model. Although the researchers have highlighted several limitations, the proposed methodology is a step forward in accounting for the energy dynamics and interdependencies of buildings in an urban context, thereby providing a significant opportunity to create more accurate multi-scale urban energy models.

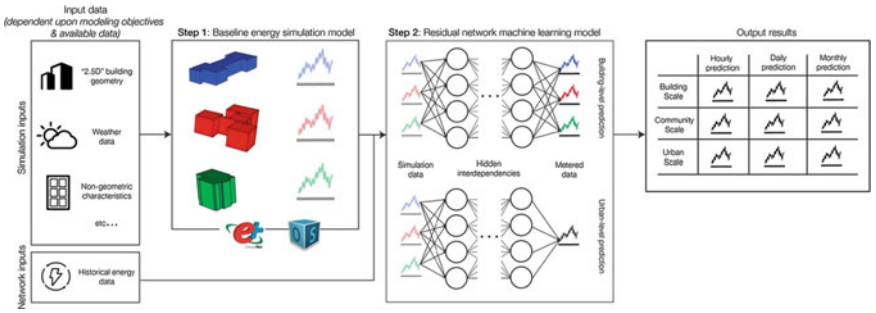

Fig. 3 The DUE-S modeling framework, wherein step 1 uses information from existing data sources to create individual building energy simulations, and step 2 employs a residual network model (ResNet) to predict the metered energy use by learning the uncertainties of the building energy simulations and their surrounding urban environment (Nutkiewicz et al. 2018)

2.3 Case Study 3: From Simulation to Data-Driven Approach

This case study is extracted from the research work of Wang et al. (2021). The study proposes an automatic framework to optimize urban design using an urban building energy model. Like the previous case study, this study too combines the strengths of both simulation tools and machine learning models, wherein the machine learning models are trained on simulated data sets. This study not just trains the machine learning models on simulated data, but also the outputs of an optimization algorithm. Three optimization goals were defined, which are, the maximum solar energy utilization, the solar lighting of the first floor, and the minimum building energy demand. Real urban morphology was integrated into the modeling process by generating 3D building blocks in Rhino. The energy calculations were performed using the Ladybug module and the optimization was done using the Wallace module. The machine learning training was done using the Long short-term memory network (LSTM) approach. LSTM was adopted for the time series data sets as it contains the cell state to memorize long-term dependencies. All the steps included in the methodology can be seen in Fig. 4.

The results of the optimization show that the annual solar PV power generation of the block is mainly concentrated in the interval above 2.1 × 10e6 kWh/yr, showing a good PV power generation. The total EUI of buildings is evenly distributed around 70.4 kWh/m^2*yr, while the value of solar hours is concentrated around 7.14 h. According to the optimization process, to increase the power generation of the block, multi-story buildings or low-rise buildings with a larger roof area were selected. However, these two types of buildings often require higher energy demand. The optimization algorithm also tried to reduce the scattered degree of the buildings to increase the PV power generation. This too reduced the inter-building shading and increased building energy use. After several iterations, the optimized solutions were captured and were divided into five clusters (Fig. 5).

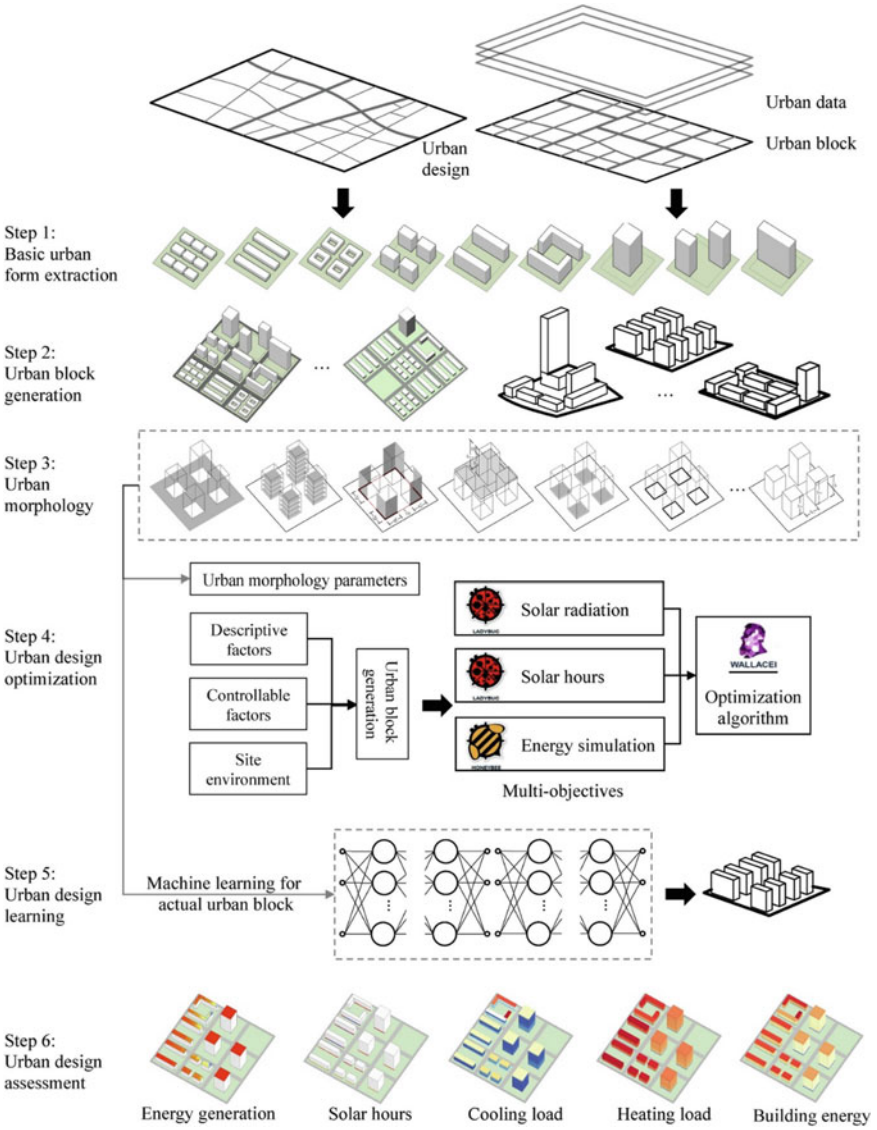

Fig. 4 Low-energy urban design framework for integrating urban morphology to urban design from simulation to a data-driven approach (Wang et al. 2021)

The LSTM model was then applied to learn the energy performance of 41 actual urban blocks through urban morphology. It is found that LSTMs can achieve good accuracy in all predictions, although the results indicate that in most urban blocks, the predicted or designed energy demand is higher than actual energy use. The authors mention that this is because the operative energy of buildings is influenced

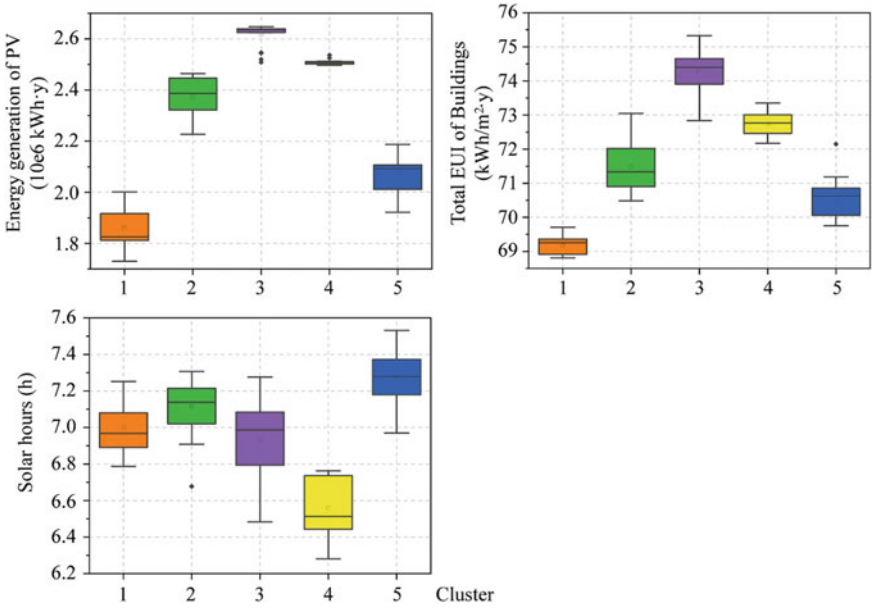

Fig. 5 Results of energy generation of PV, total EUI of buildings, and solar hours in five urban design clusters (Wang et al. 2021)

by many factors, such as the occupant's behavior. Such a study can facilitate the real application of this framework to provide different reference scenarios in urban design. It can also be used to provide technical support for new urban design or urban renewal projects by developing models on existing urban morphological and energy data sets.

3 Urbanization and Energy in India

The International Energy Agency (IEA) recognizes urbanization and industrialization as the key drivers for India's current and future energy sector (IEA 2021). It also foresees that an estimated 270 million people will be added to India's urban population by 2040. This increase in urban population is the equivalent of adding 13 cities the size of Mumbai by 2040. For India, the definition of the urban area is a place having a minimum population of 5,000 and a minimum density of 400 persons per square kilometer, and 75% plus of the male working population employed in non-agricultural activities (Census of India 2011 (2012)). Additionally, places administered by a municipal corporation, cantonment board or notified town area committee are automatically considered urban areas.

Energy consumption in India has more than doubled since 2000. India's continued industrialization and urbanization will make huge demands on the energy sector,

although its energy use per capita is well under half the global average. An increase in urbanization also increases the demand for electricity and mobility in urban areas. To meet this end, the last decade has been remarkable for India's power sector when synchronization of the grid was achieved. This makes India the fourth-largest electricity market in the world, after the United States, China, and the European Union. As per the Sustainable Development Scenario (SDS) by the IEA, a considerable increase in electric mobility and renewable energy sources is required in the coming decades. Alongside improved air quality and enhanced energy access, the SDS also sees India reach an early peak in energy-related CO_2 emissions and a rapid subsequent decline, thereby increasing the possibility of achieving net zero emissions by the mid-2060s.

There are several steps to be uncovered before this transition is made. In relation to the urban energy analysis, the first step is the development of modeling methodologies that can simulate the various independent and target variables involved in the urban energy nexus. Since electricity is foreseen as the topmost primary end-use energy in the future, the UBEM has to be flexible to link buildings with other sectors such as renewable energy and transportation. In contrast, currently, there are only a few research bodies and universities that are working on UBEM for Indian cities. Notably, the CEPT University (Centre for Environmental Planning and Technology) in collaboration with other national and international universities has been working on exploring the applications of UBEM for India. The newly formed Centre for Urban Science and Engineering (CUSE) at the Indian Institute of Technology Bombay (IIT Bombay) also envisages itself to be a key player in the future of UBEM in India. Since data-driven UBEM are strongly dependent on the availability and quality of data sets, the next section takes a summarized look into the available data sets and published UBEM models in the context of India.

3.1 UBEM and Energy Data Sets in India

UBEM research in India is in its nascent stage. Recent advancement in energy in building research has witnessed researchers openly share data repositories. One example of this is the Indian BuiLdings Energy coNsumption Dataset (I-BLEND) (Rashid et al. 2019). I-BLEND is a 52-month energy dataset from seven commercial and residential buildings of an academic institute campus in New Delhi. The dataset contains five different parameters, which are—voltage, current, power, frequency, and power factor. The data is collected at a sampling frequency of one minute. An interesting aspect of this data set is that it also provides occupancy counts using WiFi logs at the router level.

The growing interest in the field of UBEM in India is evident. Sharma et al. analyzed the usefulness of different methodologies for developing a 3D building stock model for the city of Ahmedabad (Sharma et al. 2020, 3). Evaluating various applications such as the potentials, limitations, and challenges of remote sensing techniques, namely: (a) Satellite imagery, (b) LiDAR, and (c) Photogrammetry, they

found that the use of supervised learning for image-based segmentation identifies building footprints with good accuracy. Mathur et al. developed a fit-for-purpose urban building energy modeling framework using the case city of Ahmedabad. They focused on understanding the impact of increasing the resolution of model inputs on the outputs. This was done to find a balance between the efforts spent on data preprocessing, model development, and the accuracy of the results. Applying this understanding to the case of Ahmedabad, they found that a higher Level of Detail (LoD) is required in occupancy modeling for the residential and educational buildings, whereas the same is more important for the commercial buildings' envelope characteristics.

Praharaj and Bandyopadhyay studied the open data challenge for building smart cities in India (Praharaj and Bandyopadhyay 2020). They found that many smart cities are embracing new technologies to foster an open data culture and that the city's open data platforms are more likely to sustain if developed and operated at a regional level. According to the Ministry of Housing and Urban Affairs (MoHUA), the open data platform for the 100 smart city candidates would be expanded to cover 500 cities by 2022 ("Ministry of Housing and Urban Affairs, Government of India" 2021). The Ministry has also extended this to include the "DataSmart Cities" strategy ("Data Smart Cities" 2021). This strategy recognizes the value of cultivating engagement among the government, citizens, academia, and industry. This requires a data ecosystem supported by a robust system of data acquisition that will act as a backbone for realizing the full potential of technology interventions in cities. In view of this, the India Urban Data Exchange (IUDX) is a research project implemented by MoHUA in collaboration with the Indian Institute of Science (IISc), Bengaluru. The goal of this platform is to facilitate secure, authenticated and managed exchange of data with third-party authenticated and authorized applications. Here, industry and researchers will be able to share Smart City data that could even be monetized in the future. Although this is promising, the quality and timely availability of data still poses a challenge. Additionally, the current data sets available in IUDX are waste management, civic, video systems, street lighting, urban mobility, work place, and environment. There is no specific data set on the energy consumption aspects of buildings and mobility. This is a bottleneck to the advancement of data-driven UBEM for Indian cities.

In contrast, research groups are working on ways to generate and derive useful data that can be applied for urban energy planning and design. Tong et al. presented a baseline urban energy-use data set covering all Indian urban districts in ways that align with national totals and integrate social-economic-infrastructural attributes (Tong et al. 2021). They develop a novel bottom-up plus top-down approach based on machine learning to model All Urban areas' Energy-use (AllUrE) across all 640 districts in India. The spatially granular AllUrE data aggregated nationally shows good agreement with the national total. At the state level, the goodness-of-fit ranged from 0.78–0.95 to 0.90–0.99 at the city level. Such a data set is highly valuable for large-scale modeling of the urban energy transitions in India that are consistent with national energy and climate goals.

In addition to the aforementioned data sources, emerging data-sharing platforms such as Nature Scientific Data, Elsevier Data-in-Brief, and Kaggle also provide several complete and peer-reviewed datasets. These are great avenues to develop and test preliminary data-driven models before developing one's own data collection methodology.

4 Conclusion

Energy demand in buildings and cities continues to rise, driven by improved access to energy in developing countries, greater ownership, and the use of energy-consuming devices (IEA 2018). This is well recognized worldwide, and strategies to curtail the demand for fossil fuels and increase the dependency on renewable energy sources are being intensely worked upon. UBEM complimented with data-driven analysis is a promising way forward. Many such methodologies have been developed in various parts of the world. It is seen that most employ a hybrid model that combines simulated and measured data as full data sets consisting of all variables at the urban level are still not available. Even though demand data from thousands of buildings is openly available, it is often limited either in space or time. Temporal limitations mean it is difficult to generalize the observed trends and detect seasonality in the data. Likewise, the fact that most datasets are concentrated in a few geographical regions does not lend itself to broader generalization. This is also a shift from conventional studies where measured data was only used for calibration and not training models.

In India, data-driven UBEM research is still in its nascent stage. The MoHUA has initiated the Smart Cities Mission and the DataSmart Cities strategy which oversees the India Urban Data Exchange (IUDX) platform. However, not enough data is available that can exclusively be used for UBEM. Currently, there is a need to define the major urban challenges in India. Only then can the most suitable solution strategies be devised. Digitalization and data-driven analysis are supportive tools only if the basic infrastructure is in place. For example, if the condition of buildings and roads does not improve, advanced optimization and efficiency improvements using data-driven analysis may not be fruitful. Therefore, data-driven analysis for Indian cities should first look into best practices and share and disseminate the best practice data among stakeholders. There is an immediate need to define benchmarks in building and urban energy efficient practices. These should be developed by experts who have knowledge about the way Indian cities are designed and operated in terms of energy. Data-driven UBEM provides a promising platform to uncover some of the basic challenges Indian cities face in the context of not just energy, but also other aspects such as mobility, waste management, and environment.

References

Abbasabadi N, Ashayeri M, Azari R, Stephens B, Heidarinejad M (2019) An integrated data-driven framework for urban energy use modeling (UEUM). Appl Energy 253. https://doi.org/10.1016/j.apenergy.2019.113550

Ahmad T, Chen H, Guo Y, Wang J (2018) A comprehensive overview on the data driven and large scale based approaches for forecasting of building energy demand: a review. Energy Build 165:301–320. https://doi.org/10.1016/j.enbuild.2018.01.017

Ali U, Shamsi MH, Hoare C, Mangina E, O'Donnell J (2021) Review of urban building energy modeling (UBEM) approaches, methods and tools using qualitative and quantitative analysis. Energy Build 246:111073. https://doi.org/10.1016/j.enbuild.2021.111073

Ali U, Shamsi MH, Bohacek M, Hoare C, Purcell K, Mangina E, O'Donnell J (2020) A data-driven approach to optimize urban scale energy retrofit decisions for residential buildings. Appl Energy 267. https://doi.org/10.1016/j.apenergy.2020.114861

Bollinger LA, Davis CB, Evins R, Chappin EJL, Nikolic I (2018) Multi-model ecologies for shaping future energy systems: design patterns and development paths. Renew Sustain Energy Rev 82:3441–3451. https://doi.org/10.1016/j.rser.2017.10.047

Burdett R, Rode P (2018) Shaping cities in an urban age. Phaidon Press, London, New York

Census of India 2011 (2012) Provisional population totals urban agglomerations and cities, data highlights

Cozza S, Chambers J, Deb C, Scartezzini J-L, Schlüter A, Patel MK (2020) Do energy performance certificates allow reliable predictions of actual energy consumption and savings? learning from the Swiss national database. Energy Build 224:110235. https://doi.org/10.1016/j.enbuild.2020.110235

Crawley D, Hand J, Lawrie L (1999) Improving the weather information available to simulation programs. 2

Dall'O' G, Galante A, Torri M (2012) A methodology for the energy performance classification of residential building stock on an urban scale. Energy Build 48: 211–19. https://doi.org/10.1016/j.enbuild.2012.01.034

Data Smart Cities (2021). https://smartnet.niua.org/dsc/

Deb C, Lee SE (2018) Determining key variables influencing energy consumption in office buildings through cluster analysis of pre- and post-retrofit building data. Energy Build 159:228–245. https://doi.org/10.1016/j.enbuild.2017.11.007

Deb C, Schlueter A (2021) Review of data-driven energy modelling techniques for building retrofit. Renew Sustain Energy Rev 144:110990. https://doi.org/10.1016/j.rser.2021.110990

Deb C, Eang LS, Yang J, Santamouris M (2016) Forecasting diurnal cooling energy load for institutional buildings using artificial neural networks. Energy Build 121:284–297. https://doi.org/10.1016/j.enbuild.2015.12.050

Deb C, Lee SE, Santamouris M (2018) Using artificial neural networks to assess HVAC related energy saving in retrofitted office buildings. Sol Energy 163:32–44. https://doi.org/10.1016/j.solener.2018.01.075

Deb C, Dai Z, Schlueter A (2021) A machine learning-based framework for cost-optimal building retrofit. Appl Energy 294:116990. https://doi.org/10.1016/j.apenergy.2021.116990

Dias LP, Simões S, Gouveia JP, Seixas J (2019) City energy modelling—optimising local low carbon transitions with household budget constraints. Energ Strat Rev 26:100387. https://doi.org/10.1016/j.esr.2019.100387

Energy | UN-Habitat (2021). https://unhabitat.org/topic/energy

Energy Technology Perspectives 2020 (2020) Energy technology perspectives 400

Frei M, Deb C, Stadler R, Nagy Z, Schlueter A (2020) Wireless sensor network for estimating building performance. Autom Constr 111:103043. https://doi.org/10.1016/j.autcon.2019.103043

Frei M, Deb C, Nagy Z, Hischier I, Schlueter A (2021) Building energy performance assessment using an easily deployable sensor kit: process, risks, and lessons learned. Front Built Environ. https://doi.org/10.3389/fbuil.2020.609877

IEA (2018) World energy model documentation 2018 version. https://www.iea.org/media/weoweb site/energymodel/WEM2018.pdf
IEA (2021) Urbanisation and industrialisation in India—India energy outlook 2021—analysis. https://www.iea.org/reports/india-energy-outlook-2021/urbanisation-and-industrialisation-in-india
Kavgic M, Mavrogianni A, Mumovic D, Summerfield A, Stevanovic Z, Djurovic-Petrovic M (2010) A review of bottom-up building stock models for energy consumption in the residential sector. Build Environ 45(7):1683–1697. https://doi.org/10.1016/j.buildenv.2010.01.021
Kazmi H, Munné-Collado Í, Mehmood F, Syed TA, Driesen J (2021) Towards data-driven energy communities: a review of open-source datasets, models and tools. Renew Sustain Energy Rev 148:111290. https://doi.org/10.1016/j.rser.2021.111290
Kontokosta CE, Tull C (2017) A data-driven predictive model of city-scale energy use in buildings. Appl Energy 197:303–317. https://doi.org/10.1016/j.apenergy.2017.04.005
Mastrucci A, Baume O, Stazi F, Leopold U (2014) Estimating energy savings for the residential building stock of an entire city: a GIS-based statistical downscaling approach applied to rotterdam. Energy Build 75:358–367. https://doi.org/10.1016/j.enbuild.2014.02.032
Ministry of Housing and Urban Affairs, Goverment of India (2021). https://mohua.gov.in/index.php
Mutani G, Todeschi V (2021) GIS-based urban energy modelling and energy efficiency scenarios using the energy performance certificate database. Energ Effi 14(5):47. https://doi.org/10.1007/s12053-021-09962-z
Nutkiewicz A, Yang Z, Jain RK (2018) Data-driven urban energy simulation (DUE-S): a framework for integrating engineering simulation and machine learning methods in a multi-scale urban energy modeling workflow. Appl Energy 225:1176–1189. https://doi.org/10.1016/j.apenergy.2018.05.023
On the Modelling and Optimisation of Urban Energy Fluxes (2009). Lausanne: EPFL. https://doi.org/10.5075/epfl-thesis-4548
Papadopoulos S, Kontokosta CE (2019) Grading buildings on energy performance using city benchmarking data. Appl Energy 233–234:244–253. https://doi.org/10.1016/j.apenergy.2018.10.053
Pedersen L, Stang J, Ulseth R (2008) Load prediction method for heat and electricity demand in buildings for the purpose of planning for mixed energy distribution systems. Energy Build 40(7):1124–1134. https://doi.org/10.1016/j.enbuild.2007.10.014
Perez D, Robinson D (2012) Urban energy flow modelling: a data-aware approach. In: Arisona SM, Aschwanden G, Halatsch J, Wonka P (eds) Digital urban modeling and simulation. Communications in computer and information science. Springer, Berlin, Heidelberg, pp 200–220. https://doi.org/10.1007/978-3-642-29758-8_11
Praharaj S, Bandyopadhyay S (2020) Understanding the open data challenge for building smart cities in India. pp 359–82. https://doi.org/10.1007/978-981-13-6605-5_16
Rahman A, Srikumar V, Smith AD (2018) Predicting electricity consumption for commercial and residential buildings using deep recurrent neural networks. Appl Energy 212:372–385. https://doi.org/10.1016/j.apenergy.2017.12.051
Rashid H, Singh P, Singh A (2019) Data descriptor: I-BLEND, a campus-scale commercial and residential buildings electrical energy dataset. Sci Data. https://doi.org/10.1038/sdata.2019.15
Reinhart CF, Davila CC (2016) Urban building energy modelling—a review of a nascent field. Build Environ 97:196–202. https://doi.org/10.1016/j.buildenv.2015.12.001
Robinson C, Dilkina B, Hubbs J, Zhang W, Guhathakurta S, Brown MA, Pendyala RM (2017) Machine learning approaches for estimating commercial building energy consumption. Appl Energy 208:889–904. https://doi.org/10.1016/j.apenergy.2017.09.060
Robinson D (2011) Computer modelling for sustainable urban design: physical principles, methods and applications. https://www.routledge.com/Computer-Modelling-for-Sustainable-Urban-Design-Physical-Principles-Methods/Robinson/p/book/9781844076796
Sharma K, Rawal R, Fennell P, Mathur A, Ruyssevelt P, Crawley D, Korolija I (2020) Developing a 3D geometry for urban energy modelling of indian cities

Sigrist D, Deb C, Frei M, Schlüter A (2019) Cost-optimal retrofit analysis for residential buildings. J Phys Conf Ser 1343:012030. https://doi.org/10.1088/1742-6596/1343/1/012030

Sola A, Corchero C, Salom J, Sanmarti M (2020) Multi-domain urban-scale energy modelling tools: a review. Sustain Cities Soc 54:101872. https://doi.org/10.1016/j.scs.2019.101872

The Ultimate Technical Guide to UrbanFootprint (2021) UrbanFootprint (blog). 2021. https://urbanfootprint.com/whitepaper/urbanfootprint-tech-guide/

Tong K, Nagpure AS, Ramaswami A (2021) All urban areas' energy use data across 640 districts in india for the year 2011. Sci Data 8(1):104. https://doi.org/10.1038/s41597-021-00853-7

Wang Y, Wu T, Li H, Skitmore M, Su B (2020) A statistics-based method to quantify residential energy consumption and stock at the city level in China: the case of the guangdong-hong kong-macao greater bay area cities. J Clean Prod. https://doi.org/10.1016/j.jclepro.2019.119637

Wang W, Liu K, Zhang M, Shen Y, Jing R, Xiaodong X (2021) From simulation to data-driven approach: a framework of integrating urban morphology to low-energy urban design. Renew Energy 179:2016–2035. https://doi.org/10.1016/j.renene.2021.08.024

Williams KT, Gomez JD (2016) Predicting future monthly residential energy consumption using building characteristics and climate data: a statistical learning approach. Energy Build 128:1–11. https://doi.org/10.1016/j.enbuild.2016.06.076

Wu R, Mavromatidis G, Orehounig K, Carmeliet J (2017) Multiobjective optimisation of energy systems and building envelope retrofit in a residential community. Appl Energy 190:634–649. https://doi.org/10.1016/j.apenergy.2016.12.161

Yang Z, Roth J, Jain RK (2018) DUE-B: data-driven urban energy benchmarking of buildings using recursive partitioning and stochastic frontier analysis. Energy Build 163:58–69. https://doi.org/10.1016/j.enbuild.2017.12.040

Zhao F, Martinez-Moyano IJ, Augenbroe G (2011) Agent-based modeling of commercial building stocks for policy support. pp 2385–2392