An Integrated Socio-Eco-Hydrological Framework to Assess and Evaluate Urban Water Security

Doctoral thesis

by

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Freie Universität Berlin

submitted to the

Department of Earth Sciences

in partial fulfilment of the requirements of the degree of

Doctor rerum naturalium

Berlin 2021

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Date of Disputation: 5th July, 2021

Preface

Urban Water Security (UWS) addresses various water challenges in a city including its urban and peri-urban areas where the problems are not only depending on its physical water availability in a straightforward manner but also on social, cultural, economic, and political factors. UWS lies in the heart of Sustainable Development Goals (SDGs). The concept of water security advocates for providing enough safe drinking water while maintaining sustainable environment integrating efforts to meet the SDGs-2030 Agenda. SDGs allude to the multidimensionality and crucial importance of water security to achieve sustainable development and underlines the need for a holistic approach. SDG 6 calls particularly for clean water and sanitation for all people, paying special attention to the needs of women and girls and those in vulnerable situations (Goal 6.2) by supporting and strengthening the participation of local communities for improving water and sanitation management (Goal 6B). Other SDGs also include different water and sanitation targets. Particularly focusing on urban areas, SDG 11 aims at ensuring the development of sustainable cities and communities by focusing on ensuring access to safe and affordable housing, upgrading slum settlements, investing in public transport, creating green public spaces, and improving urban planning and management in a way that is both participatory and inclusive.

This Doctoral (PhD) study aims to unravel the intertwined biophysical and socio-cultural relationships that shape the UWS from an emerging country perspective. It will show that, although several concepts and approaches for assessment of UWS have emerged, most of these approaches fail to consider social perspectives and their relationship with bio-physical environment at a micro level. Thus, to fulfil the disciplinary expertise and interdisciplinary knowledge fit to address and solve sustainable development's societal challenges, this study advocates for an inclusive and interdisciplinary UWS assessment framework – allowing us to understand the complex web of barriers to and opportunities for assuring water security for *all* in an urban area.

This study focuses on the issues, challenges, and the future research agenda for achieving UWS for the Global South and beyond while using Kolkata, India as a case study to exemplify the arguments. Kolkata is a growing mega-city in an emerging economy, which is facing rising pressures on water-environmental provisions due to the rapid population growth, urbanisation, and resultant governance as well as infrastructural issues. The study commences with an overview of the urban water (in)security and its dimensions in Kolkata city, such as water consumption and distribution in the city along with the changing land use and land cover (LULC), the changes of the ecosystem service value (ESV) associated with the LULC dynamics, water quality and, continue discussing the intrinsic intersectionality exposed from the findings which shape the *security* of/from urban water. This study concludes by presenting further research needs synthesising the findings, limitations of the research and summarising the adequacy of the already existing governance-response frameworks for allocation and management of urban water, while acknowledging water as a basic human right, for the time of pandemic and beyond, particularly in the urban system, towards a secured and sustainable future.

Acknowledgements

First and foremost, I am extremely grateful to my supervisors, Prof. Dr. Brigitta Schütt and Prof. Dr. Wiebke Bebermeier for their essential advice, continuous support, and patience during this Doctoral research. Their immense knowledge and plentiful experience have encouraged me at all times of my academic research and daily life.

My gratitude extends to Prof. Dr. Pradip K. Sikdar (IISWBM- Kolkata) for continuous assistance by providing comments that significantly enhanced the research and manuscripts, by sharing his pearls of wisdom with me during this research and, by co-authoring several publications together.

A huge chunk of my appreciation goes out to Dr. Trude Sundberg (University of Kent, UK) for her treasured support, which was really influential in shaping my experiment methods, critiquing my results, coauthoring the publication, and my life. I also appreciate all the support I received from Dr. Sukdeb Pal (NEERI-India) right from the beginning of this academic journey.

I would like to thank the German Academic Exchange Service (DAAD) who provides an esteemed fellowship that allowed me to conduct this thesis. I thank the GeoX Network for additional supports regarding the survey data collections and interviews to organise. I also acknowledge financial support by the German Research Foundation and the Open Access Publication Fund of the Freie Universität Berlin for supporting publication of the papers.

I would also like to thank my colleagues from Freie Universität Berlin who provided insight and expertise that greatly assisted the research and for their kind help and support that have made my study and life in Berlin a wonderful time. Specifically, my roommates, Ms. Luise Haufe and Dr. Motti Zohar for their great understanding and support throughout the entire period of this study. I am immensely grateful to Prof. Dr. Karl Tilman Rost, Dr. Jan Krause, Dr. Jacob Hardt, Dr. Moritz Nykamp, Dr. Fabian Becker, Ms Ricarda Baun, and Dr. Jonas Berking from Freie Universität Berlin, for their comments, guidance, and support throughout the study. I would like to extend my sincere thanks to Dr. Basudeb Bhatta (Jadavpur University-Kolkata), Dr. Kalyan Rudra (WBPCB-Kolkata) and Dr. Arunagshu Mukherjee (CGWB-India) for their enormous assistance with providing data and comments that greatly improved the research and manuscript.

I would like to thank Dr. Kai Hartmann, Department of Earth Sciences, Freie Universität Berlin, Prof. Dr. Mahalaya Chatterjee, University of Calcutta, India and Dr. Dipankar

Bhattacharya, KMDA, India who provided relevant data, insight and expertise that greatly assisted the research. I am indebted to Mrs. Ena Sen for her immeasurable and rigorous assistance in mapping and GIS data analyses. Mr. Hindol Rakhshit (EKOR Tech Gmbh) and Mrs. Prajna Debnath (HelloFresh SE) made an important effort to initiate the discussion on the issues regarding data analysis. I am thankful to them for their kind and mindful contributions for this research. I would also like to thank Mr. Tapas Dey, research scholar, IIPS-India for his kind assistance in data analyses. I would also like to show my gratitude to Mr. Sougata Saha, Comtel Consultans and Infraproject Pvt Ltd., India, Mr. Surajit Kar (University of Calcutta, India), Dr. Debanuj Dasgupta (University of California – Santa Barbara) and Prof. Dr. L.N. Satpati (University of Calcutta, India) for assistance with survey, mapping and literature review during this research and sharing their personal and erudite insights about the study area. I am also indebted to Dr. Dipanwita Chatterjee and Mr. Ayan Guin for their endless assistance in GIS analysis and mapping. I would like to offer my thanks to Mr. Mantu Biswas for helping in water quality data collection from WBPCB, India and Mr. Rituparna Acharayya for meticulous assistance with additional mapping and designing the figures used during this research. I am deeply grateful to Mr. Jaydeep Sinha and Mrs. Sankalita Mandal for their encouragement and interminable support all through my studies.

Finally, I would like to express my gratitude to my Mother, Mrs. Kumkum Mukherjee, my sister, Mrs. Pinki Chakraborty, my brother-in-law, Mr. Krishnendu Chakraborty and my nephew, Mr. Aitijhya Chakraborty for their unwavering support and belief in me. Without their tremendous understanding and encouragement in the past few years, it would have been impossible for me to complete my research.

Abstract

Urban Water Security (UWS) will remain a hugely important issue over the next decades and is a matter that will be exacerbated by climate change and related hazards, food insecurity and social instability. Despite attempts made by many researchers and water professionals to study different dimensions of water security and urban dynamics, there is still an absence of comprehensive water security measurement index for an urban landscape.

Existing urban water evaluation approaches are not holistic; often focusing more on bio-physical and technical factors (such as water supply and drainage systems within urban areas) rather than evaluating the entire socio-eco-hydrological performance of the urban area. Whilst these approaches can show how components of urban areas' water systems are performing along the dimensions of water supply and drainage systems, a comprehensive framework is needed to frame the problems, monitor, or inform progress that accounts for the wide range of factors and associated issues that impact overall water security. This will in term impact the chances of successfully and sustainably addressing issues of urban water insecurity.

This study examines a novel integrated socio-ecohydrological assessment framework which seeks to incorporate both the bio-physical and social factors of the UWS. Kolkata is a growing megacity in a developing country, which is facing rising pressures on water-environmental provision due to the rapid population growth and urbanization and resultant governance and infrastructural issues. Kolkata, an Asian deltaic megacity, which is facing critical water issues in water management, has been used as a case study. The research examined whether the proposed comprehensive framework for measuring and evaluating water security for the cities, particularly for emerging countries, may be effectively applied to environments where urban growth and resultant shrinking resources have created complicated and fragile systems.

Based on the results obtained from the datasets from the census, and a household survey, we identified a lack of supplies associated with water, sanitation, and hygiene (WaSH) provisions in these areas of Kolkata. The WaSH provisions in the slum areas of Kolkata city are facing various issues related to regularity, quality, and quantity of supplied water. Additionally, there is poor maintenance of existing WaSH services including latrine facilities and per capita allocation of a sustainable water security among the slum dwellers. By adding to our understanding of the importance of factors such as gender, religions, and knowledge of drinking water in deprived areas, the study analyses and establishes the links between both physical and social issues

determining vulnerability and presence of deprivation associated with basic WaSH provisions as human rights of slum communities.

Based on land use and land cover (LULC) data retrieved from remote sensing interpretation, this study computed the changes of the ecosystem service values (ESV) associated with the LULC dynamics, water quality and, finally, UWS during the pre- and post-monsoon periods of 2009, 2014 and 2019 in Kolkata and its peri-urban wetlands named East Kolkata Wetlands (EKW). The area under wetlands reduced comprehensively in 2009–2019 due to the conversion of wetlands into various other classes such as urban settlement, etc. The quality of surface water bodies (such as rivers, lakes, canals, and inland wetlands) deteriorated. The groundwater quality is still under control, but the presence of arsenic, manganese and other metal(oid)s are a clear indication of urban expansion and related activities in the area. As a result, there were changes in the ESV during this timeframe. These changes can be attributed to the peri-urban wetlands and the benefits or services arising out of them that contribute more than 50% of the total ESV. Thus, despite the continuous reduction in areas under wetlands, EKW supports the UWS by providing sufficient ecosystem services for Kolkata city.

This assessment framework provides an interdisciplinary understanding of UWS by extracting and integrating relevant empirical knowledge on urban intersection and water issues in the city from physical, environmental, and social sciences approach. This study further recommends future research guidelines that include the need to comprehend the possible alternatives to the existing water policies towards a sustainable water secure future ‘leaving no one behind’. However, the findings of the thesis are not limited to cities in developing countries (although the examination of bio-physical, institutional, and cultural barriers for developing and implementing new water management practices may be particularly relevant to these States) but may be related and applied towards other regions addressing water security and governance related challenges.

Zusammenfassung

Wasserversorgungssicherheit im urbanen Raum ist als eine der großen Herausforderungen anzusehen, die in den kommenden Jahrzehnten nicht nur eine wichtige Rolle spielen sondern sich vermutlich zunehmend verschärfen wird – insbesondere im Hinblick auf den Klimawandel und damit einhergehende Risiken, ebenso wie Ernährungsunsicherheit und soziale Instabilität. Auch wenn in den letzten Jahren von Wissenschaftler:innen und Wasserwirtschaftler:innen verschiedene Aspekte von Wassersicherheit und urbaner Dynamik untersucht wurden, wurde bisher kein detaillierter Index erstellt, um Maßnahmen für eine sichere Wasserversorgung im städtischen Raum umfassend zu evaluieren.

Bisher vorliegende Bewertungsstrategien verfolgen keinen holistischen Ansatz, sondern richten meist den Fokus auf bio-physikalische und technische Faktoren (wie etwa die Wasserversorgungs- und -entsorgungssysteme in urbanen Räumen), ohne dabei die Gesamtheit der sozial-ökologisch-hydrologischen Zusammenhänge im städtischen Raum in den Blick zu nehmen. Allerdings bedarf es eines umfassenderen Ansatzes, der es ermöglicht sämtliche Faktoren einzubeziehen, die Einfluss auf die städtische Wassersicherheit haben. Ein solcher Ansatz erhöht langfristig die Erfolgsaussichten, Probleme der städtischen Wasserverknappung nachhaltig zu bewältigen. Innerhalb der vorliegenden Arbeit wird ein integratives sozio-öko-hydrologisches Bewertungssystem entwickelt, das sowohl bio-physikalische als auch soziale Faktoren der urbanen Wassersicherheit integriert.

Die in einem Deltagebiet gelegene Megacity Kalkutta/Indien ist aufgrund eines raschen Bevölkerungswachstums und einer Verstädterung sowie der daraus resultierenden Governance- und Infrastrukturprobleme mit einem steigenden Druck auf die Wasserversorgung konfrontiert und dient im Rahmen dieser Arbeit als Fallstudie. Es wird analysiert, inwieweit das vorgeschlagene Bewertungssystem zur Erfassung und Evaluation von urbaner Wassersicherheit (insbesondere in Schwellenländern), in Räumen genutzt werden kann, in denen Verstädterung und der damit einhergehende Rückgang von Ressourcen ein fragiles System geschaffen haben.

Auf Grundlage einer Auswertung von Zensusdaten sowie einer Haushaltsumfrage konnte im Rahmen der Dissertation ein Defizit in der Wasser-, Sanitär- und Hygieneversorgung (WaSH) in Kalkutta festgestellt werden. Insbesondere für die Slumgebiete der Stadt sind die Regulierung und Menge als auch die Qualität des Wassers als problematisch einzustufen. Darüber hinaus weist die Versorgungs- und Entsorgungsinfrastruktur, einschließlich der

Latrineneinrichtungen, einen schlechten Wartungszustand auf und die Pro-Kopf-Zuweisung einer nachhaltigen Wassersicherheit ist unter den Slum-Bewohner:innen ungleich verteilt. Im Rahmen dieser Studie wurde das Zusammenspiel von physischen und sozialen Aspekten analysiert und die Vulnerabilität sowie die Mängel innerhalb der WaSH-Grundversorgung als Menschenrecht der Slumgemeinschaften bestimmt. Es wird gezeigt, dass insbesondere die Faktoren Gender, Religion und das Wissen über Wasser eine überaus wichtige Rolle für Analysen zu Wassersicherheit spielen. Mittels Fernerkundung gewonnene Landnutzungs- und Landbedeckungsdaten (LULC), die die Vor- und Nachmonsunperioden in den Jahren 2009, 2014 und 2019 in Kalkutta und den umliegenden peri-urbanen Feuchtgebiete namens East Kolkata Wetlands (EKW) repräsentieren, wurden ausgewertet. Ziel der Studie war es, Veränderungen der Ökosystemdienstleistungswerte (ESV), die mit der LULC-Dynamik, der Wasserqualität und schließlich den UWS zusammenhängen, zu analysieren. Es wurde festgestellt, dass die Fläche der Feuchtgebiete in den Jahren 2009-2019 aufgrund einer Verstädterung und damit einhergehender Landnutzungsveränderungen deutlich abgenommen hat. Die Qualität der Oberflächengewässer (wie Flüsse, Seen, Kanäle und Binnenfeuchtgebiete) verschlechterte sich, während die Grundwasserqualität relativ stabil blieb. Im Grundwasser nachgewiesenes Arsen, Mangan und anderen Metall(oid)e sind jedoch bereits als deutliche Anzeiger einer zunehmenden Verstädterung anzusehen. Infolge der städtischen Expansion haben sich darüber hinaus die Ökosystemdienstleistungen im genannten Zeitfenster verändert. Die peri-urbanen Feuchtgebiete tragen 50% zu den gesamten Ökosystemdienstleistungen in Kalkutta bei und sind daher trotz ihrer kontinuierlichen flächenmäßigen Abnahme ein zentraler Baustein der Wassersicherheit der Stadt.

Durch die Intergration von empirischem Wissen über urbane Intersektion und Probleme der Wasserver- und -entsorgung aus den Natur-, Umwelt- und Sozialwissenschaften trägt der vorliegende Ansatz zu einem interdisziplinären Verständnis von Wassersicherheit im städtischen Raum bei. Aufbauend auf den Ergebnissen wurde in der vorliegenden Dissertation eine Forschungsrichtlinie entwickelt, die auf die Notwendigkeit hinweist, Alternativen zu der bestehenden Wasserpolitik aufzuzeigen und eine Politik im Sinne einer nachhaltigen Wassersicherung für die Zukunft zu betreiben, die integrativ vorgeht. Auch wenn sich die Analysen primär auf die Megacity Kalkutta beziehen, sind die Ergebnisse nicht auf Entwicklungsländer beschränkt (auch wenn die Untersuchung von bio-physikalischen, institutionellen, und kulturellen Barrieren sowie die Implementierung von neuen Wassermanagementpraktiken in diesen Staaten besonders relevant erscheinen), sondern können auch auf andere Regionen angewandt werden, um dort die Herausforderungen der Sicherung und Governance von Wasserver- und- entsorgung zu meistern.

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1. Introduction

1.1. Prologue

Water security is a conceptualized term which ensures every citizen with the amount of quality water they need daily (Narain, 2010). Water insecurity can result from unrestricted population growth, poor governance, and mismanagement of the water supply system in an urban setting. Furthermore, parallel physical processes such as climate change do accelerate the insecurity of water. Different socio-economic activities in metropolitan, urban, and sub-urban areas affect urban water security (UWS). Different characters, such as the ratio between availability and required amount of drinking water supply, are the main components to establish a sustainable urban and peri-urban water management system.

UWS issues are particularly pertinent and worsening in megacities in the developing world due to rapid and unplanned growth. India is one of the countries where these issues have been found to be worse. Particularly in urban India, the rapid expansion of population combined with increasing levels of both consumption and pollution has increased water insecurities (Mukherjee et al., 2018). At present, the existing water security assessment techniques are limited by non-integrated, and 'silo' approaches relative to its influence in practice and bridled by localized findings that are difficult to generalize. They have been criticized for being based on a technology-centric, top-down approach of the urban space that most commonly seeks to improve resource-use efficiency or management, enhance policy integration, and/or promote sustainable resource-use practices. In this approach, citizens are either less visible or the needs of certain groups of citizens are taken as the norm. This approach risks excluding other bodies, lives, and needs. Addressing this gap, this research attempts to develop new research method that can analyze the experiences of a mega city in India in terms of water security and access, and urban expansion from an interdisciplinary approach.

The changes have been studied for Kolkata Municipal Corporation area (Figure 1.1), India, covering one of the world's most densely populated areas, characterised by complex inherited social structures and diverging communities and religious groups. The study focuses on a highly different socio-economic trajectory in terms of economic development, political culture, and human rights. For Kolkata, this study looks at the changes since the 1980s, given that the socio-metabolic profile of India strongly changed in the 1980s. While India's consumption of resources (per capita) has been slightly lagging its population growth and is characterized mainly by biomass (2/3 of the total consumption of resources) until the 1980s, it has been rising by 60% during the following three decades (Mukherjee et al., 2020). This socio-metabolic transition corresponds with the period of economic and political change commonly known as 'liberalization', which functions also as a central marker in the collective memory of India.

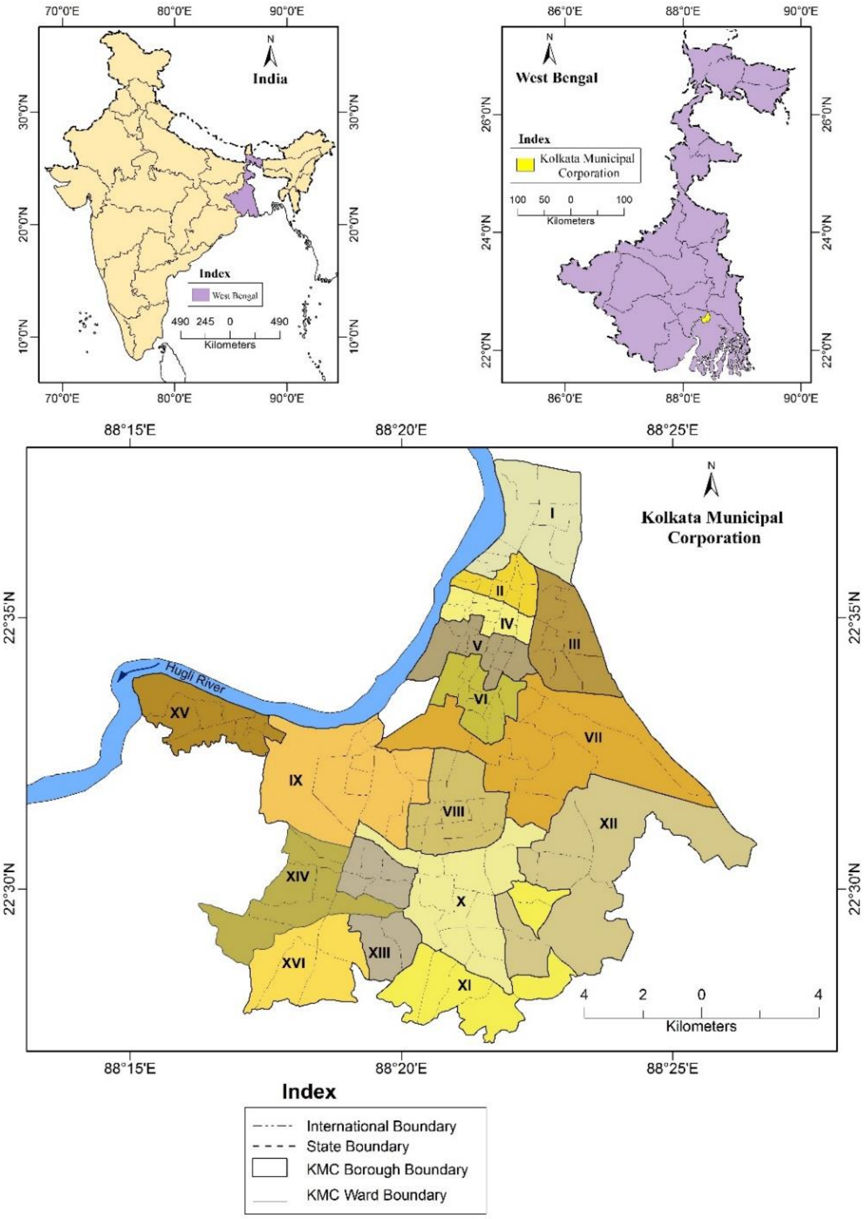

Figure 1.1. Location of Kolkata Municipal Corporation (KMC) boroughs (featuring the wards associated in a borough) within West Bengal, India. Roman numbers mark the borough numbers. Data source: Mukherjee et al., 2018.

This doctoral research prioritises to obtain new understanding on the rapid changes of cityscapes affecting the water security and how they impact sustainable livelihoods and human wellbeing for all. This has been done by developing the state-of-the-art data and statistical model-based analysis of historical changes by environmental, land-use, and social, political, economic, demographic, and perception trends. The co-created knowledge through survey and focus group interactions helped to develop our existing methods to understand the changes in populations' vulnerability to water security issues, management and governance regimes, legislation, and policies.

To go further into the details of the processes and resultant effects of the urban growth and its related water-environmental insecurity at a micro-level scale in a city region, the research argues that the new economic development is giving rise to the new urban forms including geographically disaggregated production and consumptions of patterns of the utilization of the resources. These new urban forms are ultimately leading to an inequality in lifestyles and different environmental issues (such as pollution and waste management). As a result, the impacts of the urban environmental problems are becoming critical to manage in traditional ways as they are not distributed equitably among all the urban areas. A questionable future of water security in the region is a prime concern.

Referring to various desiderata, this doctoral study intends to answer four major **research questions** arising from the dynamics of the processes of change impacting UWS of the study area of Kolkata Municipal Corporation, in India. These are, to know:

1) What are the key factors affecting urban water security of Kolkata?
2) What are the impacts resulting from the rapidly changing socio-eco-environmental processes within the study area affecting water, sanitation, and hygiene (WaSH)?
3) What is the extent of the ability of the polycentric urban region to attend the varying sustainable and equitable water security at the micro level?
4) How do the social, cultural, economic, political and institutional factors influence individuals' and specific groups' (groups in vulnerable positions from a intersectional point of view) water security in a city?

1.2. Objectives of the study

Focusing on the research questions, the doctoral research sets an overall **aim to develop methods to construct an assessment framework that can capture the complexities of UWS of a rapidly growing Indian Megacity, Kolkata, in the context of an appreciation of contemporary theories of water security, particularly as they relate to concepts of**

sustainability. The major concern of this study is to analyze a complex set of biophysical and social issues which influence various levels of UWS and to find out who are water-secured. This, in turn, would contribute towards achieving water security for all in the long run from a bottom-up and inclusive approach. Hence the application of the participatory qualitative and quantitative methods is crucial to get a clear picture of the inequalities in the water resource management and its universal access. This study focuses on inter-disciplinary boundaries, using a mixture of resources from the natural and social sciences to explore the drivers of vulnerability in the urban and peri-urban sites. It also proposes the cost-effectiveness of technological and institutional alternatives to build adaptive capacities ensuring an equitable share of water security for all.

Thus, the **overall objective of the research is to establish and assess the linkages between bio-physical and social dimensions in the city area at the household level including key factors, sensitivities, and the uncertainties to quantitatively analyze and evaluate the UWS of the Kolkata city, both qualitative and quantitative ways, to know the extent of**

a. impacts resulting from the rapidly changing socio-eco-environmental processes and outcomes within the study area showing the variation in water security across and within areas defined as slums, by focusing on water, sanitation, and hygiene (WaSH) and identify the key socio-economic factors affecting urban water security of socially excluded population in Kolkata based on primary data collected in the frame of this study,

b. the ability of the polycentric urban region to attend the varying sustainable and equitable development at the micro level (household) scale, investigating the trade-offs between Kolkata's urban environmental water security and its peri-urban wetland area,

c. the social, cultural, economic, political and institutional factors influencing individuals' and specific groups' (groups in vulnerable positions from a intersectional point of view) water security in the city, with the objective to create indices that can reliably measure water security to develop sustainable solutions to fight water insecurity and inequality.

1.3. Organisation of the thesis

This doctoral research provides an overview of the basic strategy and the methodological assessment framework. The discussion begins with the UWS and the environmental sustainability issues in the context of the rapid and unplanned growth of the cities in developing countries especially Indian mega cities, and their temporal changes in a detrimental way. The next section discusses the state-of-the-art methods proposed for the assessment of urban water system with a proposed framework for measuring and evaluating the status of UWS in the study area. The following section outlines the methodologies applied for undertaking three different case studies touching the concerns of the above-mentioned research objectives. Finally, this study synthesises the findings and discusses the issues regarding data and methodology applied while addressing the agreements, liabilities, and tasks of different stakeholders, in relation to groundwater planning, management and concerns for security as drinking water during and after Covid-19 pandemic This doctoral thesis is a cumulative dissertation that encompasses seven peer-review papers, including four journal articles, two book chapters and a conference paper. Therefore, it cannot, in all cases, be prevented that repetitions of texts and figures occur. The presented cumulative doctoral thesis, thus, comprises the following:

- **2. Literature review**

Mukherjee, S., Sundberg, T. and Schütt, B., 2021. Issues, Dimensions and Approaches of Assessing Urban Water Security, *In:* Sikdar, P.K. (ed.). *Developing and Emerging Countries: An Inclusive Perspective. Environmental Management: Issues and Concerns in Developing Countries*. Springer, Switzerland. pp.151-184. https://doi.org/10.1007/978-3-030-62529-0_9

Own contribution = 85%

- **3. Study area**

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

Own contribution = 85%

- **5. Assessments: Case studies**
  - **5.1. Case study 1:**

Mukherjee, S., Sundberg, T. and Schütt, B., 2020. Assessment of water security in socially excluded areas in Kolkata, India: An approach focusing on water, sanitation, and hygiene. *Water*, *12*(3), p.746. https://doi.org/10.3390/w12030746

Own contribution = 85%

- **5.2. Case study 2:**

Mukherjee, S., Sikdar, P.K., Pal, S. and Schütt, B., 2021. Assessment of environmental water security of an Asian Deltaic megacity and its peri-urban wetland areas. *Sustainability*, *13*(5), p.2772. https://doi.org/10.3390/su13052772

Own contribution = 85%

- **5.3. Case study 3:**

Mukherjee, S, Sundberg, T, Sikdar, P.K. and Schütt, B., 2021. An integrated quantitative assessment of urban water security of Kolkata, India: An inclusive approach (Draft of a journal article; status: Internal review)

Own contribution = 90%

- **6. Synthesis**
  - **6.2. Role of data and statistical analysis for assessment of urban water security in the Global South:**

Mukherjee, S., Sundberg, T., Sikdar, P.K. and Schütt, B., 2021. Role of data and statistical analysis for assessment of urban water security in the Global South. *In:* Sahu et al. (eds). Proceedings of the virtual international conference on statistical tools and techniques for research data analysis (ICSTRDA -2021) from 21.01.2021 to 22.01. 2021, organized virtually by Central University of Gujarat, India.

Own contribution = 90%

- **6.3. Sustainable governance of groundwater as drinking water in the Post CoViD-19 world: An Urban Water Security perspective:**

Mukherjee, S., Sikdar, P.K. and Pal, S., 2021. Sustainable governance of groundwater as drinking water in the Post CoViD-19 world: An Urban Water Security Perspective. *In:* Mohapatra et al. (eds). *Legacy, Pathogenic and Emerging Contaminants in the Environment*. CRC Press. (*in Press*)

Own contribution = 90%

2. Literature review

Issues, dimensions, and approaches of assessing urban water security in developing and emerging countries: An inclusive perspective[1]

Abstract

Urban water security (UWS) addresses various water challenges in a city including its urban and peri-urban area where the problems are not only depending on its physical water availability in a straightforward manner but also on its relations *to* and influences *by* social, cultural, economic, and political factors. Hence, this chapter takes a review approach and aims to unravel the biophysical and socio-cultural relationships that shape the UWS from an emerging country perspective, exploring the implications of including social and environmental changes and the possibilities in achieving UWS. We will show that, although several concepts and approaches have emerged focusing on issues such as water-energy-climate nexus and urban water sustainability, most of these approaches fail to consider social perspectives and their relationship with bio-physical environment at a micro level. Existing urban water evaluation approaches are not holistic; often focusing more on bio-physical and technical factors (such as water supply and drainage systems within urban areas) rather than evaluating the entire socio-eco-hydrological performance of the urban area. They currently do not account for the multiple functions of water as a resource across the urban landscape and do not consider the interwoven relations between water and socio, cultural, political, and economic factors. This constrains our ability to measure what influence on water security, design interventions, and manage urban areas in ways that may achieve overall water security. Whilst these approaches can show how components of urban areas' water systems are performing along the dimensions of water supply and drainage systems, a comprehensive framework is needed to frame the problems, monitor, or inform progress that accounts for the wide range of factors and associated issues that impact overall water security. This will in term impact the chances of successfully and sustainably addressing issues of urban water insecurity. The chapter first discusses the various dimensions, measurement approaches and indicators used in similar research. In the second part, we propose a comprehensive framework for measuring and evaluating water security for the cities, particularly for emerging countries, in a holistic

[1] Mukherjee, S., Sundberg, T. and Schütt, B., 2021. Issues, Dimensions and Approaches of Assessing Urban Water Security, *In:* Sikdar, P.K. (ed.). *Developing and Emerging Countries: An Inclusive Perspective. Environmental Management: Issues and Concerns in Developing Countries*, Springer, Switzerland. pp.151-184. https://doi.org/10.1007/978-3-030-62529-0_9

manner aiming to contribute positively to the future planning and management of sustainable UWS.

Keywords: SDGs, dimensions, Gender, Inclusive approach, DPSIR

2.1. Background

Water security entails ensuring every citizen with the amount of quality water they need to safely live their everyday life (Narain, 2010). In urbanized areas, unrestricted population growth (Falkenmark and Widstrand, 1992; Ravell, 2014), poor governance (Bakker and Morinville, 2013; Biggs et al., 2013; Cook and Bakker, 2012) and mismanagement of the water supply system (Piesse, 2015) as well as social inequality (Blanca, 2017; Goff and Crow, 2014; Jepson et al., 2017) are among the factors that cause and influence water insecurity. In addition, superordinate physical processes like effects of climate change accelerate the insecurity of water (Bar and Stang, 2016; Turral et al., 2011). Overall, urban water security (UWS) can be conceptualized as being the result of socio-economic activities in metropolitan, urban and sub-urban areas (Grey and Sadoff, 2007).

This chapter focuses on challenges of urban water insecurity in emerging countries. These countries frequently are subject to a dearth of financial potential to mitigate water-related problems. Water security is one of the most concerning topics in these countries, and already disadvantaged parts of the population are disproportionately affected (Obani and Gupta, 2016; Pahl-Wostl et al., 2016). However, due to a range of constraints, including economic conditions and socio-political circumstances, accomplishing UWS status is not given the priority it merits in most emerging countries (Pahl-Wostl et al., 2016).

Rapid and continuous changes dominated by the economic part of the development are forming new urban geographies in emerging countries. As a result, new geographies are created on top of old, colonial geographic areas for the production and consumption of the resources. These economic developments are leading to spatial and social inequalities and increase water insecurity as well as environmental problems such as pollution and waste management. The rising pressures and issues in water security signify that urban environmental problems are becoming critical to manage.

This chapter reviews different practices to evaluate the UWS as they relate to concepts of sustainability. We also review in what ways water insecurity is related to societal issues in emerging countries. Quantification of UWS is the heart of any water management approach

(Mukherjee et al., 2018). This chapter forms part of a growing body of quantitative approaches to analyze water security. Addressing the lack of research taking a holistic approach by including physical and social, economic, and political factors, this chapter outlines an assessment framework of water insecurity in urban areas that considers all related disciplines and their interrelationships. A conceptual model is provided that encompasses the complexity of the interrelated issues associated with UWS. Incorporating socio-economic indicators in its proposed quantitative framework intends to achieve a holistic measurement model. The chapter starts out with a discussion on the UWS and the environmental sustainability issues of the cities in emerging countries. The next sections discuss the various dimensions, approaches and indicators used in similar studies. Finally, the chapter proposes a comprehensive framework for measuring and evaluating the status of UWS, particularly for emerging countries.

2.2. Issues of urban water security

There is no universally accepted definition of water security. All the current definitions make use of different approaches to measure water security based on different sets of goals, such as 'water supply security' (e.g., Lundqvist et al., 2003; Padowski et al., 2016; Grafton, 2017), 'urban water sustainability' (Yang et al., 2016) etc. (see Appendix 2.1 for definitions of water security). Even though the definitions differ, there are a few common factors which are integrated in all of them, such as safeguarding clean and adequate water accessibility, minimizing water-related threats, and implementing policies for governing the water as a vital resource. Adequacy of water and sanitation is the priority in an equity-based goal of human prosperity and financial improvement, to guarantee security against water-borne contamination and water-related catastrophes, and maintaining ecosystem services (Brears, 2017).

Over the past decades, definitions of water security have shifted from a focus on human livelihood and its involvement in the physical water management to its engagement with the ecosystem (Appendix 2.1). Water security has become a main factor in social, political, public health, economic, environmental, and other concerns—and acts as a central link between them (Lundqvist et al., 2003). In consequence, we find that a range of core issues is required to be addressed in order to achieve and maintain water security in different geographic scales and contexts. When it comes to research on water security in urban areas, the main issues considered in previous studies include:

- *Supply* of enough water for socio-economic development and other different activity areas like energy, transport, industry, tourism etc.

- *Equal and impartial access* to safe and enough drinking water at affordable costs to meet basic needs including sanitation and hygiene, and to maintain health and levels of well-being.
- Protection of *human rights* for safe access to adequate water for all.
- Preservation and protection of *ecosystems* in water allocation and management to maintain their ability to deliver and sustain functioning of essential ecosystem services including cultural ecosystem services.
- *Collection and treatment of wastewater* for safeguarding human life and the environment from pollution.
- Collaborative approaches within and between countries to promote sustainability and cooperation for *transboundary (intra or inter states) water resources management.*
- *Uncertainties and risk management* for water-related hazards, such as floods, droughts, and waterborne diseases within a given time duration and
- Good *governance and accountability*, appropriate and effective legal regimes, transparent, participatory institutions, meticulously planned, operated, and maintained infrastructural facilities, and capacity development.

As can be seen from the above researchers have approached water security from a range of angles, however we argue that as current pluralistic societies face many challenges studies analyzing water insecurities should reflect these pluralities by applying comprehensive approaches to research. Water security in today's urbanized areas is driven by various environmental, economic, political, and social forces. They form a complex system of tightly coupled processes and feedback effects that are not yet sufficiently understood. Knowledge of these interactions is essential since the water as a resource is the base for all human activities. While seeking to achieve water security at a global scale, specific attention is required to analyze the aggregated effect of water management decisions and the effects at micro level. This is crucial for decision makers to consider as they seek to achieve the sustainable development goals (SDGs).

Water security is crucial to address in emerging countries. The highest number of people affected by water related risks in urban areas—such as scarcity of required quality water or exposure to meteorological hazards such as floods—are from emerging and developing countries (ADB, 2013; WHO, 2017). Moreover, almost 99% of the 3.4 million people lethally affected by water-related hazards are from the developing countries (WHO, 2008). Gaps between national and regional water policies and the absence of enough management plans are major causes for water insecurity in these countries. Issues include not having the necessary funding for the upkeep of water purification, distribution, and water extraction facilities, to reduce or mitigate the problems associated with wastewater generation and related threats to downstream areas; approximately 1.1 billion people are affected by these issues (Watkins, 2006). Technical and managerial inefficiency in water-supply infrastructure which endangers quality issues related to water-environment sectors sculpts the symptoms of water insecurity in the urban areas of developing and emerging countries (Lundqvist et al., 2003; Mukherjee et al., 2018; Shaban and Sattar, 2011).

Securing water, for both society and environment, emphasizes the integrated management of water resources to maintain sustainable growth (Sarvajayakesavalu, 2015; Barbier and Burgess, 2017). SDGs allude to the multidimensionality and crucial importance of water security to achieve sustainable development and underlines the need for a holistic approach such as that presented here. SDG 6 calls particularly for clean water and sanitation for all people, paying special attention to the needs of women and girls and those in vulnerable situations (Goal 6.2) by supporting and strengthening the participation of local communities for improving water and sanitation management (Goal 6B). Other SDGs also include different water and sanitation targets, such as:

- end of malaria and other water-borne diseases (Goal 3.3),
- reduction in number of deaths from water and other pollution and contamination related risks (Goals 3.9 and 6.3),
- proper management of water related disasters (Goal 11.5), chemical wastes to minimize the hazardous impacts on water (Goal 12.4),
- with the focus on protecting the poor and people in vulnerable situations (Goal 11.5) and
- conservation, restoration and sustainable use of terrestrial and inland freshwater ecosystems and their services including wetlands (Goals 6.4 and 15.1).

Particularly focusing on urban areas, SDG 11 aims at ensuring the development of sustainable cities and communities by focusing on ensuring access to safe and affordable housing, upgrading slum settlements, investing in public transport, creating green public spaces, and improving urban planning and management in a way that is both participatory and inclusive. Heading for ‘UWS’ faces complex relations inside and amongst the human and water relationship in urban areas, including a high spatiotemporal variability. This cooperation changes regionally in time and space including physical characters as well as urban development, demography, socio-economy and administration and might be affected from past urban developments (Brears, 2017). Thus, UWS is nothing but a '*persistent condition in a limited urban region under which water ecosystems can ensure the adequate access, safety, and affordability of water to meet minimum livelihood standards and human feelings of psychological security'* (Huang et al., 2015, p. 3903).

2.3. Dimensions for quantitative assessment of urban water security

For the concept of water security there is no established or widely approved set of dimensions for assessment. Accordingly, here we set out to establish a comprehensive framework to study this complex issue. An urban area is defined as a socio-ecological system interacting between different socio-environmental dimensions (Romero-Lankao and Gnatz, 2016). In the literature, assessment dimensions of urban water systems include environment, society, culture, economy, politics, technology, and governance (Romero-Lankao and Gnatz, 2016; Cunha et al., 2015). However, scholars have differed in how they measure and which dimensions they include to assess the sustainability of urban water systems. The Global Water Partnership (GWP) (2002) separates socio-economic dimension into social and economic categories for all scales. Gray and Sadoff (2007) propose to use health, livelihood, ecosystem, and production (Pahl-Wostl and Knüppe, 2016) and Shaban and Sattar (2011) argue that infrastructure for water supply and wastewater management also should play a vital dimensional role. In addition, management of risks emanating from climate change issues are also mentioned as an important dimension to consider (Shaban and Sattar, 2011). Therefore, in order to integrate socio-cultural-economic-political issues in UWS assessment, the following challenges are amongst the most urgent issues identified to date:

1. Secured access to enough and quality water to cover basic human needs for all despite of socio-economic, political, and cultural odds,
2. Technological as well as governance efficiency and
3. Systems transformation to provide sustainable water services.

In the following, we will discuss different dimensions related to availability of water, risks associated with water, issues related to water management in the developing countries and the dynamic relationship between the bio-physical environment, society as well as accessibility issues related to gender, culture, and politics, which are needed to be considered at the end to achieve a comprehensive and holistic analysis of UWS.

- *The availability of fresh water*

As cities grow and their populations increase, so does demand for water. A recent report from the World Bank (2017) points out that around 50% increase in urban water demands is anticipated within the next 30 years. By 2025, annual demand for municipal water in the world's large cities is expected to have increased by nearly 80 billion cubic meters, from around 190 billion cubic metres per year in 2012 to about 270 billion cubic metres per year in 2025 (Bergkamp et al., 2015). Many cities, regions, and countries around the world are faced with a trifecta of pressures: rapid urban population growth, economic expansion, and competing demands. These forces of change are tightening the availability of water resources in areas where tackling water scarcity is already a critical challenge (World Bank, 2017). The mission of securing and planning a sustainable water supply for urban areas in water scarce regions, particularly developing and emerging countries, is clearly no easy feat. Particularly for developing and emerging countries, water scarce cities are facing these challenges every day. Regions as diverse as the Middle East and North Africa, South and Central Asia, and parts of Latin America are still trying to explore new approaches for a water-secured future. Another aspect of water supply is leakage in the distribution system. Leakage-loss-rates of 50% are not uncommon in urban distribution systems. Around 250–500 million m3 of drinking water gets lost in many large and mega cities each year. Saving this amount could provide an additional 10–20 million people with drinking water sole in the mega cities (UN Water, 2015). With the concentration of large numbers of people and economic activities to relatively small geographical areas, augmentation of supply of water, i.e., availability of freshwater, for the cities is the first dimension to be considered for any assessment approach (Lundqvist et al., 2003).

- *The importance of risk*

Water related risk has been mentioned as a crucial dimension by a range of authors. According to UN Water (2015), in 2014, 828 million people lived in slum conditions, lacking basic services and this number grows by 6 million each year. Many slum dwellers die each year as a result of inadequate drinking water and sanitation services. Many slums are built in flood-prone areas and the areas and people in them are particularly vulnerable and at risk (UN Water, 2015). Cook and Bakker (2012) identified vulnerability to water related hazards (such as flood etc.), development-related human needs and sustainability as the major dimensions to assess water security. Whilst Lautze and Manthrithilake (2012) emphasize basic needs, environment, risk management and independence dimensions are to be considered for assessing UWS. They also suggest including a 'risk-management' indicator that is particularly linked with water related disasters (Lautze and Manthrithilake, 2012). Hall and Borgomeo (2013) argue that the risk dimension is the defining attribute among all dimensions of UWS. Therefore, Lautze and Manthrithilake's (2012) 'risk' indices can be interpreted as indicators (i) of not satisfying basic needs (for given proportions of time and quintiles of the population), (ii) of harmful environmental impacts, and (iii) to the reliability of water supplies from the actions of neighbouring countries.Underlining the importance of risk, Hall and Borgomeo (2013, p. 1), water security signifies '*the absence of intolerable risks* (related to water insecurity) *leads to consideration of a broad range of risks and context-specific evaluation of their tolerability*'. However, the approach has not specified the *time* dimension in their risk management indices; neither any specific limit in terms of how to deal with a risk when it emerges, nor to prevent it.

- *Urban water security assessment with a developmental lens*

The Asian Water Development Bank (ADB) (2013) proposes five key dimensions to analyse water security at a country level scale focusing on poverty reduction in people's lives, livelihood and governance. The overall framework proposed by Asian Water Development Bank (2013) is a comprehensive approach where all the considered dimensions are related and interconnected. However, UWS is accounted exclusively from a water management perspective measuring the adequacy and efficiency of water supply, pollution management, wastewater treatment and drainage services to the urban dwellers. Other aspects of water security such as health and sanitation, resilience to water-related disasters like floods or water-borne diseases are not accounted for in their UWS measurement scheme. Similarly, the indicators for the environmental water security are derived only for the measurement of environmental health in terms of water body restoration and considerations of water as resource; other ecosystem services are not included in this scheme. According to UN Water Report (2015), 95% of the urban expansion in the next decades will take place in developing and emerging countries. In Africa and Asia, the urban population is expected to double between 2000 and 2030. Between 1998 and 2008, 1052 million urban dwellers gained access to improved drinking water and 813 million to improved sanitation. However, the urban population in that period grew by 1089 million people and thus undermined the progress. Since 2014, 497 million people in cities rely on shared sanitation (UN Water, 2015), in 1990 this number was 249 million; in consequence the framework of Asian Water Development Bank (2013) lacks a detailed assessment of issues related to sanitation and hygiene at the city level scale.

- *The importance of overlapping relations of the environment and the society*

One of the most widely used dimensions of UWS is environment (among others Garrick and Hall, 2014; Pahl-Wostl and Knüppe, 2016; Romero-Lankao and Gnatz, 2016). The analysis of environmental vulnerability related to water insecurity has primarily been applied to assess health hazards related to climate change (e.g., Patz and Balbus, 1996; Dickin and Schuster-Wallace, 2014; Garrick and Hall, 2014). Many of the previous studies focus either on the risk of water insecurity for the society (e.g., Grey et al., 2013) or give attention to water conflicts as a threat to international security and peace (e.g., Tignino, 2010). Water pollution is included in this dimension as pollution of rivers and seas remains a big problem affecting especially coastal cities, where, for instance, more than 60% of the Latin American population lives (UN Water, 2015). Therefore, it is a fact that the risks related to water insecurity out of climatic and humanmade disasters are high in low- and middle-income countries, where up to 50% of the urban population lives in slums (World Bank, 2011). Here, social dimension of the UWS issues overlap with environmental vulnerability issues. The urban poor are vulnerable to water insecurity and related hazards due to the location of their suburbs within cities and the lack of reliable basic services and education (World Bank, 2011).

A holistic study on water insecurity needs to understand people's struggle to survive in difficult circumstances because the impact of the water insecurity stressors varies for different social groups. Different social groups have unequal access to resources, leading to unequal strengths and capabilities in coping with stressors (Udas et al., 2018). Ciurean et al. (2013) highlight effective adaptation policies for climate change that consider the assessment of social vulnerabilities through a bottom-up approach in relation to physical vulnerabilities. Leb and Wouters (2013) argue that social inequity, economic inefficiencies, and unbearable environmental conditions disrupt the pathways to achieve water security, which in turn affect national security negatively. The conceptual framework presented in this chapter builds on these studies and expands on the social dimension to better understand and assess water security issues.

- *Gender-based vulnerability and urban water security*

When it comes to water security, social, political, cultural, and economic vulnerabilities need to be considered. Gender based vulnerability as a subset of social vulnerability is part of a process that creates differential vulnerabilities for people belonging to different gender categories (Sugden et al., 2014; Goodrich et al., 2017). Here, it is crucial to apprehend that 'gender' is not just an indicator for women and men; rather, it encompasses heterogeneity in gender categories and intersectional approaches are needed to understand the intersecting factors and positions that create vulnerabilities to water insecurity (Ravera et al., 2016). It is well known that floods and droughts have an adverse gendered impact on health (WHO, 2014a, b). However, less is known about the variations within gender and the influence of other intersecting factors such as ethnicity and socio-economic factors on water hazards and injustice.

We also know that our relation to, use of and access to water differ according to gender, i.e., water collection is in its majority carried out by women (UN Women, 2018) which means that gender matters in water security. Thus, without considering the facts of inequalities in the society and their individual impacts, the inclusive character of an assessment of water security, particularly for the urban areas, are incomplete. The importance of gender continuum in understanding water insecurity has not been analysed to any extent in water security studies thus far, a shortcoming, our framework seeks to address. We underline the importance of the intersectional position and gender to understand individuals' and groups' vulnerability to water insecurity. Among the issues we seek to explore is the complexity of gender and how it affects water insecurity, which we will do by opening the gender concept to include people across the gender continuum, something which has not been done so far.

- *Cultural urban water security*

Culture is understood as a system of shared values, beliefs, behaviour, and symbols that the members of society, groups or individual families use to interact within their social environment (Spencer-Oatey, 2012). It is a comprehensive outcome of societal values, traditional practices, local belief, taboos associated with sexual orientations, gender issues as well as other differences.

(Schelwald and Reijerkerk, 2009; Warner et al., 2008). Social aspects affect social and interpersonal behaviour and herewith the behaviour related to use and views of water (Pfau-

Effinger, 1998; Van Oorschot et al., 2008). Thus, these socio-cultural factors are not only constructed by social norms and interpersonal interactions but also institutionalized into policies and public institutions (Van Oorschot et al., 2008). All these aspects have only rarely been studied related to water security, something that has resulted in inadequate knowledge about how these aspects influence water security. We argue that this is crucial for the understanding of how people relate to water, and different water sources (i.e., the position of the Ganges in India), who uses water, how and when water security occurs. Culture is crucial to consider as it influences not only individual and group behaviour, but also through its institutionalization into systems of governance affecting how water security is dealt with in different areas.

- *Politics and urban water security*

Water security characteristically is a political issue (Bogardi et al., 2012; Leb and Wouters, 2013) and persistently visible in transboundary conflicts (Singh, 2008; Abdolvand et al., 2015). In the case of urban areas, water security is an issue for conflicts between coexisting social, cultural, religious, and political groups. It is also an issue that is dealt with by and through different levels of governance, i.e., local, regional, national, and international, creating a complex web of politics of water. Here, we see politics as a determinant of water accessibility and management, as politics relates to the way people deal with each other, select others for elected offices, form political parties, negotiate, contend with other parties and the entire system whereby this happens. On the

other hand, governance refers to the social, economic, administrative as well as political systems that affect water's use and management within the city. Thus, governance is a determinant of the equity and efficiency in water resources and services allocation and distribution, and ultimately balances water uses between social, economic and political activities and ecosystems (Bakker and Morinville, 2013).

Water security as a key component of human security must be addressed into the assessment framework (Biggs et al., 2013; Leb and Wouters, 2013). The socio-economic and political issues of UWS that power dynamics at the international, national, regional, and even local level also impact the equitable allocation of water to stakeholders, including business, communities, and ecosystems (WWF, 2016). Singh (2017) argues that for a proper water resources management, socio-political issues need to be considered to the same degree as technical and financial issues.

Financial challenges can undermine the effectiveness of infrastructural or technological actions to achieve UWS (Singh, 2017). For example, in 2014, 27% of the urban dwellers in the developing and emerging countries did not have access to piped water at home and 828 million people lived in slums or informal settlements that were scattered around the cities whereas they paid up to 50 times more for a litre of water than their richer neighbours, since they often had to buy their water.

from private vendors (UN Water, 2015). Hence, wherever water is concerned, the effective use of the available water resources is important as water plays a crucial role for many objectives regarding the urban human habitat (Bengtsson and Shivakoti, 2015). Nevertheless, to take full advantage of such synergies requires carefully conceived cross-sectoral engagements to reach the goal of UWS, which is based on good understanding of inter-linkages between various objectives.

(Bengtsson and Shivakoti, 2015). In our comprehensive framework we will encompass measurements of governance and politics, both explicitly, to enable recommendations for better solutions to achieve water security for all.

2.4. Quantifying urban water security through an inclusive assessment framework

The inclusive assessment framework for UWS needs to address the complex and interwoven *environmental, social, cultural, political, economic, governance and technological* dimensions to create a tool that can measure the complex web of issues contributing to UWS. The supply and usage of quality water as a renewable resource at the minimum replaceable limit to fulfil the population's need/demand needs to be considered as a basic human right. Therefore, availability and accessibility of adequate water as well as affordable to all must be accounted for. The next important issue to be considered is the urban ecosystem services at a minimum depleting rate of the non-renewable, where allocation of enough water is necessary to maintain a sustainable urban ecosystem service. Wastewater management concerns the alarming levels and concentration of pollutants generated in these growing urban agglomerations specifically for the poor areas within and outside of the main city due to the lack or poor waste management. Thus, properly planned infrastructural and technological capabilities concerning water-borne diseases and natural hazard must be a crucial response from governance and institutions for the proper management of water resources (Bakker and Morinville, 2013).

- *Issues of concern for conceptualization of the inclusive framework*

The measurement approaches for a quantitative assessment of the sustainability of urban water systems as provided by the literature (see Appendix 2.2) focus predominantly up to a meso (regional) level. Therefore, the variations within a city level scale, such as neighbourhood effects, intersectional issues and cultural aspects within the urban ecosystem services were missed. Case-specific quantitative index models, which reflect coupled human-water-system dynamics in comparative temporal and spatial scales are rare to find. Besides, the trade-offs between different water issues related to ecosystem services as well as socio-economic potentialities need to be addressed in selecting indicators and developing overall indices. The assessment approaches listed in Appendix 2.2 are primarily looking at the sustainability of urban water systems. The focus is hence distributed either on the environment or the policy or the urban water system services issues more than on holistic procedure. The different measurement approaches for sustainability (Appendix 2.2) and their compatibility with the dimensions and issues are compiled in Table 2.1.

Table 2.1. Compilation of approaches, dimensions, and issues of urban water security.

Approach	*Dimensions							**Issues									
	Env.	Soc.	Cult	Pol.	Econ.	Gov.	Tech.	Av	Ac	HR	WQ	WM	NH	WD	Mg	Tech	UES
Integrated Urban Water System Modelling (IUWSM) (Behzadian and Kapelan, 2015; Last, 2010; Makropoulos et al., 2008; Mitchell et al., 2001; Rozos and Makropoulos, 2013; Urich et al., 2013; Venkatesh et al., 2014; Willuweit O'Sullivan, 2013)	X				X	X	X	X			X	X				X	
United Nations Commission on Sustainable Development (UN-CSD) (UN-CSD, 2001)	X	X			X	X		X	X		X		X	X	X		X
Ecological Network Analysis (ENA)	X				X			X	X							X	X

(Zhang et al., 2010; Bodini et al., 2012; Pizzol et al., 2013)																	
System Dynamics (SD) (Baki et al., 2012; Sahin and Stewart; 2013)	X	X	X		X	X	X	X							X	X	
Territorial Material Flow Analysis (UM-MFA) (Ayers and Ayers, 2002; Codoban andKennedy, 2008; EIU, 2011; Kennedy et al., 2007; Kennedy et al., 2015; Mollay et al., 2011; Newman et al., 1996; Newton et al., 2001; Pina and Martinez, 2014; Singh et al., 2009; Wernick and Irwin, 2005)	X				X	X	X	X	X		X	X				X	
Water Mass Balance (UM-WMB) (Bhaskar and Welty, 2012; Chrysoulakis et al., 2013; Kenway et al., 2011; Marteleira et al., 2014; Thériault & Laroche, 2009)	X					X	X	X	X			X			X	X	
Life Cycle Assessment (LCA) (Fagan et al., 2010; Lane et al., 2015; Lundin, 2003)	X				X	X	X	X	X		X	X	X	X	X	X	X
Water Footprint (WF) (Hoff et al., 2014; Vanham, 2012)	X	X			X			X	X	X	X					X	X
Environmentally Extended Input-Output Analysis (EIO) (Lenzen, 2009; Lenzen and Peters, 2009)	X	X			X												
Aqueduct water risk indicators (Gassert et al., 2013)	X	X			X	X	X	X	X				X		X	X	X
Index of water security threats	X	X			X	X	X	X	X							X	X

(Vorosmarty et al., 2010)																	
Pressure-State-Response (PSR) (OECD, 2004; OECD, 2003)	X	X			X	X	X	X	X		X	X	X	X	X	X	X
Driver-Pressure-State-Impact-Response (DPSIR) (Marsili-Libelli et al., 2004; Pirrone et al., 2005; WWAP, 2006; WWAP, 2002)	X	X			X	X	X	X	X		X	X	X	X	X	X	X

*Dimensions: Env: environmental; Soc: social; Cult: cultural; Pol: political; Econ: economics; Gov: governance: Tech: technology

**Issues: Av: availability; Ac: accessibility; HR: human rights; WQ: water quality; WM: waste management; NH: natural hazards; WD: water-borne diseases; Mg: management; Tech: technology; UES: Urban Ecosystem Services.

- *Considering culture as a dimension*

To include social indicators, which are not commonly included in water security research, provides an improved tool to assess UWS and is the precondition to develop sustainable strategies that enable water security for all. Culture affects the access, use, consumption and, importantly, vulnerabilities when it comes to water security. For example, there are clear differences of attitudes towards the use of water, sanitation and hygiene facilities and the handling of excreta between diverse cultures. Despite an instinctive repulsion towards excreta, different cultures influence different attitudes towards handling of excreta and maintenance of personal hygiene in terms of water usage (Warner et al., 2008). Cultural values related to gender affects who uses water, how, where, and when, i.e., who washes the clothes, using water from where and at what time. Thus, cultural values, gender and water insecurity are tightly interlinked and need to be explored and included in the measurement tool. Culture affects water security also in terms of how we see and define our water sources, e.g., the meaning of the river Ganges in India. In addition, culture is institutionalized into governance and governmental institutions. In consequence, we need to identify how cultural norms may enable or hinder UWS as a part of the comprehensive UWS assessment.

- *Water justice and gender*

The approaches of UWS to date mainly focus on the assessment of the urban water system and its sustainability from either environmental or economic perspectives (Table 2.1). However, as the UNESCO proposal for the global sustainable development goals on water-Target 1 claims; “universal access to safe drinking water and sanitation for all” and, thus, points out that the right to clean water is fundamental. Violations of the right to water can be traced back to injustices including poverty and other social exclusion issues (Leb and Wouters, 2013). Overall, the role of gender in water insecurity issues is crucial. In the social sciences it is recognized through studies on how gender shapes issues of water access, use, governance, and adaptation to water insecurities and environmental crises (Alston, 2006; Fletcher, 2018; Sommer et al. 2015, WWAP, 2015; UNEP, 2016). Gender roles and relations are important explanatory issues for UWS as water access, needs, and uses are all shaped and influenced by gender roles and are in relationship to any given society (Ray, 2007; Wallace and Coles, 2005). The importance of gender is further underlined by the fact that water security risks are higher amongst women and third gendered people (Demetriades and Esplen, 2010; Denton, 2002; MacGregor, 2009); in consequence women and third-gender people are often more vulnerable and exposed to risks related to water (Fletcher, 2018; Sommer et al., 2015). This includes a high vulnerability of women and third gendered people due to natural disasters like floods and droughts (Fletcher, 2018). Accordingly, UWS cannot be achieved without accounting for gender equality and social inclusion within an assessment framework (Pangare, 2016). The inclusion of gender mainstreaming in UWS research is an opportunity to involve women and third gendered people in the design, planning, implementation of water services, management of natural resources, and in the development of disaster risk reduction strategies; gender-insensitive policies will only impede global efforts to eradicate poverty and achieve water security. Investing in the infrastructure needed to provide adequate water and sanitation facilities can also sharply reduce health costs and improve productivity (Pangare and Pangare, 2008). Previous studies in different disciplines have highlighted that vulnerabilities and experiences of water security vary according to a range of socio-economic issues (Demetriades and Esplen, 2010; Denton, 2002; MacGregor, 2009; Pangare, 2016). The approach of the proposed framework addresses the role of poverty and gender and the combination of intersectional vulnerabilities by including variables related to gender issues rarely included in empirical studies on water security.

- *Including governance measurements*

Water crisis is not always or only due to physical scarcity of water but is also frequently due to inadequate or inappropriate water governance (Bridges, 2007). When it comes to urban water governance, different aspects need to be considered. First, urban water governance is related to and influences the extent to which the goals of UWS can be reached. Secondly, it influences and is directly related to the management and coordination of UWS. In consequence, urban water governance is a crucial dimension to be included in any UWS assessment scheme. We will include indicators directly related to the organization and management structures and we will explore other processes in which governance matters, such as in how successfully achieving UWS, and to what extent urban water governance contributes to higher or lower levels of UWS. In line with the comprehensive approach pursued stakeholders in different positions (e.g., NGOs, civil servants and people living in water insecure areas) need also to be included to identify the ways in which urban water governance matters. For example, due to increasing urbanization, the municipal water demand in Chinese cities is projected to grow 70% in 2030 (Wang et al., 2017). Although China's need for renewable freshwater continues to escalate, availability is barely one-third of the world's average. Shanghai falls among China's 36 worst cities regarding water quality (Zhen et al., 2017), and between 2010 and 2012, it was reported by the city's water census that 3% of local surface water was clean for fish farms or household use. Shanghai typifies the water governance problem China is facing from one mega city to the next and, hence, backs the urgent need for a comprehensive UWS assessment framework for the policy makers.

- *Achieving sustainable UWS*

Sustainability analysis to achieve UWS needs to account for the inter-relationship between water systems and economic production in a way that includes health and welfare. Reviewing various approaches related to UWS and sustainability it becomes evident that there are understated assumptions regarding what UWS means and how it can be achieved. For example, United Nations Commission for Sustainable Development (2011) considers sustainable development as directly compatible with economic growth. Hueting and Reijnders (2004) oppose this and consider sustainable development as an assumption 'neither demonstrated nor plausible'. Otherwise, any action taken by a city administration to augment the supply and ensure the sustainability of the urban water system can have an opposite effect, such as increasing the gap between demand and supply, or producing more pollution. Moreover, low or absence of proper maintenance of the storm-water management system can have a stronger adverse effect in slum areas than other parts of the city. It affects supply and water quality which raise the insecurity of water in the city. These social, environmental, and economic effects that affect the city's water security are vital to include in measurements to understand what actions should be considered to maintain a water secured city. Hence, the concept of risk should be deployed across 'the environmental, social, and medical sciences', and therefore the framework should be compatible with an interdisciplinary approach to analyse UWS (Hall and Borgomeo, 2013).

In the proposed conceptual framework, social equity, cultural, political, and economic aspects are considered for the development of the resource management plans (Leb and Wouters, 2013). Underlying this concept is also an acknowledgment that it is difficult to separate the social and cultural aspects from each other. They are intertwined, and their combination impacts the water security in a society—for example, through sanitation and hygiene behaviour of a certain population. The relationships between culture and policies in each society are factors that have been studied in other public policy areas, such as welfare policies (Hiroko, 2011). Including gender values and norms in an UWS assessment matrix, and to account for how it influences water security and the vulnerability and behaviour related to water security is deemed crucial in the proposed conceptual framework. Van Oorschot et al. (2008, p. 11) argue that culture affects and combines 'the short-term effects of social interactions at the micro level with the more enduring cultural values and models at the macro level of society'. Accordingly, it becomes crucial to incorporate measures that can start unpacking and understanding these complex interactions, and to take them into account when designing policies and campaigns that can help to achieve UWS. In consequence, the proposed framework will include intersectional measurements and will, thus, include questions considering ethnicity/origin/race and socio-economic vulnerability to water insecurities. This concept also reviews factors that can enhance our understanding of a person or group's vulnerability in relation to UWS.

- *The need for new data at city levels*

There is an intrinsic importance of baseline data collection for the appropriate assessment of water security (Mukherjee et al., 2018). Achieving water security is definitely a paradigm shift for emerging and developing countries from the ways this valuable resource is being 'managed' so far (Mukherjee et al., 2018). Despite the deep-rooted affinity to underestimate the necessity of research of water security at all levels, the value for baseline data collection remains indispensable for the sustainable management of the water resources for the security of the inhabitants of a country. It is also crucial to include city level data in analyses of water security to ensure a more comprehensive understanding of what drives and determines water security, such as availability and accessibility of quality water at the household level. Coherent collection of long-term data coupled with local knowledge is the priority for such research. The primacy of institutional responsibilities for data collection, the level of existing data availability, and data sharing options between different institutions need to be addressed. Also, these aspects are important to frame conditions to provide appropriate recommendations that can ensure an appropriate data collection technique as well as appropriate mechanisms for data sharing. It has therefore been decided that intensive survey at household level and existing data from the authorities from the lowest level will be required and henceforth, combined to create data that satisfy the need for detail that is required to create an improved UWS index.

2.5. Conceptualising the inclusive framework for urban water security assessment

The formation of our quantitative inclusive framework is based on the ecosystem services and system approach. The concept of UWS, here, emphasizes the basis of sustainability of ecosystems, focusing on reducing the probability or risk of ecological disaster caused by human-induced stresses. To assure long-term sustainability, UWS assessment needs to be addressed from an integrated social-ecological systems perspective (Pahl-Wostl and Knüppe, 2016). The main spirit of all the definitions of water security published so far (Appendix 2.1) maintains a trade-off between usage and management of water resource for both the human and the environment (Stewart-Koster and Bunn, 2016; Grey and Sadoff, 2007; Naiman et al., 2002). Therefore, managing the conflict between supply (enough quality and quantity) and risk (anthropogenic and environmental) to the provision of water ecosystem services in an urban area is a challenge for the water scientists and managers (Stewart-Koster and Bunn, 2016). Pahl-Wostl and Knüppe (2016) argue that the ecosystem services need to be served as a connection for integrating fragmented institutional settings to support and negotiate about trade-offs for water security without jeopardizing the environment. From this point of view, urban ecosystem services principles are central to define an inclusive and holistic sustainable approach for the quantification of UWS. Thus, a modified version of Driver-Pressure-State-Impact-Response (DPSIR) as a framework is proposed here to assess the dynamic interactions and feedback effects between water and people in an urban area.

This quantitative framework will encapsulate the UWS dimensions and factors of a system approach (Driver, Pressure, State, Impact and Response) into three major matrices: *Pressure* (Driver and Pressure), *Process* (State) and *Impact* (Impacts and Responses). *Pressure* matrix will deal with the Driver and Pressure factors of the problems, the *Process* matrix will comprise the State factors and the *Impact* matrix will involve Risks and Response factors from both physical and socio-economic dimensions of UWS. Rather than setting a simple DPSIR framework, we added to the DPSIR a more integrated and bottom-up approach to assess the scenario quantitatively. This conceptual framework will include the most affected and vulnerable groups for better understanding of the issues related to UWS. The concept includes the identification of the issues faced by these groups and how they are being perceived within themselves. The issues are then put together into three main queries:

1. What are the Drivers and Pressure factors on the water services?
2. What are the State factors (i.e., uses and consumption) of the water resources available and supplied? and,
3. What are the Impacts and associated risks and the Responses from the governance and instructional perspectives?

The answers are expected in numbers and will include all the dimensions (and issues) mentioned above. In this way, the mitigation decision will be easier to take than under the present conditions. The framework of the quantitative indicator system will have to include the following measurements:

i. *Pressure* matrix

The *Pressure* matrix will cover Drivers and Pressures associated with the urban water system of a city, which determine the ultimate security from water for the environment and the citizens.

Driver factor (D) illustrates the social-economic and political scenarios in the communities in and around the city as well as the consistent changes in lifestyle, consumption, and production patterns. Decadal population growth, population density, gross domestic production, per capita income, Gini coefficient and other factors that directly or indirectly influence urban ecosystem services and over all UWS will be included here.

Pressure factors can be congregated in bio-physical and socio-economic aspects. *Pressure* indicators (P) try to find the reason behind the status of the water security in a city, measuring the impacts that human activities exert on urban water systems. Special focus is on the effect of human activities on ecosystem services and on the water demand (quantity) and increasing exposure to water-related hazards (quantity, quality). Conflicts between water availability and accessibility often occur in any mega cities in developing and emerging countries despite of having an adequate amount of freshwater resources available. As a result, the total water-resource utilization, water-quantity ratio of inputs and outputs in a city area, per capita water-resource use, and ecological water demand and related data are required to be included in the index of UWS evaluation. The gap between demand-supply related to physical, social such as caste, religions, sexual minority issues should also be considered.

In addition, some specific socio-economic pressures, such as the presence of water-intensive industries, widespread open defecation, or gender issues in access to water and sanitation need to be included as *Pressure* indicators.

Land subsidence due to unsustainable groundwater abstraction, huge building construction, encroachment of wetlands suitable for urban expansion need to be considered as effects causing water stress in cities, both in terms of flood problems and water scarcity. Besides, in case artificial drainage systems occur, inadequate environmental flow in and around the city also need to be considered as *Pressure* indicators for the UWS.

ii. *Process matrix*

The *Process* matrix expresses what is happening to the state at the various scales of city's UWS status. The *Process* matrix will cover the State indicators (S) of the UWS, which reflect the ecological health as well as socio-economic status of the city. Regarding water quality, pollutant

emissions are the main stressor. Therefore, various sources of pollutants should be considered. Water quality indicators can be obtained from conventional water monitoring and sampling. The State indicators will concern the infrastructure to manage the quality and quantity of water as well. The quantity of water in a city can be described in terms of water stocks and flows and exchanges with areas outside the municipal boundaries considering groundwater and surface water. Groundwater extraction from wells within and outside municipal boundaries is an important source for urban water supply.

Surface water and groundwater quality will be compared to ambient water quality standards including both, chemical and biological pollutants. Biological contamination is particularly relevant for shallow groundwater wells, often used by households in cities with inadequate water supply systems, which are contaminated from leaking sanitation infrastructure (leaking sewers, septic tanks, latrines, etc.). Water supply infrastructure from the abstraction points to the household-levels, sanitation infrastructure and flood protection infrastructure need to be considered when evaluating the state of urban water infrastructure. Relevant indicators for the state of the infrastructure include coverage of water supply systems in terms of connection rates and supply capacity, drinking water quality standards, percentages of wastewater collection and treatment, distinguishing between primary, secondary, and tertiary treatment, leakages in drinking water supply and sewerage systems, and adequacy of storm water and flood protection infrastructure. Lastly, there is a strong link between solid waste management in a city and the amount of garbage in streams, canals, and wetlands. Therefore, indicators related to the site, and treatment facilities associated with city's solid waste management is an integral part of the *Process* matrix.

iii. *Impact matrix*

The *Impact* matrix will cover a significant number of indicators for a comprehensive analysis of impact and responses from the government and non-governmental institutions associated with the urban water systems. Impact indicators (I) characterize the changes in the state which reflect on the functioning of the urban water system from all individual, societal, institutional and ecosystem perspectives. It can be bio-physical (e.g., floods etc.) or societal factors (e.g., accessibility due to the societal discrimination) which affect the quality and quantity of ecosystem services and, certainly, the livelihood of the inhabitants. The *Impact* factor expresses the risks accompanying the manifestation of insecurity from water in a city in terms of disasters or scarcity.

Unlike, State indicators, Impact indicators will not only focus on the bio-physical part of the entire water system in a city but will also include the provision of risks and problems associated with water-borne diseases. Risks related to water quality and sanitation which are related to the physical infrastructure and financial condition of the city governance for managing uncertain calamities like floods are also needed to be included in the assessment. For cities like Kolkata, the risks related to urban water system are also not linear in character. There are possibilities to have malfunctioning of water supply system in terms of breaking down during high demand period or is contaminated due to the leakage. These aspects along with the affordability for poorer households, should be considered for the assessment as risks to UWS.

Response indicators (R) are majorly decisions and policies which are taken repetitively to act for or against the impacts on the water security. They control the Drivers, decrease Pressures, and reduce negative impacts of malfunctioning urban water services and functions (Sekovski et al., 2012) through regulation, prevention, or mitigation to maintain/restore the state of the sustainable

UWS. Response towards gender mainstreaming in the policy related to urban water management will also be taken into consideration here. The focus of these response indicators should not only be on the governmental response while societal response is equally important.

Generally, urban water systems are complex and dynamic, Response indicators should cover the innovative and developmental decisions taken for all technical, institutional, and organizational dimensions considering their own timeframes and scopes. Further, many responses require dealing with uncertainty and ambiguity, e.g., when it concerns policymaking for future climate change issues. Therefore, a significant number of indicators must cover all the existing policy or decision-making focused on future uncertainty for resilient, adaptive, and robust urban water systems for sustainable functionality.

To design a resilient and valid quantitative assessment framework, we need to focus on the sustainable water future of the urban area from social, economic, and environmental perspectives including the management of infrastructure required to achieve sustainable urban form and structure (Mukherjee et al., 2018). UWS issues are linked with different urban ecosystem services, which signify the sustainability of the quality of life. This sustainability is reliant upon input and output of the urban area. The urban input-output system depends on the lifestyles (according to the socio-economic standard and their ‘needs/demands’) and the usage/accessibility of technology to control the consumption of resources and creation of wastes (including pollution). Therefore, urban water and sustainability measurement approaches vary with the different value-added activities in different socio-economic pockets of a single urban area depending on their resource-consumption rates and the production of the wastes and pollution. Systematic measurement of these different urban characteristics in different socio-economic and environmental compartments of an urban area are necessary to identify and assess the water resource efficiency. Our proposed assessment framework is inclusive in character because it focuses not only on the physical/environmental side of the urban water system but also on socio-economic, political, and cultural aspects that are related to and impact water security. Overall, the proposed framework is conditioned to add to our understanding of barriers impeding UWS for all communities at household level.

2.6. Conclusions

UWS is a complex system where a multiple of actors and factors are at play. This makes addressing water insecurity issues a difficult task. It is also a task where we need to disentangle this web of factors to create strategies capable of addressing the issues impeding a water secure future. This chapter reviewed existing research and identified gaps. A multitude of approaches to measure UWS are available. Only a few studies have identified the need for water security as the main factor for growth and sustainability for the society. The proposed assessment framework has been conceptualized to facilitate active discussion and mitigation approaches between participating experts and the stakeholders. This framework is proposed to consider the strategies for cities that assures water security for all but not in exchange for ecological integrity. This inclusive conceptual framework needs to be developed at a micro level to identify the best measurements for a holistic measurement tool. On this basis, it can be scaled up to regional and national levels to be incorporated in planning and management decisions. The importance to engage wider public in debates on emerging scientific issues such as UWS is to provide a successful adaptive plan for capacity building and making the society more resilient to the climate change related disasters in developing and emerging countries. It also underlines the importance and relevance of science for policies. Through this strong linkage, it will be ensured that the citizens keep informed on the development and the role of the scientists. Simultaneously, the policy makers will play a role in broadening the understanding of the needs to make the city more sustainable and provide the assurance to achieve water security for all.

The focus of the proposed integrated assessment framework of UWS is to associate and amalgamate human-oriented and environmental perspectives. The focus of the proposed conceptual framework will be on each key dimension to achieve goals of UWS. The bottom-up concept of the assessment will foster the idea of integration through a decentralized and holistic management technique. Integration of local ideas will be involved in the procedure to touch the various aspects of needs, demands, risks and developmental perspectives. This way, the ‘integration’ will bridge ‘people, planet and profit’.

3. Study area

An overview of the impacts of land use land cover changes (1980 -2014) on urban water security of Kolkata [2]

Abstract

Urban Water Security is essential in urban planning to manage cities' water infrastructures and strengthen their water stress resilience and adaptive capacities. Decision making, governance and socio-economic factors play important roles in achieving Urban Water Security. Kolkata is a growing megacity in a developing country, which is facing rising pressures on water-environmental provision due to the rapid population growth and urbanization and resultant governance and infrastructural issues. This review focusses on Kolkata, which is facing critical water issues, as a case study. The study presents an overview of the urban water (in)security and its dimensions in Kolkata city, such as water consumption and distribution in the city along with the changing land use - land cover of the city area, based on the results obtained from the satellite data-based land use - land cover classification, available literature, and documents from public institutions.

Keywords: population growth, land use - land cover, image classification, change detection, water security

3.1. Background

Urbanization is a human-induced process and results in land use – land cover (LULC) change and concurrent alteration of the quantity and quality of surface and groundwater resources especially in the peri-urban areas (Mohan et al., 2011; Maiti and Agarwal, 2005). Land use is a combined result of human activities and natural factors. Land cover, on the other hand, is either natural or the effects of land use changes due to, especially, human activities. (Mukhopadhaya , 2016a; Reveshty, 2011) Changing societal needs and priorities come along with the growing number of people and housing densities (Maiti and Agarwal, 2005; Ramachandra et al., 2012) and in turn affect the environment (Mohan et al., 2011). Unplanned urbanization results in sprawled regions within and outside of the city centers; these areas usually lack basic infrastructure such as treated water supply, sanitation, and electricity

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

(Ramachandra et al., 2012; Sudhira et al., 2004). In consequence, the resulting water insecurity in the urban and peri-urban areas is either triggered directly by population increase, demand-supply problems, problems regarding surface water bodies and availability, problems in slums regarding sanitation and hygiene or indirectly by the environmental risk related issues (such as floods) and preconditions (such as shrinkages of surface water bodies, impervious surface effect on groundwater recharge and urban heat islands) (Romero-Lankao and Gnatz, 2016).

"Water Security" is a conceptualized term, which ensures every citizen with the amount of quality water required for his or her everyday life (Narain, 2016). There is no universal definition (neither measurement index) of Water Security as it varies with approaches and perceived with different set of goals it deals with. There is, rather, a range of published definitions of water security by different government, non-government agencies and scholars till date. Every definition is different from each other, but there are a few common factors which integrate all of them. These are the goals which drive the approach to reach water security in a region. The concept of urban water security emphasizes the availability and accessibility of safe and enough water without harming the sustainability of ecosystems, focusing on reducing the probability or risk of ecological disaster caused by human-induced stresses. Therefore, in this article we adapted the Sustainable Development Goal 6 which refers to clean, accessible water for all, but the right to water security entitles everyone to sufficient, safe, acceptable, physically accessible, and affordable water for domestic uses (UN, 2015). Since the issues are huge and needs individual attentions to the details, for this article, the discussion is based on only three broader aspects, i.e., water demand and supply, accessibility and the risks associated with flood, water-borne diseases, and waste management, to get an overview of the study area in terms of water security. Water insecurity in urbanized areas in general bases on various socio-economic factors: next to uncontrolled population growth, for example, it bases on poor governance and mismanagement of the water supply system. Parallel, physical processes like climate change must be considered as a catalyst. To establish a sustainable urban water management system character such as the ratio between availability and required amount of drinking water supply, physical and virtual water demand and supply of water are the major components that need to be considered.

New or newly emerging countries can be characterized as being in a dearth of financial potentiality to mitigate water-environmental issues. The greatest number of people who are affected by water related problems in urban areas such as water scarcity of required quality water live in emerging countries (WHO, 2013). Gaps between national and regional policies for water result in the lack of efficient management plans. In consequence, management decisions regarding purification, distribution, and extraction facilities, and to reduce problems associated to sewage disposal and related threats to the downstream areas are deficient to missing governance structures (Watkins, 2006).

Kolkata is the capital of West Bengal state of India. Core Kolkata city spreads over around 200 km^2 and has a population of 4.5 million people. The greater urban area includes 41 other cities and hosts nearly 15 million inhabitants, making it the third largest city area in India. Since 1690, the approximate year when the British founded Kolkata, it has been expanding randomly without having a proper master plan (Anon, 2011). Besides, Kolkata is blessed ecologically because it has, "*the Ganga flowing beside its western end, traditionally huge groundwater reserve and wide wetlands area in its eastern fringe which naturally treats its wastewater and turns that as raw water for fishery and agriculture."* (Basu, 2016). Despite these advantages, the city is at present increasingly running into water insecurity.

The Ganga river system contributes significantly towards the transport of pollutants to the coastal areas of the Bay of Bengal (Pal et al., 2012; UNEP-DHI and UNEP, 2016). The river's poor surface water quality is closely related to insufficiency of wastewater treatment facilities (Sengupta et al., 2014; Singh et al., 2015). In consequence, waterborne diseases are still an important issue to deal with (Sengupta et al., 2014). Beyond, Kolkata has recently received the 'extreme risk' tag as it ranks 7^{th} on the global list of cities most vulnerable to climate change (Maplecroft, 2016). It is assumed that until 2025 Kolkata frequently will be hit by storms, cyclones and hurricanes coming along with extreme temperature and rainfall events. These weather extreme events will directly affect the existing water-environment and socio-economic activities bringing risks to human health and eco-system health (Sengupta et al., 2014; Barata, et al., 2011).

In this article the linkages between LULC change and urban water security are explored for the Kolkata Municipal Corporation (KMC) area. Focus is set on uncontrolled urbanization processes and insufficient water management practices, which have their resultant combined effects on water insecurity within the KMC area. Building on land use-land cover change detections and literature survey, the dynamic linkage between land use-land cover change and urban water security is overviewed. The local scale of urban water security problems within the KMC area caused by land use-land cover changes over the last four decades and the resulting impacts (direct and indirect) on the existing infrastructure are addressed through the review of scientific literature and reports.

3.2. Study area

The study area encompasses Kolkata Municipal Corporation area (KMC), located at the left (eastern) bank of the river Hooghly in the western Ganga delta (Figure 3.1; 22˚ 28′ 00” - 22˚37′ 30” N 88˚ 17’ 30” - 88˚25’ 00” E). The climate of Kolkata is a tropical wet-and-dry climate (Aw according to Köppen climate classification system). The city experiences a hot pre-monsoon season from late March to mid-June followed by a monsoon period from mid-June till mid-September and lastly a slightly cooler dry season from mid-October until mid-March (Mishra, 2011). The annual temperature averages 26.8 °C with monthly mean temperatures ranging from 19 °C in January to 30 °C in May (Maplecroft, 2016). The hot pre-monsoon season in Kolkata is windy in the afternoon and often violent dust storms are brought by the convective '*Kal Baishakhi*' winds (Nor'westers), accompanied by spells of thunderstorms or hailstorms and heavy rains with ice pellets or sleets. During late pre-monsoon season (May and June) maximum temperature rises to 38° C. The Monsoon season is characterized by heavy rainfall which especially is expected in August (monthly average 306 mm). The annual rainfall averages 1,582 mm (1971-2010), comprising average monsoon rainfalls of 1182 mm (1971-2010) and average non-monsoon rainfall of 365 mm (1971-2010) (CSE, 2015). The annual sunshine hours in Kolkata average 2,528 h (1971-2010) with maximum number of sunshine hours occurring in March. Kolkata is located approximately 150 km upcountry the Bay of Bengal coast, still being under the influence of sea wind movement and close enough to make it highly humid corresponding to air moisture (Mishra, 2011).

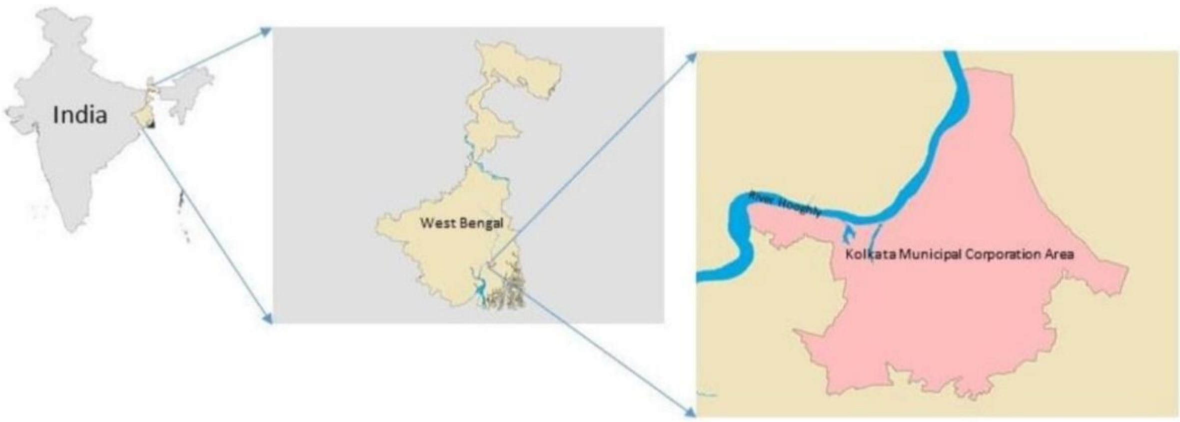

Figure 3.1. Location of Kolkata Municipal Corporation (KMC) area. Data source: Kolkata Municipal Corporation, 2016.

Kolkata Municipal Corporation area (KMC, area 205 km^2) forms the centroid of the Kolkata Metropolitan Area (KMA, area 1886.67 km^2) and corresponds to the urban agglomeration of the city of Kolkata (Figure 3.2). KMC currently is composed of 144 (including the newly added three) *wards*, which are grouped into 16 *boroughs* or administrative blocks (Table 3.1; Figure 3.3) having 21 assemblies and 3 parliamentary constituencies. Within the KMC area no so-called "big industry" occurs; the majority is small scale industries which are mostly spread along the banks of river Hooghly. The Kolkata industrial hub is a major market in eastern India. The Kolkata port functions as a major entry point for neighboring countries like Nepal, Bangladesh, and Bhutan as well as for northeast India.

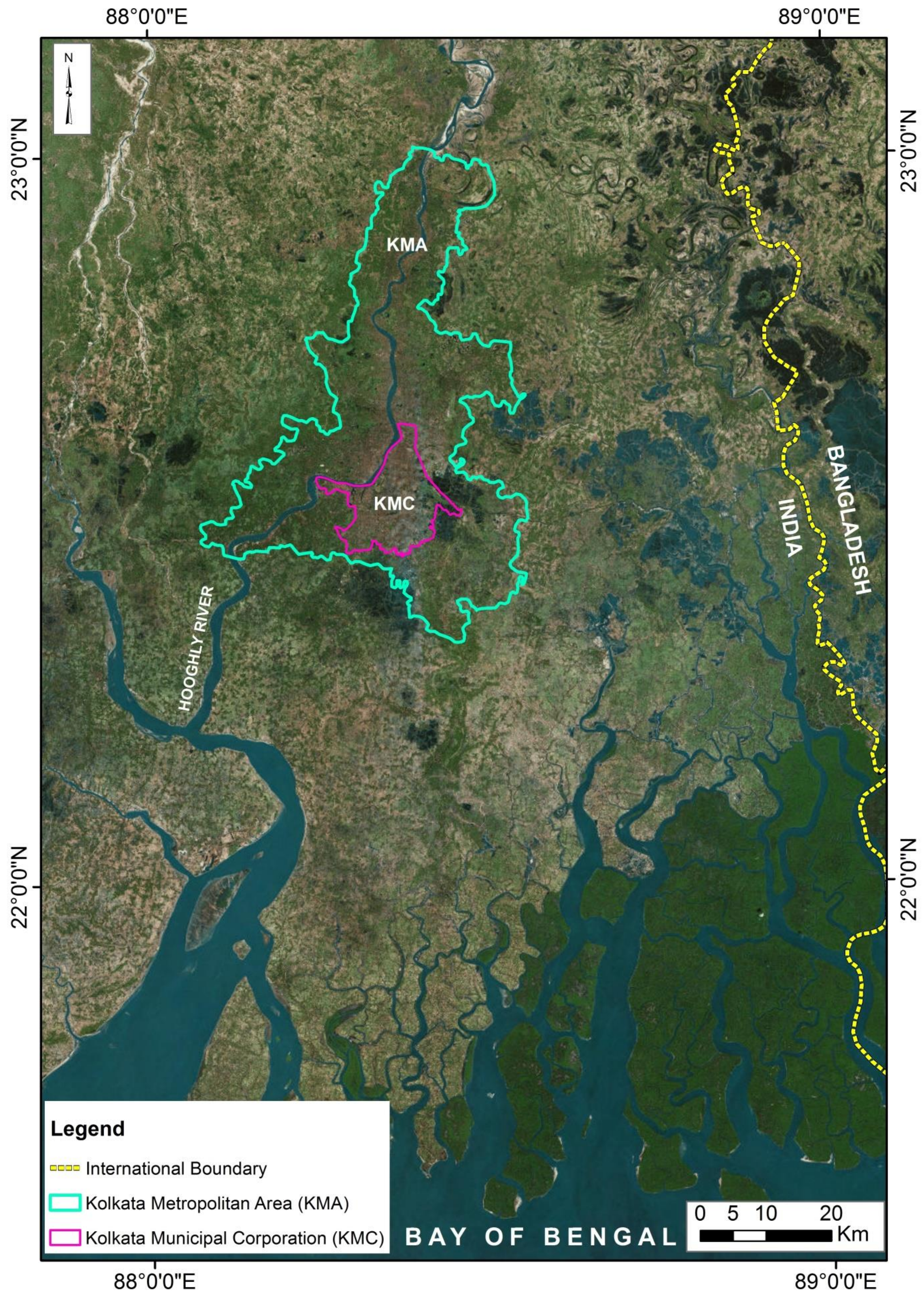

Figure 3.2. Map showing Kolkata Municipal Corporation (KMC) area and Kolkata Metropolitan Area (KMA) located within the vicinity of the coast and close to the international border of Bangladesh. Data source: Kolkata Municipal Corporation, 2017, Google Map: Google Corporation Pvt Ltd, 2018.

Table 3.1. List of boroughs and the associated wards of the Kolkata Municipal Corporation (KMC); excluding the newly added three wards until 2016 annual report published by KMC. Data source: Kolkata Municipal Corporation, 2016. Kolkata Municipal Corporation, 2016).

Borough	Ward No.
I	1,2,3,4,5,6,7,8 &9
II	10,11,12,15,16,17,18,19 & 20
III	13,14,29,30,31,32,33,34 & 35
IV	21,22,23,24,25,26,27,28,38 & 39
V	36,37,40,41,42,43,44,45,48,49 & 50
VI	46,47,51,52,53,54,55,60,61 & 62
VII	56,57,58,59,63,64,65,66 & 67
VIII	68,69,70,72,83,84,85,86,87,88 & 90
IX	71,73,74,75,76,77,78,79,80 &82
X	81,89,91,92,93,94,95,96,97,98,99 & 100
XI	103,104,110,111,112,113 & 114
XII	101,102,105,106,107,108 & 109
XIII	115,116,117,118,119,120 &122
XIV	121,127,128,129,130,131 &132
XV	133,134,135,136,137,138,139,140 & 141
XVI	123,124,125,126

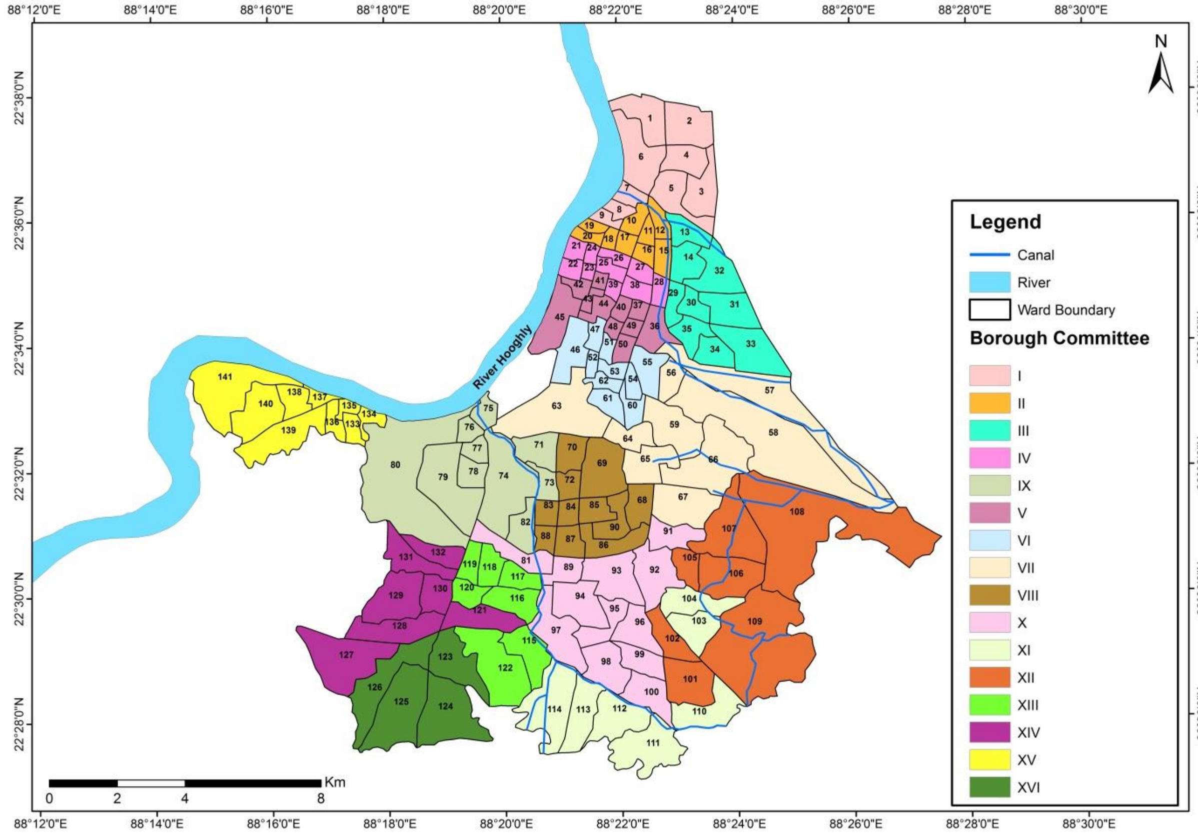

Figure 3.3. Borough Map of Kolkata Municipal Corporation (KMC) area featuring all the associated wards for each borough. Data source: Kolkata Municipal Corporation, 2016.

Kolkata Municipal Corporation is in the lower deltaic plains of the Ganga-Bhagirthi-Hooghly river system, i.e., the southern (Indian) part of Ganga-Brahmaputra Delta. The down-stream channel of Bhagirathi Channel in the tidal stretch is called Hooghly. The elevations in this area range between 3.5 to 6.0 meter above mean sea level (amsl) and relief is flat (Das and Chattopadhyay, 2009). Locally low-lying depressions such as marshes and shallow lakes (*Jhils*) occur within the deltaic plain. Most of these formations represent paleo-river channels of the Bhagirathi. The main slope of the surface dips towards the south. Levees, inter-distributary marsh and paleo-channels are the most important geomorphological features in the deltaic plain. The Hooghly River and several canals like *Bagjola Khal (canal)* in the north and *Beleghata* and *Circular Khal* (canal) in the central part and *Adi-Ganga* canal along with *Talli nala (canal)* in the southern part of the city drain the area. Presently these waterbodies are largely silted.

The details of Water Statistics of Kolkata Municipal Corporation (KMC) area are compiled in table 3.2. The data are primarily based on Census of India (Census of India, 2011a; Census of India, 2011b).

Table 3.2. Water statistics of Kolkata Municipal Corporation (KMC). Data source: Anon, 2011; Census of India, 2011a; Census of India, 2011b; Wankhade et al., 2014; WWF, 2011; KMC, 2012a).

Demography	
Kolkata Municipal Corporation (KMC) Area (2011)	205 km^2
Population	4, 496,694
Floating Population	6,000,000 Per Day
Total Water Demand (based on KMC)	925 MLD (as per KMC); 952 (as per CPHEEO)
Per Capita Demand	170 MLD
Water Supply System	
Sources	Hooghly River and groundwater from deep and hand tube-wells
Surface Water Contribution	89%
Groundwater Contribution	11%
Total Water Supplied	1,216 MLD
Per Capita Supplied	224 LPCD
Loss due to Leakage	35%
Actual Supply (After Loss)	790 MLD
Per Capita Supply (After Loss)	145%
Population served by Water Supply System	92% (KMC, 2012a); 85% (Anon, 2011)
Per Capita Water Supply Served	134 LPCD (Census of India, 2011b); 171 LPCD (Anon, 2011)
Demand-Supply Gap (After Loss)	135 MLD
Continuity of Water Supplied (in Hours)	8

Residual Pressure	3.6 PSI
Number of Water Treatment Plants	4
Designed Capacity for water Production	1,787 MLD
Actual Capacity	1,080 MLD
Operational Capacity for Surface Water Production	1,260 MLD
Operational Capacity for Ground Water Production	114 MLD
Reservoir Capacity	256 ML
Hand Tube-wells	12,000
Large Tube-wells	400
Water Supply Distribution Pipes	5,687 Km
Number of Piped Connections	245,019 (KMC, 2012a)
Household with access to water	79%
Water Price for Domestic Usage	Unbilled for up to one connection/premise additional water supply: US$ 0.15/m^3
Water Price for Commercial, Industrial and Institutional Usage	Flat rate between US$ 11.6 and US$ 66 (Monthly) Additional Water Supply: US$ 0.33/m^3

3.3. Data and Methods

3.3.1. Data

The study is primarily based on literature review and analysis of secondary data from various sources including data bases available at the Kolkata Municipal Corporation. In addition, satellite images were analyzed to detect changes of the distribution of the major land cover classes surface water bodies, building area and vegetated area since 1980 in ten-year time steps. Satellite images with their Date of Acquisition (DoA) applied are:

1. Landsat Multispectral Scanner (MSS) image (path 148, rows 44 and 45) DoA: 16th January 1980;
2. Landsat Thematic Mapper (TM) image (path 138, row 44) DoA: 14th November 1990;

3. Landsat Enhanced Thematic Mapper Plus (ETM+) image (path 138, row 44) DoA: 17th November 2000;
4. Indian Remote Sensing (IRS) Resourcesat-1 Linear Imaging Self-Scanning Sensor (LISS) III image (path 108, row 56) DoA: 03rd February 2010;
5. Indian Remote Sensing (IRS) Resourcesat-1 Linear Imaging Self-Scanning Sensor (LISS) III image (path 108, row 56) DoA: 11th April 2014.

The details of the spectral and spatial resolutions of the satellite imagery used are given in the appendix (3.1). For all images exclusively, optical bands with 30m*30m spatial resolution were considered to analyze land use and land cover. In a first step, standard images were geometrically and radiometrically corrected, thereupon images were co-registered to match the overlay with sub-pixel accuracy (RMS errors ≈ 0.21). For resampling, nearest-neighborhood technique was performed for the classification to retain the original pixel values.

3.3.2. Methods

In a first step, geometrically and radiometrically corrected standard images were obtained; thereupon images were co-registered to match the overlay with sub-pixel accuracy (RMS errors ≈ 0.21). As imagers were taken from 4 different sensors (as well as satellites), the resampling technique was performed to encounter the differences in spatial resolutions of the images used. Resampling to change the pixel size can change the neighboring pixel values, images were kept to the original pixel size despite of varying accuracy levels of classification with different spatial resolution. Hence, for resampling, nearest-neighborhood technique was performed for the classification to retain the original pixel values. A vector map of KMC area was used for clipping and subsetting the imagery. The classification was performed on the clipped part of each imagery.

The supervised classification was employed to detect the changes in Land Use-Land Cover (LULC) within the Kolkata Municipal Corporation area (KMC) since 1980 until 2014. Classification of land use and land cover was performed on co-registered images using non-parametrical feature-space classifier using ERDAS Imagine software (v. 2015). Three broad classes representing urban areas (associating all the urban settlements and impervious surfaces including roads and bare ground), vegetated areas (including the road side trees and open fields with grasses) and surface waterbodies (excluding the river Bhagirathi Hooghly in the west) were mapped. The application of the feature-space classifier allowed extracting broadly classified classes with a non-normal distribution (ERDAS, 1999).

For the assessment of the accuracy level of the classification procedure topographical maps (scale 1: 50,000 surveyed in 1975-76 by the Survey of India) for checking the accuracy for the image of 1980 , LULC maps of 1990 & 2000 (scale of 1:50,000; published by National Atlas and Thematic Mapping Organization, India at the) for the image of 1990 & 2000, complemented by ground-truth data obtained from field surveys (using GPS device with 1m accuracy) between 2008-2016 and analysis of secondary data (maps and other government reports) collected from the KMC within 2008-16 were compared with the classified satellite imagery of 2010 & 2014. The overall accuracy obtained is 71% (for 1980), 83% (for 1990), 81% (for 2000), 85% (2010) and 88.89% (for 2014). The review of literature (Chen, 2003; Ismail and Jusoff, 2008; Bhatta, 2008; Bhatta, 2009; Bhatta, 2009b; Bhatta, 2009c) suggests for the acceptance of the achieved accuracies. However, these accuracies can be further improved with mixed pixel classification technique (Mukhopadhaya, 2016b). Finally, data generated from the classified imagery were integrated into spreadsheets to calculate the changes in each class for the duration from 1980 to 2014. The areas of each class were calculated by clipping the classified imagery for each class and then multiplying the number of pixels in each image by pixel size.

3.4. Land use-land cover change in Kolkata Municipal Corporation (KMC) area since 1980

The supervised classification was applied to detect the changes in Land Use-Land Cover (LULC) within the Kolkata Municipal corporation area (KMC) since 1980 until 2014. It reveals the spatial patterns of the city showing the changes of the three major land use classes (1) *urban settlements* including all the sealed areas such as roads, (2) *vegetation patches* including roadside tress and green fields and (3) *wetlands* including all the ponds, lakes, and canals. Presentation of results follows at first an *overviewing analysis for the Kolkata Municipal Corporation area (KMC) and then continues with a borough wise analysis for the Kolkata Municipal Corporation area (KMC) to get detailed information.*

3.4.1. Overviewing analysis for the Kolkata Municipal Corporation (KMC) area

For the Kolkata Municipal Corporation area (KMC) the three major land use classes (1) *urban settlements* (2) *vegetation patches* and (3) *wetlands* were mapped in five time slices covering the period from 1980-2014. During this time, the spatial patterns of these major land use classes show distinct changes: In 1980 the *urban settlements* covered 49% of the total KMC area while in 2014 it almost captured the whole KMC area covering 79% (161.91 km^2) of the total area (Figure 3.4). The *urban settlements* area under the KMC only slightly increased (2%) between 1980 and 1990, transforming from 100.17 km^2 to 103.89 km^2. Between 1990 and 2000 the *urban settlements* area increased abruptly, covering 71 % (145.34 km^2) in 2000 followed by an additional increase of 7% until 2010 (78 % or 162.08 km^2 of the total area of KMC; Figure 3.4). Within the whole study period (1980-2014) the space occupied by *wetlands* decreased from 47.15 km^2 to 8.70 km^2 and that covered by *vegetation patches* from 58.60 km^2 to 35.31 km^2 (Figure 3.5).

Areas of *vegetation patches* comprising predominantly big trees in 1980 almost covered an area of 29% (58.60 km^2) of the total KMC area and even expanded to 39% (81.12 km^2) until 1990. Since then, the area covered by *vegetation patches* continuously shrank, covering 21% of the total KMC area in 2000 and ultimately, 17% in 2014 (Figure 3.5). Between 2010 and 2014 the area covered by *vegetation patches* increased slightly in the eastern part of Kolkata and in some scattered parts of southern Kolkata in comparison to the other parts of the study area. Nevertheless, at the same time the areas covered by *wetlands* reduced from 47.15 km^2 to 20.90 km^2 (Figure 3.6). This indicates that *wetlands* are not necessarily transformed directly to urbanized areas but were desiccated and overgrown by vegetation. The areas covered by *wetlands* decreased to more than half within the whole KMC area between 1980 and 1990 (23% in 1980 and 10% in 1990) (Figure 3.6). In the following decades the areas covered by *vegetation patches* as well as those covered by *wetlands* constantly declined. In 2014, the percentage of areas covered by *wetlands* accounted only 4 % (8.7 km^2) of the total KMC area which, however, was 1 % more than in 2010 (7.42 km^2) (Figure 3.6).

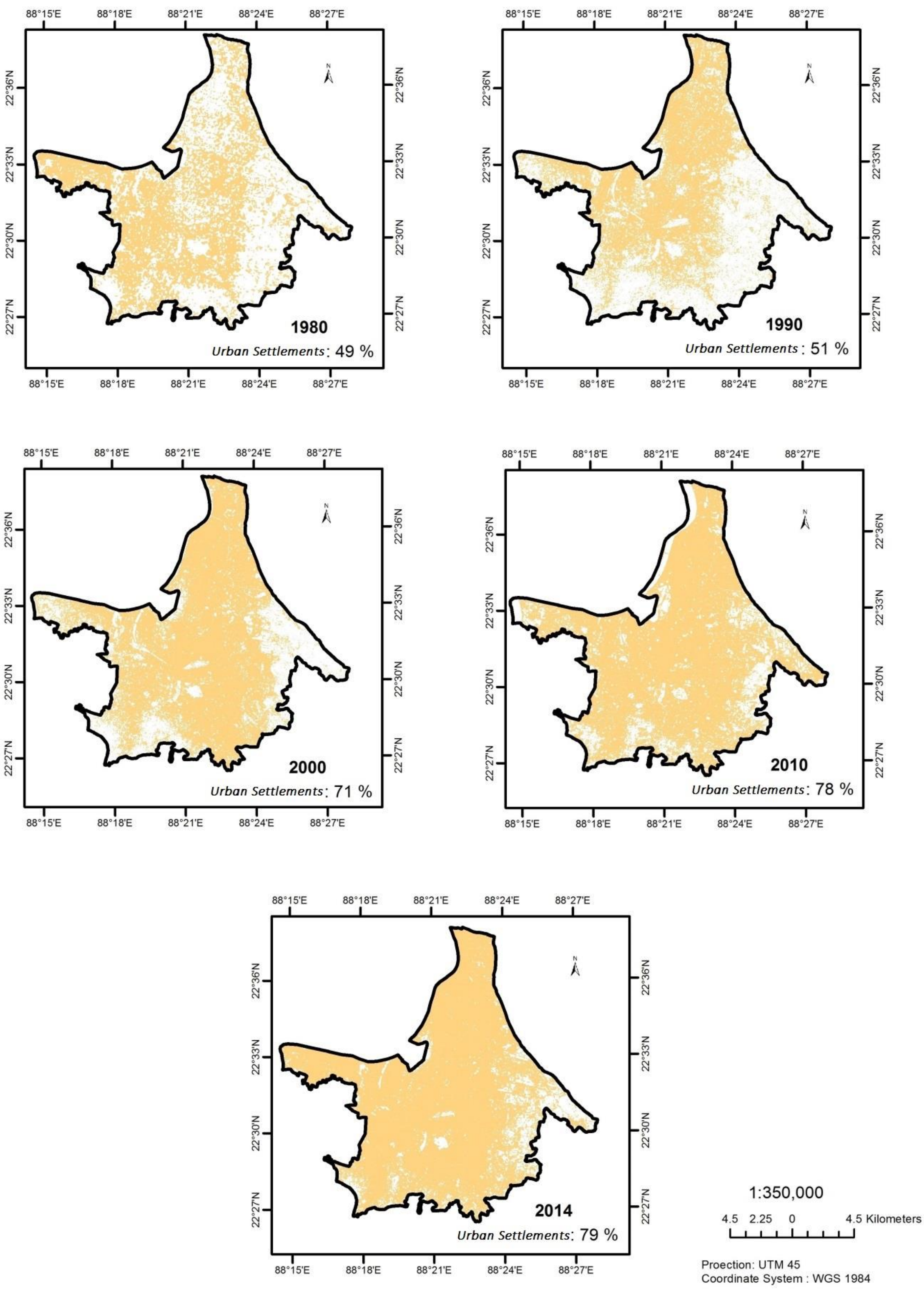

Figure 3.4. Distribution of *urban settlements* (brown patches) within Kolkata Municipal Corporation (KMC) area in time slices from 1980 to 2014 (decade-wise). Data source: Satellite Image interpretation from Landsat (USGS) and LISS III series (ISRO, India) and the Govt. of West Bengal, India).

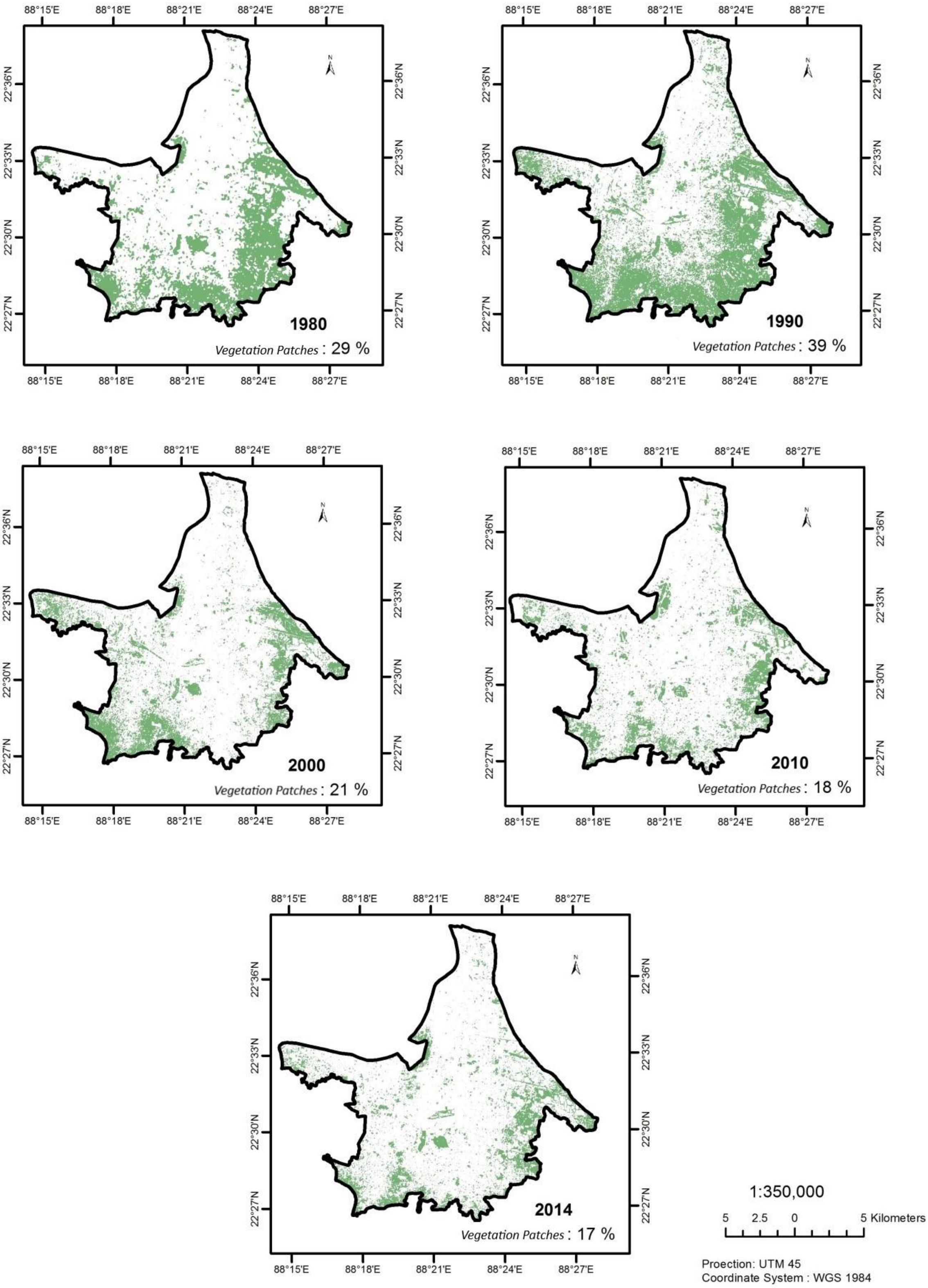

Figure 3.5. Distribution of *vegetation patches* (green patches) within Kolkata Municipal Corporation (KMC) area in time slices from 1980 to 2014 (decade-wise). Data source: Satellite Image interpretation from Landsat (USGS) and LISS III series (ISRO, India) and the Govt. of West Bengal, India).

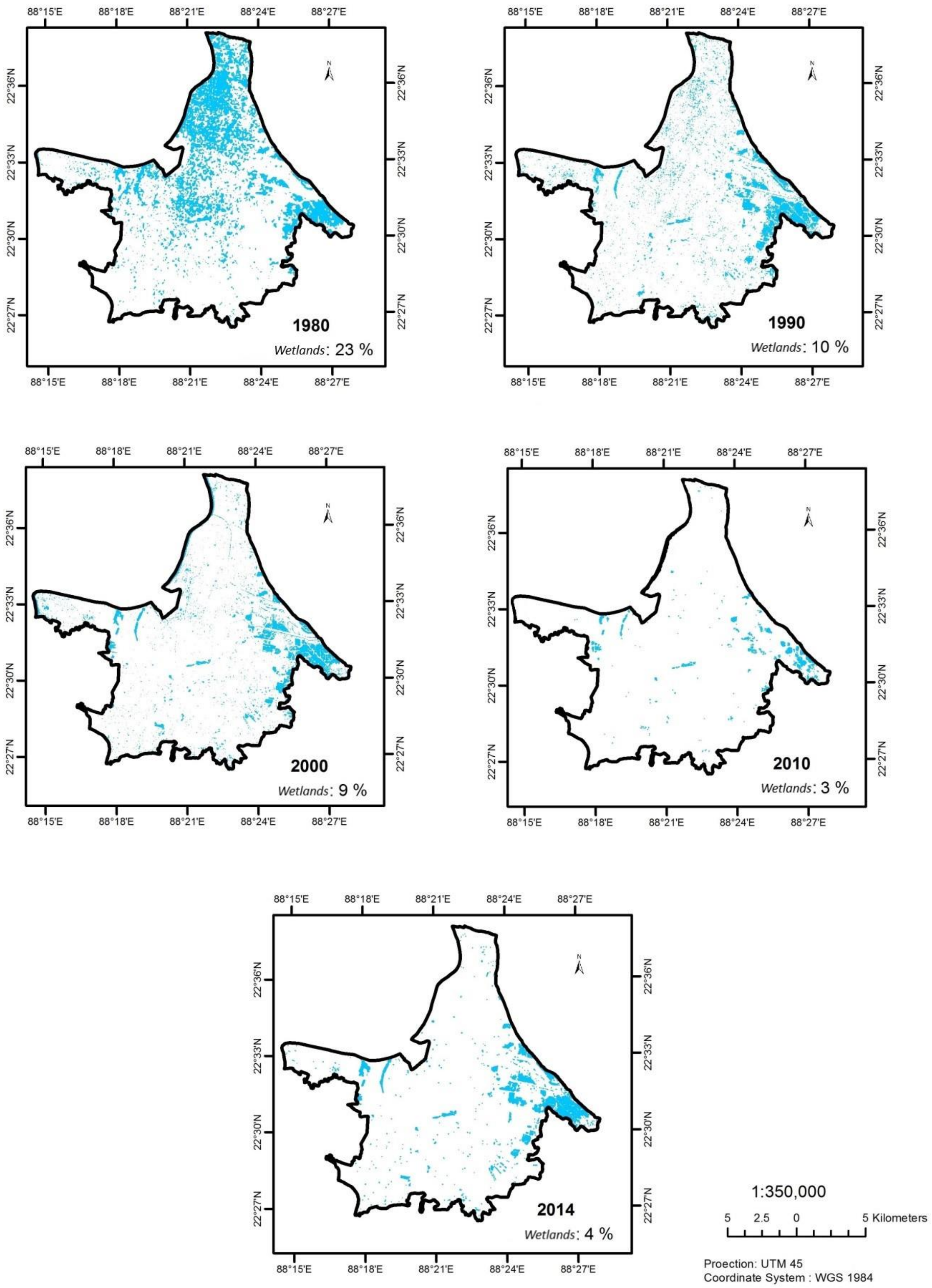

Figure 3.6. Distribution of *wetlands* (blue patches) within Kolkata Municipal Corporation (KMC) area from 1980 to 2014 (decade-wise). Data source: Satellite Image interpretation from Landsat (USGS) and LISS III series (ISRO, India) and the Govt. of West Bengal, India).

3.4.2. Borough wise analysis for the Kolkata Municipal Corporation (KMC) area

For spatially more detailed analyses of land use - land cover the wards were clustered into boroughs. The results show borough wise the amount of increase and decrease of spatial distribution of the three broad land use - land cover classes throughout the study period in percentage (Figure 3.7) and in km^2 (Figure 3.8). The distribution of impervious urban area covered latest in 2014 75 % or more of the KMC (Figure 3.7). The variations in the spread of the three major land cover classes itemized by boroughs clearly indicates that the spread of *urban settlements* took place by replacing areas allocated to *vegetation patches* or *wetlands*. The results reveal that boroughs II, IV, V and VI, which are mainly concentrated in the north and center of the KMC, lost major areas of *wetlands* within 1980 to 2014.

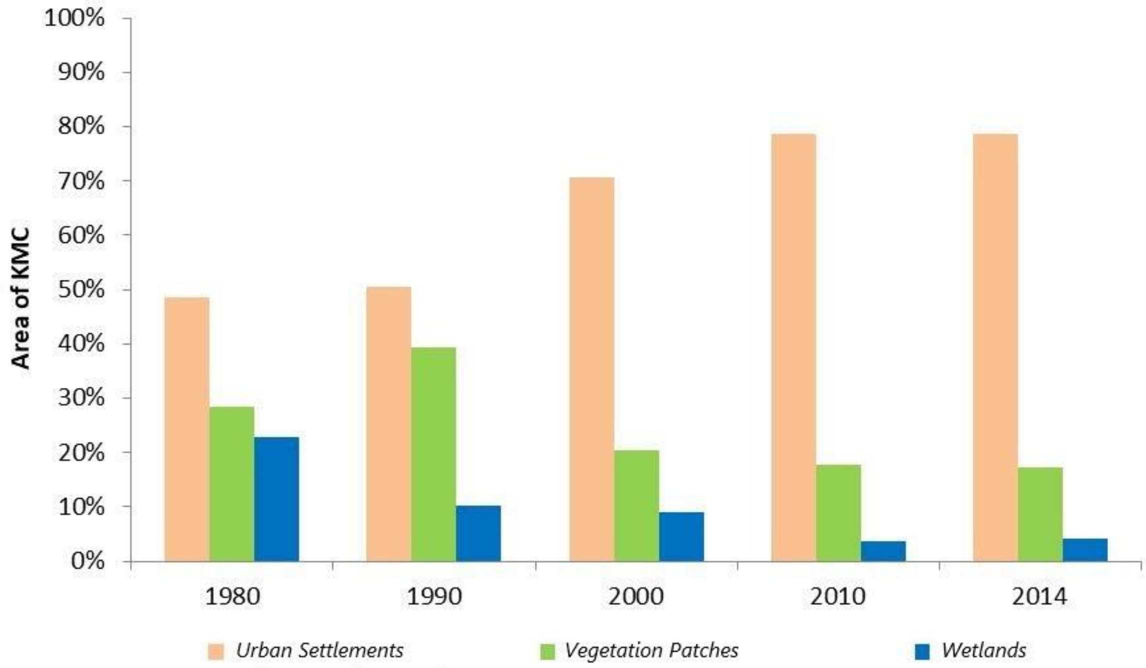

Figure 3.7. Relative distribution of major land use-land cover classes In Kolkata Municipal Corporation (KMC) area showed decade-wise since 1980. Major land use-land cover classes are differentiated into *urban settlements*, *vegetation patches* and *wetlands*; also compare Figure 3.4-3.6. Data source: Satellite Image interpretation from Landsat (USGS) and LISS III series (ISRO, India) and the Govt. of West Bengal, India).

Borough wise results for the first decade studied (1980-1990) (Figure 3.8) depict that all the boroughs except boroughs no. VII, IX and XII lost almost the entire *wetlands* areas by 2014 (Figure 3.8). The most severe loss in *wetlands* is observed for borough II, where the area declined from 84% to 14%. In contrast, within borough II, *urban settlements* increased from

16% to 84% between 1980 and 2014 (Figure 3.8). In the decade 1990 to 2000, distribution of *vegetation patches* and the areas covered by *wetlands* declined in almost all the boroughs of KMC, but the major declines were evident in boroughs in the central and northern part of the KMC (I, III, VII, VIII, XI and XIII) for *vegetation patches* and borough II in the north of the KMC for the spread of *wetlands*. Within the decade from 2000 to 2010 *urban settlements* continued spreading within the KMC covering an area of 162.08 km^2 in 2010 (2000: 145.33 km^2). Concurrently, areas covered by *vegetation patches* continuously declined from 41.96 km^2 (2000) to 36.43 km^2 (2010). Even more pronounced the spread of *wetlands* declined from 18.62 km^2 (2000) and 7.42 km^2 (2010). These trends stopped or even reversed between 2000 and 2014 when *urban settlements* covered 161.91 km^2 (+8% compared to 2000), areas under *vegetation patches* covering 35.31 km^2 (-4% compared to 2000) and *wetlands* covered 8.70 km^2 (-5% compared to 2000) of the KMC in 2014. These changes became particularly apparent in the southern part of the KMC (Figures 3.5, 3.6, 3.7), which gets especially apparent by the borough wise break down of the land use-land cover change (Figures 3.8 and 3.9).

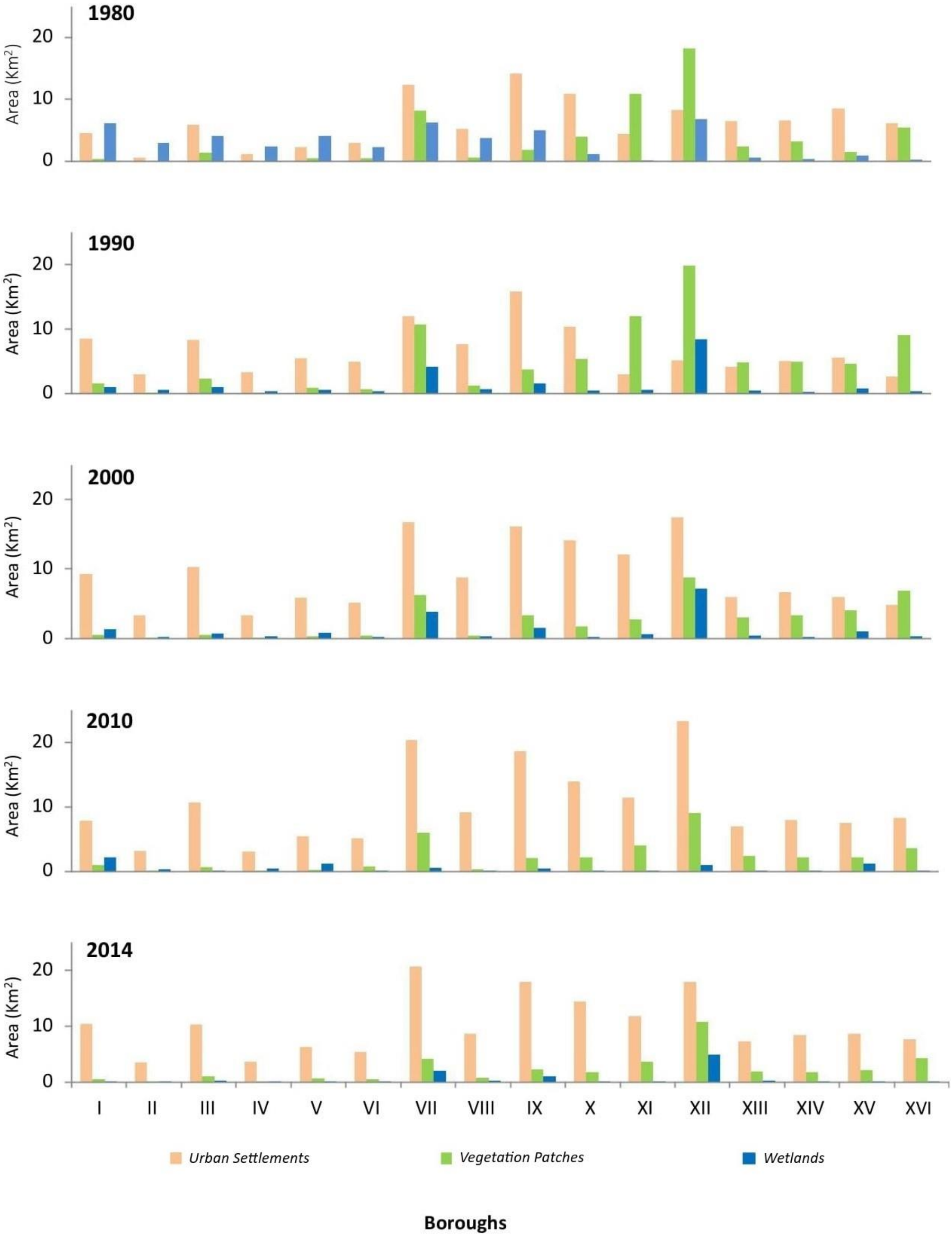

Figure 3.8. Borough wise decadal distribution of the major land use-land cover classes (km^2) in Kolkata Municipal Corporation (KMC) area decade-wise since 1980 differentiated into a) *urban settlements* (built-up and sealed areas), b) *vegetation patches* and c) *wetlands*. Data source: Satellite image interpretation from Landsat (USGS) and LISS III series (ISRO, India) and the Govt. of West Bengal, India).

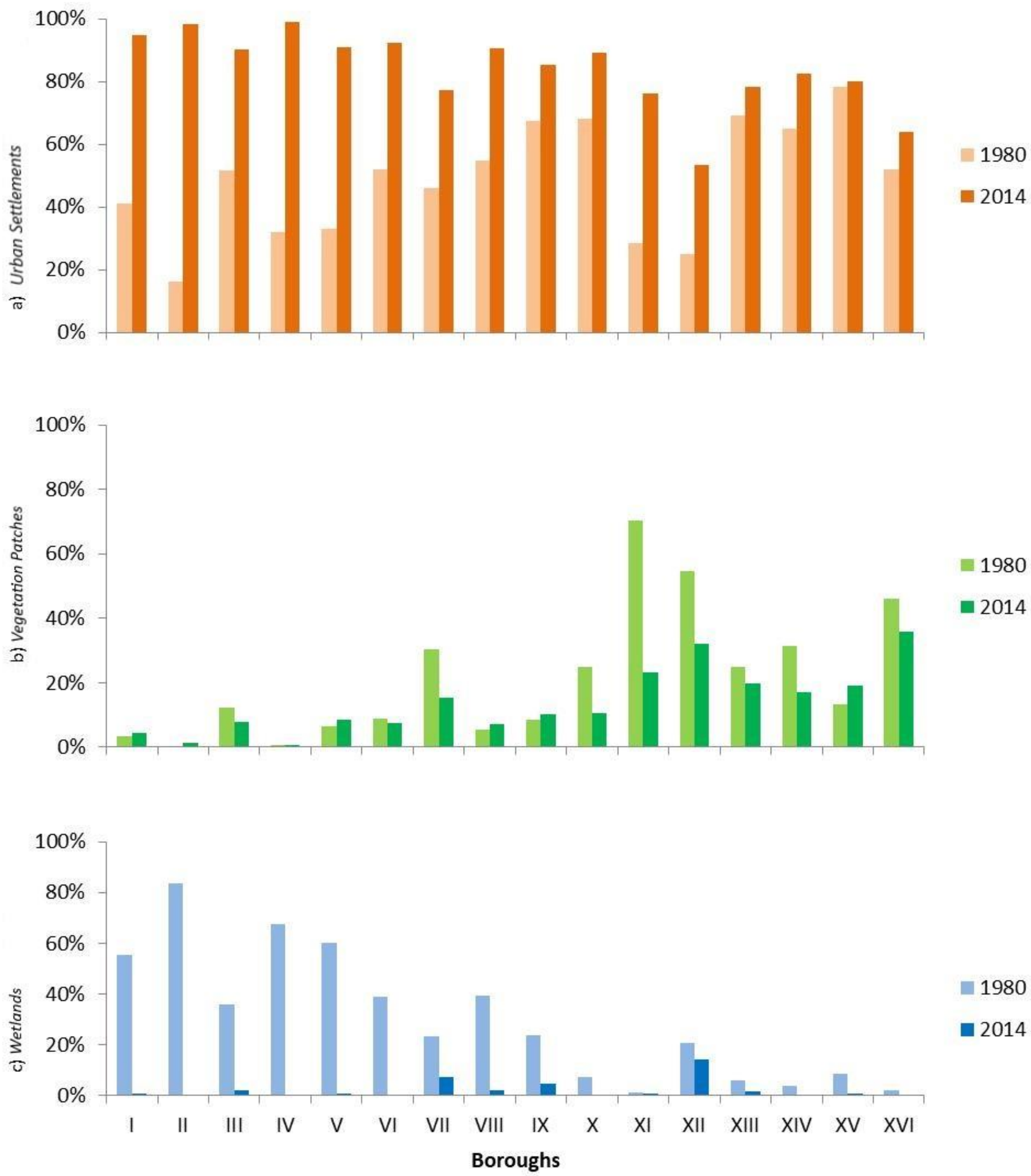

Figure 3.9. Borough wise differentiated relative distribution of major land use-land cover classes in Kolkata Municipal Corporation (KMC) area in 1980 and 2014. Major land use-land cover classes are shown differentiated by in a) *urban settlements*, b) *vegetation patches* and c) *wetlands*. Data source: Satellite image interpretation from Landsat (USGS) and LISS III series (ISRO, India) and the Govt. of West Bengal, India).

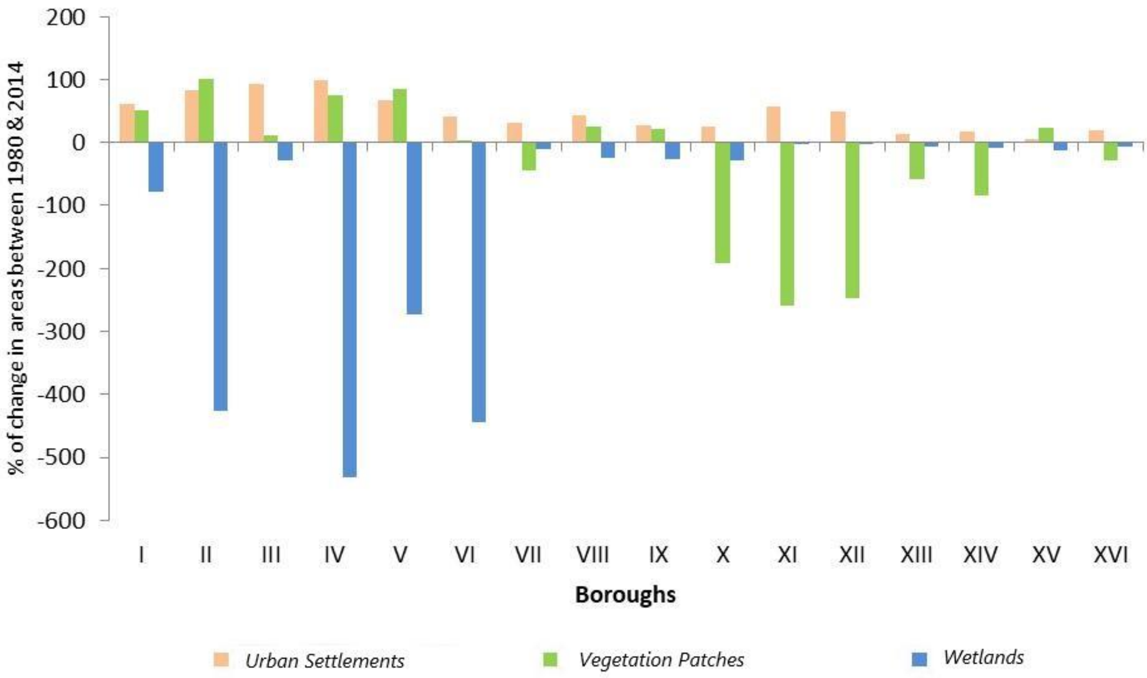

Figure 3.10. Borough wise change (%) of *urban settlements*, *vegetation patches* and *wetlands* in Kolkata Municipal Corporation (KMC) area from 1980 to 2014. Data source: Satellite image interpretation from Landsat (USGS) and LISS III series (ISRO, India) and the Govt. of West Bengal, India).

The relative change of the distribution of each major land use-land cover class was calculated dividing the difference in area coverage between 1980 and 2014 by the area covered by the respected land use-land cover class in 2014. The positive results of a class signify the increase whereas the negative results indicate the decrease in areas between 1980 and 2014 (Figure 3.10). Areas covered by *wetlands* show the highest relative decrease in distribution; in boroughs I to VI the areas under the coverage of any lake, ponds, or other surface waterbodies in 1980 changed until 2014 either into *urban settlements* or *vegetation patches*. The distribution of *vegetation patches* declined in the boroughs X, XI and XII between 1980 and 2014, being transformed into *urban settlements*. The change for the *vegetation patches* were major in the boroughs of II, VI and V. Simultaneously, a continuous and stable process of urbanization occurred in boroughs X - XVI. Nevertheless, the areas covered by *wetlands* were mainly changed in the boroughs I – VIII (Figure 3.10).

3.5. Water security in Kolkata Municipal Corporation (KMC) area

Changes in land use-land cover patterns increase pressures on water resources which ultimately affects the linkage between land tenure and water security (Narain, 2010). This section seeks to complement the observations on land use-land cover change by a literature review to contribute for developing a shared understanding of some of the core concepts related to water security in Kolkata city. Rapid changes in land use-land cover patterns and simultaneous insufficient water management practices in the entire KMC area caused poor water quality (Rudra, 2009). Water security entails ensuring every citizen with the amount of quality water they need to safely live their everyday life (Narain, 2010). In an urbanized area, amongst other aspects, unrestricted population growth (Falkenmark and Widstrand, 1992; Ravell, 2014), poor governance (Bakker and Morinville, 2013; Biggs et al., 2013; Cook and Bakker, 2012) and mismanagement of the water supply system (Piesse, 2015) as well as social inequity (Blanca, 2016; Goff and Crow, 2014; Jepson et al., 2017) can result in water insecurity. The nature of urbanization processes has undergone a paradigm shift since the neo-liberal economic reforms of 1991, which ultimately leads the process of the acquisition of land and water creating a potential insecurity for urban water system in KMC area (Narain, 2016; Narain, 2010). In addition, parallel physical processes like climate change accelerate the insecurity of water (Bar and Stang, 2016; Turral et al., 2011). The following section picks three major aspects of urban water security: water demand and supply, water accessibility and water related disasters which include risks and environmental health.

3.5.1 Water demand and supply

Time series analysis of land use-land cover change in Kolkata Municipal Corporation (KMC) area shows that Kolkata city has been transformed during the past four decades into almost a completely urbanized area. Population growth and resulting population density (Table 3.3) are the most important drivers which act as Catalysts for urbanization. Founded by the British East India Company in the early 17th century, Kolkata was the first major Asian city which evolved as a provincial city and eventually became the headquarters of the British India government (Kundu, 2003). The amount of its population, Kolkata’s importance in trade and commerce, the varieties of employment that it offers, the diverse nature of its inhabitants make it a cosmopolitan city in character (Roy et al., 2004).

Table 3.3. Population data of Kolkata Municipal Corporation area (KMC) from 1971 to 2011. Data source: Census of India (2011a).

Years	Population			Growth Rate (%)
	Total	Male	Female	
1961	2,927,298	1,815,791	1,111,498	+8.48
1971	3,148,746	1,924,505	1,224,241	+7.57
1981	3,305,006	1,930,320	1,374,686	+4.96
1991	4,399,819	-	-	+33.12
2001	4,572,8976	2,500,040	2,072,836	+3.93
2011	4,486,679	2,362,662	2,124,017	-1.88

At the beginning of the 20th century, Kolkata was the first city in India with a population of more than one million inhabitants. According to the 1901 census KMC area's population totaled 933,754, while according to the 1951 census 2,698,494 inhabitants were counted and increased to 4,572,876 inhabitants in 2001 (Census of India, 2011a). Corresponding to the last Census report of India (2011b), the decadal growth rate of population in the Kolkata Urban Area (including KMC) amounted 6.87 % between 2001 and 2011, which was far below the standard growth rate of India or West Bengal state (Yadav and Bhagat, 2014). This declining of population growth rate in the KMC area has been covered up by the continually increasing population growth rate of greater Kolkata agglomeration areas, especially in the peri-urban zones along the banks of river Hooghly. As per 2011 census, the KMC area had a population of 4,496,694 of which 52.41% (54.67% in 2001) were male and 47.58% (45.33% in 2001) were female. The population density of KMC area averaged 22,000 inhabitants per km^2 (24,718 inhabitants per km^2 in 2001) (Census of India, 2011a). The population growth and rigorous sprawling impacts on the changing nature of the land use-land cover within KMC area cause an increasing demand of water in the city and impose stress on the local ground water regime (Mishra, 2011). This results in increased pressure on the existing demand-supply system and basic infrastructural functionality according to recent reports on water demand (Mishra, 2011; Banerjee, 2016).

Rapid and uncontrolled growth of urban areas is the result of, firstly, natural increase in population, and secondly, migration into urban areas (Bhatta, 2010). In total, migration significantly contributes to the urban growth of Kolkata (Bennett and Hindle, 1996; Bhatta, 2010). According to the 2007-08 census data, the migrant population in Kolkata city amounted 30.9 % of the total KMC population; work participation rate of migrants within KMC (44.5 %) is much higher than West Bengal (34.7 %) and in India (37.3 %) (Banerjee, 2016). Although insignificant, comparing to the migration of people within India, international migration (mainly, refugees and undocumented migrants during and after the Bangladesh Liberation War of 1971) also must be considered as growth factor. By the beginning of the 20th century, the urbanization in Kolkata took place majorly along the eastern bank of river Hooghly (currently areas under KMC boroughs I – VII). Since the 1980s most of the surface waterbodies in the peri-urban areas of KMC were impoldered and sealed (Mishra, 2011). Table 3.3 reflects the total population and its decadal growth rates in the KMC area since 1961 until 2011: Population growth rate in the 1961 was higher than in 1971 and 1981; nevertheless, the growth rate increased and peaked in 1991. An important factor triggering rapid urbanization is economic growth and its related development of infrastructural facilities (World Bank, 2009; Tacoli et al., 2015), frequently forcing uncontrolled urban sprawl (Theobald, 2001; Bhatta, 2010). In general, the rapid growth of cities stresses their capacity to provide technical infrastructure and services such as energy, education, health care, transportation, sanitation. Since governments have less revenue to provide the basic maintenance and provision of services, massive urban sprawl occurs, locally affecting urban ecosystem (Bhatta, 2010). In many developing countries rapid urbanization and low levels of technology are expected to affect ecosystem services and to put more pressure on the urban community to cope with these changes (D'Souza and Nagendra, 2011). Studies like Mukhopadhaya, (2016a) can be combined with the frequent LULC changes to predict the futuristic pressure on the urbanization in accordance with water security.

KMC's water supply system is based on both, surface and subsurface waters (Bhandari and Gupta, 2010) Bhagirathi-Hooghly, a major distributary of the Ganga with about 500 km in length, is the main water source for the entire city's water supply system. In 1997, the average water supply for KMC's urban population lasted less than four hours a day (ADB, 2007). In 2014, in India (data from 28 cities) daily water supply was 3.3 hours on average while the hours of supply varied from 1 hour per 3 days to 18 hours per day (Guha, 2014). In contrast, in KMC the daily water supply was still 4 hours on average, while serving 81% of population and providing an average of 123 liters per capita per day (KMC, 2012a). It exceeds the national average of 71.2% in terms of the number of the people served (Table 3.4) (KMC, 2012a; NIUA, 2015).

Leakage from piped water supply systems, mainly originating from rusted iron pipes frequently causes interruption of water supply (Wankhade et al., 2014). Leaky water pipes expose the drinking water to contamination and, thus, affect the public health (Ghosh, 2002). Leakage and cracks in the piped water system also might cause fecal contamination of drinking water, which turns the whole system into insecurity (Roy et al., 2004). However, according to the Central Pollution Control Board of India (CPCB) Indian cities should focus on the required availability and quality of the supplied drinking water (CPCB, 2013). In 2006 and 2011, all over India the non-revenue water due to leakages, unauthorized connections, billing, and collection inefficiencies, etc. was estimated to be 40-70% of the water distributed (World Bank, 2006; World Bank, 2011; CPCB, 2013). For Kolkata, the economic effects of water leakage can be sketched as follows: water is supplied through a distribution network of 5,500 km of underground water pipes, supported by 13 pumping stations in the four zonal mains (Anon, 2011). 30-35% of the pumped water is lost during transmission either through leaks or theft. The resulting costs of water loss are estimated to about 2.7 million rupees annually (treated at 4.50 rupees per 1,000 liters) (Mukherjee and Ghosh, 2015).

Table 3.4. Comparison between national and municipal urban service delivery status in Kolkata Municipal Corporation (KMC) area. Data source: Census of India, 2011a; NIUA, 2015.

	Water Supply					**Sewerage**
	Coverage (%)	Per Capital Amount (IPCD)	Hours (Hours/Day)	Non-revenue Water	Metered Connections (%)	Coverage (%)
National Average	81	123	4	-	25	28
KMC	92	134	8	93	0.1	43

Groundwater, the second major source of fresh water in the KMA, gets extracted for domestic and agricultural use in large quantities in areas distant from the river (WWF, 2011). Due to the hydrogeologic situation of Kolkata city, groundwater contamination by infiltration of polluted floodwater is constricted (Mishra, 2011). Nevertheless, Kolkata and the Ganga-Brahmaputra delta lie in a geological zone with naturally occurring arsenic in deeper strata. In consequence, arsenic concentrations higher than the WHO's recommended maximum concentrations of $10\mu g*l^{-1}$ were detected in groundwater from 65 of 100 sampled wards in Kolkata monitored over a twenty-year study period (Chakraborti et al., 2009). The natural occurrence of arsenic in the aquifer is exacerbated by the over-extraction of groundwater (Segane, 2000). A most recent study shows that the groundwater extraction in the KMC area was about $32*10^4$ m^3 per day and significantly exceeded groundwater recharge (Sahu and Sikdar, 2011). Over-extraction of the groundwater and reduced rate of aquifer recharge also cause ground subsidence (Chatterjee et al., 2006).

3.5.2. Water accessibility

Changes in land use-land cover influence the interaction of structural and behavioral factors associated with technological and environmental capacity, demand-supply and social relations. As a result, the increased physical water demand of the growing population affects the accessibility of water for the citizens (Verburg et al., 2004). In case of urban India, nearly 70% of the households have access to tap water, out of which 62% have access to treated tap water (Wankhade et al., 2014). Correspondingly, less than 30% of Indian urban households depend on other sources of water than tap water (Census of India, 2011a; Census of India, 2011b; Wankhade et al., 2014). All over India less than 50% of the urban population has access to piped water within their premises (Census of India, 2011a). In 2007 in KMC area around 74% of population were served with water by house connections (and public taps in case of slum areas) and provided continuous and uninterrupted water supply of 8.3 hours daily (ADB, 2007); the rest of the households were accessing groundwater through private pumps or wells (ADB, 2007). In the census data from 2011 (Census of India, 2011a), the percentage of household having access to piped water within the KMA increased to 79% (Singh et al., 2015; World Bank, 2011).

Between 2006 and 2011 revenues from user charges covered c. 30-40 % of the operation and maintenance costs of the water supply and sanitation infrastructure within KMC area (World Bank, 2006; World Bank, 2011). The KMC does not levy tax on drinking water for the citizens

(Ray, 2014). Most urban water supply operations survive on large operating subsidies and capital grants (World Bank, 2011). The policy of not pricing water for domestic use has received the authority's criticism as it sends wrong signals to consumers and thus promoting wastage (ADB, 2007; McKenzie and Ray, 2009). The consequence of underpricing, coming along with KMC's overstaffing and large amount of unaccounted water is that KMC can hardly cover maintenance costs or provide capital through tariff revenues for infrastructure improvement (McKenzie and Ray, 2009; WWF, 2011). KMC's recovery of operational costs with an average of 15 % is one of the lowest among Indian cities (McKenzie and Ray, 2009). According to Majumdar & Gupta (2009), the issue of water conservation within the KMC area is completely neglected, which over time has also required a mounting of government subsidies on water. An analysis of the decade (from 1992 to 2002) reports that the expenditure for water supply and sewerage increased five times, whereas revenues only doubled (Majumdar & Gupta, 2009). Additionally, there has been a sharp decline in the groundwater level especially in central to south Kolkata as well as along the *Eastern Metropolitan Bypass* in the east of KMC area (*Rajpur-Sonarpur* areas). In both areas settling-up intensified in recent years with the newly settled areas being only barely tapped (Basu, 2016). In consequence, the wealthy residents settling in these newly constructed multi-story apartment blocks pump their own water as they do not confide on the quality of the water supplied by civic bodies. Groundwater pumping within KMA is increased wherever the access to surface water is limited (Basu, 2016).

Slums result from uncontrolled and invariable urban sprawl in and around Kolkata city since the Colonial era. Kolkata's slums are characterized by high socio-economic and ethnic disparities and accommodate approximately one third of Kolkata's population occupying about half of the Kolkata metropolitan area (KMA) (Basu, 2016; Census of India, 2011a; Census of India, 2011b). Slums and squatter settlements are in general physically distinct, with tile roofed kutcha huts, often made of brick, mud and wattle and poorly serviced in terms of water, sanitation, sewerage, drainage, and waste disposal (Bhatta, 2010). Accessibility to public water supply is limited and is mostly only available at some few stand posts (Basu, 2016); during the summer days the supply shortage generally increases, and water quality degrades (Beistline, 2016). The water supply provision of KMC does not sufficiently cover the water demand of these slum areas with 90 liters per capita per day (lpd) while the estimated water demand of KMC's inhabitants amount 180 lpd (Chakrabarti, 2013).

Poor and inadequate living conditions and municipal services increase the chances to lethal health and sanitation issues (Douglas, 1983). These problems are especially critical in slums and squatters in fringe areas (Kundu, 2003). Peri-urban fringe areas (e.g., newly added wards, such as 101, 141-46) are lacking access to piped water supply from the municipality. The residents must either use the groundwater through handheld tube wells or get access from KMC supports such as water delivery by water trucks few times a week. The increasing numbers of slum dwellers have been the key concerns for urban planning in respect to accessibility of safe drinking water and availability of adequate sanitation facilities (Sau, 2017).

3.5.3. Water related disasters

In Kolkata seasonal flooding and its impact on the environment affects human health and is a significant challenge. Established in the Ganga delta frequent flooding is a natural phenomenon. Urban spread and unplanned occupation of the natural drainage system is a major source for the exposure of urbanized areas to flooding. 17.3% of Kolkata's population live in areas of high flood risk (especially in ward numbers 14, 57, 58, 63, 66, 67, 74, 80, 108, 111-115 and 122-126; Table 3.1) (SAFE-IWMI, 2017). These high-risk areas are located along canals and wetland areas which originally served as by-pass or retention areas during flooding while today most of the canals are super structed (SAFE-IWMI, 2017). The land use-land cover changes observed in the class of *urban settlements* clearly show that urbanization processes affected the distribution surface waterbodies during the observation period (1980-2014). It resulted in the drainage of wetlands and its replacement by either compact surfaces or barren land for further development. Another reason for the shrinkage of surface waterbodies was vanishing of the trees in the city and resultant increased surface runoff (SAFE-IWMI, 2017). Consequently, groundwater table lowered (Kiran and Ramachandra, 1999; Hagler, 2007; Ali et al., 2008; Mendoza et al., 2011). With the increasing surface runoff and due to the poor sanitation conditions in these areas, contamination of surface waterbodies by dissolved and solid matters increased. To improve water quality 25 sewage treatment plants (STPS) have been installed in West Bengal under phase II of the Ganga Action Plan between 1993 and 1996, but the capacity available is still not sufficient (Seth, 2007). There are two sewage treatment plants (*Bangur* and *Garden Reach* STPs) installed outside the KMC area receiving wastewater from the KMC area; both were underutilized due to a lack of household connections in their catchments as until 2006 only 17 % of the population in these areas had sewer connections (ADB, 2006; Seth, 2007). Due to the insufficiency of these measures dissolved oxygen levels, measured in July 2007 by the National River Conservation Directorate and WBPCB, pointed out unsuitable bathing conditions at all monitoring stations in Kolkata when the value of dissolved oxygen levels reached less than 4 mg O_2*1^{-1} (Seth, 2007). Beyond, the total coliform count has been rising while the average levels of coliforms in 2001-02 were mostly within levels to be suitable for bathing (max. 500 most probable numbers $*100\ ml^{-1}$), the 2005-2006 average increased to 423,125 most probable numbers $*100\ ml^{-1}$ at the Howrah Monitoring Station (Seth, 2007). During severe flooding, such as in September 1999, the slum areas suffered from a paucity of power supply, acute shortages of safe drinking water, outbreaks of water borne diseases such as *Gastro-enteritis, Typhoid, Entamoebiasis, Hepatitis* etc. and a long period of water logging (Kiran and Ramachandra, 1999).

Palit et al. (2012) conducted a study on the potential of different water sources, both for drinking and domestic purposes, for diarrheal disease transmission in Kolkata's urban slums. The results show a significantly higher prevalence of fecal coliforms (58%) in stored water for washing than the stored water for drinking (28%) and tap/tube well water (8%) collected (Palit et al., 2012). Samples containing stored water for washing also had the highest non-permissible range of physico-chemical parameters. Household water containers storing water for washing were rich in fecal coliforms and residual chlorine contents. Palit et al. (2012) found less than the satisfactory level of residual chlorine (57%), TDS (37%) and pH (20%) present in almost two thirds of the samples of water stored for washing.

The urbanization processes in KMC area over the past four decades went along with a decline in vegetation cover and water bodies (Figures 3.7 and 3.8). The loss of green spaces coinciding with an increase of built-up and sealed areas affects surface temperatures and causes the development of urban heat islands (Buyadi et al., 2013). Urban heat islands in turn have effects on rainfall patterns and intensities, threaten biodiversity, and consequently affect water security (WWF, 2011; Buyadi et al., 2013). The eastward expansion of Kolkata has been accommodated at the expense of natural ecosystems, mainly the East Kolkata Wetlands. The Basic Development Plan for the city completely disregards the ecological sensitivity of the East Kolkata Wetlands and proposes to develop two major townships near them (WWF, 2011). Reclamation of wetlands for other commercial usages such as garbage dumping also seems to continue unabated, according to the same WWF India report (2011). In consequence, unplanned and rough handled socio-economic activities in the Kolkata Metropolitan area stress water quality (WWF, 2011; Buyadi et al., 2013; Haque and Singh, 2016).

3.6. Conclusions

This review provides a qualitative snapshot on the effects of land use-land cover change and water management strategies to urban water insecurity in Kolkata Municipal Corporation (KMC) area during the last four decades. Beyond water's functions in the hydrological cycle, it has social, economic, and environmental values, and is essential for sustainable development. Unprecedented population growth, a changing climate, rapid urbanization, expansion of infrastructure, migration, land conversion and pollution translate into changes in the water fluxes, water pathways and water stores. Population density and per capita resource use have increased dramatically over the past four decades in KMC area; parallel, urban ecosystems have undergone significant modifications that affect the vitality, quality, and availability of the water resources in KMC. The trends observed in land use-land cover change in the KMC area reveal the drivers of the environmental changes which indirectly, sometimes directly, affect the urban water security of KMC. Major driver is uncontrolled urbanization. Increased water use associated with domestic and small-scale industries and real estate business is leading to changes in water supply infrastructure, high rates of groundwater use, and new water conveyance networks. Collectively these changes lead to cumulative effects on water quality and quantity of available water resources. Hence, the review envisages the relationship between urban water-based livelihood, water pollution, stakeholder interventions and institutional responses. Selection, quantification, and integration of responsible bio-physical and socio-economic factors are needed to be studied in detail in the future and transferred into the policy that combines bio-physical and social dimensions of the urban water security and governance.

4. Research methodology

This study reports on interdisciplinary analyses using data in an innovative way, combining it with biophysical data and complementing it with survey based socio-economic data. As the aim of this novel approach is to combine biophysical and social data to start exploring the new understanding, such approaches can yield in the field of water security.

In developing a set of principles to guide the development of the methodology for the research, identification, analysis, and interpretation of the issues associated with UWS components as defined by Grey & Sadoff (2002) have been referenced. Thus, the approach set for this research has been conceptualized to check the livability (accessibility in terms of socio-economic equity issues), viability (availability in terms of socio-physical environmental issues) and sustainability (risk and other environmental factors) of the UWS in the long run (Figure 4.1).

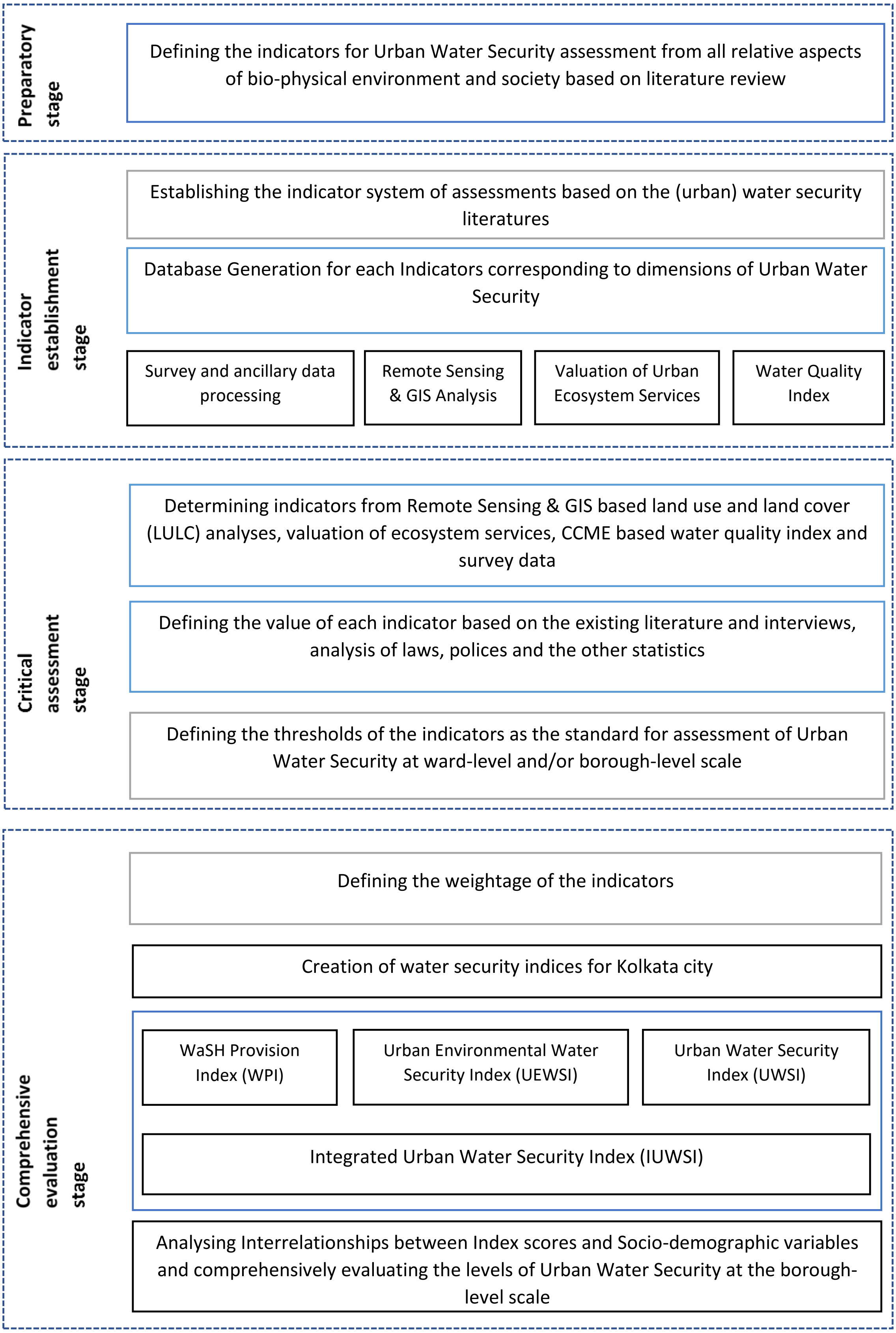

Figure 4.1. A conceptual flow chart based on an integrated framework to assess and evaluate Urban Water Security

The research takes the assistance of existing methodologies such as GIS mapping, valuation of ecosystem services and working with affected communities. After formulating the objectives, this study unites robust satellite based remote sensing data analyses with bivariate analysis and significance testing of data collected through the household survey and focus group interviews. Table 4.1 enumerates the methods applied in this doctoral research, with reference to the associated chapters of the thesis for details.

Table 4.1. List of methods applied and the associated chapters of the thesis.

			Chapters					
			2	**3**	**5.1**	**5.2**	**5.3**	**6**
Methods	**Literature review**		x	x				
	Primary data processing				x		x	
	Ancillary data processing			x	x	x	x	
	Statistical analyses	Principal component analysis					x	
		Descriptive statistics			x		x	
	Remote Sensing data processing	LULC change between 1980–2014		x	x			
		LULC between 2009–2019				x		
	Estimation of value of Ecosystem Services (ES)					x		
	Calculation of Water Quality Index (WQI)					x		
	Urban Water Security Index creation	WaSH provisions Index (**WPI**)			x			
		Urban Environmental Water Security Index (**UEWSI**)				x		
		Urban Water Security Index (**UWSI**)					x	
		Integrated Urban Water Security Index (**IUWSI**)						x

4.1. Literature review

a. **Data used:** Academic literature including peer reviewed journals, theses, books, grey literatures such as reports from local, national, and international agencies, government documents and internet-based news reports.

b. **Method (s):** The literature review was performed in *three* parallel steps: the first one was to set the background and to formulate the aims, objectives, and the scope of the study, while the second one was to define the challenges in terms of research questions, particularly from the study area, upon which the third phase of literature review was performed to select the methods and data, interpret the findings and justify the methodological choices for both quantitative and qualitative strategic assessments.

4.2. Primary and Ancillary Data Processing

i. Primary Data Processing

a. **Data used:** The primary data base on a survey using (1) Stratified Random Sampling collection of data from 45 households from each borough of KMC and (2) two LGBTQ focus groups consisting of 35 respondents were conducted in November-December 2018. Total respondents were 720+35=755. Furthermore, the survey included the presence of drinking water provisions and toilets in the house. The respondents were a mixed from slum and non-slum areas of the entire KMC.
The Survey questionnaire forming the basis of the household survey consisted of **48** questions divided into 5 segments.

- The first 4 segments are differentiating issues of (**32 questions**) 4 components of water security (Water Availability, Water Accessibility, Water Quality and Water Risks and Hazards).
- The last segment included demographic data **(16 questions**) assemblage to reflect the social aspects of water security in the city's neighbourhood which includes information on socioeconomics such as income, literacy, gender, religion, and ethnicity (based on language spoken) statistics.

b. **Method (s):** The primary data is based on a household survey using Stratified Random Sampling method. It collected data from 50 households from each of the boroughs of Kolkata Municipal Corporation (KMC) area. Altogether 720 households were surveyed within November-December 2018.

ii. Ancillary Data Processing

a. **Data used:** Census data of India, 2011, Reports, official documents, and published materials from the State Water Investigation Department (SWID) and Department of Urban Development of Government of West Bengal.

   Public toilets and Slum data from the Kolkata Municipal Corporation (KMC) (Department of Slum Development, Department of Water Engineering), and Kolkata Municipal Development Authority (KMDA). These include information on socioeconomics such as condition of the slum housing, income, literacy as well as water provisions in term of latrines, dugwell, tubewell and standposts; data on gender, religion and language statistics were also obtained from this data set.

b. **Method (s):** The ancillary data were taken into consideration not only to fulfil the gaps inherited in primary data sourced from household survey, such as population data, but also to support the findings and maintain the consistency using different statistical methods used in this study. Census Data of India (2011) was used to extract the detailed slum data (Census of India, 2011).

4.3. Statistical analyses

a. **Data used:** Survey data comprising of questionnaire divided between 4 components of water security (Water Availability, Water Accessibility, Water Quality and Water Risks and Hazards).

   Socio-demographic variables collected through Household Survey and ancillary data.

b. **Method (s):**

   1. Principal component analysis (PCA): Principal Component Analysis (PCA) allows to identify the principal directions in which the data vary by transforming a set of correlated variables into a set of uncorrelated ‘components. Principal components are the eigen vectors of a variance–covariance matrix. The first principal component is selected as the linear index of all the variables that captures the largest amount of information common to all the variables which may then be used as the index. This approach allows the determination of the most appropriate weightings for each variable to derive an index which captures maximum variation.
   2. Descriptive statistics: Methods of descriptive statistics were applied to assess the distribution of data (Boxplot), linear correlation between

variables (Pearson's r and Chi Square test) and recapitulate the relationship between different variables (Crosstab) in SPSS.

4.4. Remote Sensing Data Processing

a. Data used:

1) Landsat Multispectral Scanner (MSS) image (path 148, rows 44 and 45) DoA: 16.01.1980,
2) Landsat Thematic Mapper (TM) image (path 138, row 44) DoA: 14.11.1990; 10.05.2009 and, 15.10.2009.
3) Landsat Enhanced Thematic Mapper Plus (ETM+) image (path 138, row 44) DoA: 17.11.2000,
4) Indian Remote Sensing (IRS) Resourcesat-1 Linear Imaging Self-Scanning Sensor (LISS) III image (path 108, row 56) DoA: 03.02.2010 and
5) Indian Remote Sensing (IRS) Resourcesat-1 Linear Imaging Self-Scanning Sensor (LISS) III image (path 108, row 56) DoA: 11.04.2014.
6) Landsat Operational Land Imager (OLI) (path 138, row 44) DoA: 22.04.2014; 16.11.2014; 06.05.2019; 30.11.2019.

b. Method (s): There are two different Land use-land cover (LULC) change detection performed:

1) LULC change between 1980, 1990, 2000, 2010 and 2014 for an overview analysis using three major LULC classes – urban *settlements*, *vegetation,* and *wetlands* within Kolkata Municipal Corporation (KMC) areas.
2) LULC change between 2009, 2014 and 2019 for detailed study using 6 major LULC classes – *urban settlement, agricultural lands, vegetation, lakes, inland wetlands,* and *open spaces* within KMC areas and its peri-urban wetlands namely, East Kolkata Wetlands (EKW).

For both, firstly, standard set of imagery was geometrically and radiometrically corrected, thereupon image was co-registered to match the overlay with sub-pixel accuracy (RMS errors ≈ 0.21). For re-sampling, nearest-neighbourhood technique was performed for the classification to retain the original pixel values. The maximum likelihood based supervised classification was employed to detect the changes in LULC within the Kolkata Municipal Corporation area (KMC). Classification of LULC was performed on co-registered images using a non-parametrical feature-space classifier on ERDAS Imagine software (v. 2015), and the LULC classes were mapped. For the assessment of the accuracy level of the classification procedure topographical maps (scale 1:50,000 surveyed in 1975-76 by the Survey of India), complemented by ground-truth data obtained from field surveys between 2008–2018 and analysis of secondary data collected within 2008-18 were compared with the classified satellite imagery. The average overall accuracy obtained for all was 85%.

4.5. Estimation of value of ecosystem services and changes in value due to LULC changes

a. **Data used:** To quantify the ecosystem service value (ESV) for the six land use categories *urban settlement, agricultural lands, vegetation, lakes, inland wetlands,* and *open spaces*, the Global value coefficients (GVCs) proposed by Costanza et al. (1997) have been used after suitable modification. The modified ESVs were estimated following Mamat et al. (2018) based on the ecosystem service valuation model of Costanza et al. (1997). All estimated monetary values given in US$ are based on the 2018 valuation.

b. **Method (s):** The following equations are applied to quantify ESV:

$$ESVk = Ak \times GVCk \quad (1)$$

$$ESV_t = \Sigma A_k \times GVC_k \quad (2)$$

$$ESV_f = \Sigma A_k \times GVC_k \quad (3)$$

where, ESV_k is the ecosystem service value (ESV) for individual land use categories, ESV_t is the total ecosystem service value and ESV_f is the individual ecosystem service function; Ak is the area in hectare (ha) and GVC_k is the global value coefficient (US$ $ha^{-1}year^{-1}$) for land use category k. GVC_{kf} is the global value coefficient (US$ $ha^{-1}year^{-1}$) for land-use type k and ecosystem service function type f.

After estimation of total ecosystem service values (ESV) the average ecosystem service value (ESV_{avr}) is computed applying:

$$ESV_{avr} = ESV_t/U_a \quad (4)$$

where, ESV_{avr} is the average ecosystem service value (US$ $ha^{-1}year^{-1}$), ESV_t is the total ecosystem service value (US$ $ha^{-1}year^{-1}$) for a certain study year and U_a is the total geographical area of the urban area (ha).

Using the concept of elasticity applied in economics, coefficient of sensitivity (CS) has been calculated as follows:

$$CS = [(ESV_j - ESV_i)/ESV_i]/[(VC_{jk} - VC_{ik})/VC_{ik}] \quad (5)$$

where, CS is the coefficient of sensitivity, ESV is the estimated ecosystem service value, GVC is the global value coefficient after Costanza et al. (1997), i and j denotes the initial and adjusted values respectively, lastly k represents the land use category.

4.6. Calculation of Water Quality Index

a. **Data used:**

Surface water quality data were obtained from West Bengal Pollution Control Board (WBPCB) of 13 stations, including:

- River
- Inland wetlands (canal and ponds)
- Lakes

Groundwater quality data from 270 groundwater monitoring stations were provided by McArthur et al., 2018.

b. **Method (s):** To calculate the WQI the Canadian Council of Ministers of the Environment (CCME*) model was used. The CCME WQI model consists of three measures of variance from selected water quality objectives: scope, frequency, and amplitude. The resulting CCME WQI values range between 0 and 100, representing the overall water quality. The CCME WQI values are then converted into rankings by applying the index categorization scheme. Chemical and bacteriological parameters considered as per CCME WQI categorization schema.

***CCME Water Quality Index** (CCME WQI) developed by the Canadian Council of Ministers of the Environment (CCME) with the aim of creating a means of communicating water quality issues to scientists, decision makers, and stakeholders is an important index, (CCME, 2001). The CCME WQI has been used widely worldwide (Alexakis et al., 2016). The CCME WQI offers several advantages over other methods, including compliance with different legal requirements and different water uses, eligibility for water quality assessment in specific areas, flexibility in the selection criteria, and tolerance for missing data (Terrado et al., 2010; Mohebbi et al., 2013; Yan et al., 2016).

The CCMEWQI summarizes the surface water and groundwater quality data into simple terms (e.g., excellent, good, fair, marginal, and poor) and facilitates reporting in a consistent manner. The conceptual framework of CCMEWQI is presented below:

The CCME WQI is based on a combination of three factors:

- *Scope:* the number of variables, whose objectives are not met,
- *Frequency:* the frequency with which the objectives are not met, and
- *Amplitude:* the amount by which the objectives are not met.

Factor 1: F1 (Scope)

Scope assesses the extent of water quality guideline non-compliance over the time-period of interest, which means the number of parameters whose objective limits are not met. It has been adopted directly from the British Columbia Water Quality Index

$$F_1 = \left(\frac{\text{Number of failed variables}}{\text{Total number of variables}} \right) \times 100 \quad (1)$$

Where, the variables indicate those water quality parameters whose objective values (threshold limits) are specified and observed values at the sampling sites are available for the index calculation.

Factor 2: F2 (Frequency)

The frequency (i.e., how many occasions the tested or observed value was off the acceptable limits) with which the objectives are not met, which represents the percentage of individual tests that do not meet the objectives ("failed tests"):

$$F_2 = \left(\frac{\text{Number of failed tests}}{\text{Total number of variables}} \right) \times 100 \quad (2)$$

The formulation of this factor is drawn directly from the British Columbia Water Quality Index.

Factor 3: F3 (Amplitude)

The amount by which the objectives are not met (amplitude) that represents the amount by which the failed test values do not meet their objectives and is calculated in three steps.

The number of times by which an individual concentration is greater than (or less than, when the objective is a minimum) the objective is termed an “excursion and is expressed as follows. When the test value must not exceed the objective:

$$\text{excursion}_i = \left(\frac{\text{Failed Test Value}_i}{\text{Objective}_j}\right) - 1 \tag{3}$$

For the cases in which the test value must not fall below the objective:

$$\text{excursion}_i = \left(\frac{\text{Objective}_j}{\text{Failed Test Value}_i}\right) - 1 \tag{4}$$

The collective amount, by which the individual tests are out of compliance, is calculated summing the excursions of individual tests from their objectives and then dividing the sum by the total number of tests. This variable, referred to as the normalized sum of excursions (nse) is calculated as:

$$\text{nse} = \frac{\sum_{i=1}^{n} \text{excursion}_i}{\text{number of tests}} \tag{5}$$

F3 is then calculated by an asymptotic function that scales the normalized sum of the excursions from objectives (nse) to yield a value between 0 and 100.

$$F_3 = \left(\frac{\text{nse}}{0.01\text{nse} + 0.01}\right) \tag{6}$$

The CWQI is finally calculated as:

$$\text{CWQI} = 100 - \left(\frac{\sqrt{F_1^2 + F_2^2 + F_3^2}}{1.732}\right) \tag{7}$$

The factor of 1.732 has been introduced to scale the index from 0 to 100. Since the individual index factors can range as high as 100, it means that the vector length can reach a maximum of 173.2 as shown below:

$$\sqrt{100^2 + 100^2 + 100^2} = \sqrt{3000} = 173.2 \tag{8}$$

The above formulation produces a value between 0 and 100 and gives a numerical value to the state of water quality. Note a zero (0) value signifies extremely poor water quality, whereas a value close to 100 signifies excellent water quality.

The success of the CCME WQI has led many research to make water quality assessments based on the legal standards of their respective countries (Terrado et al., 2010; Boyacıoğlu and Boyacıoğlu, 2010; Sharma and Kansal, 2011; Akkoyunlu and Akiner, 2012; Espejo et al., 2012; Damo and Icka, 2013; Mostafaei, 2014; Uddin et al., 2017).

4.7. Formulation of Urban Water Security Indices

This PhD study aims to formulate an integrated index which is a composite measure of more than one index accumulating scores from a variety of individual variable. In order to capture the Urban Water Security (UWS) issues holistically, the study constructed three indices, namely, i) WaSH provisions Index (WPI), ii) Urban Environmental Water Security Index (UEWSI) and iii) Urban Water Security Index (UWSI). At the end, Integrated Urban Water Security Index (IUWSI) was formulated aggregating the other three indices at the borough level to have a normalised borough wise comprehensive value representing urban water security of KMC area, which can be regarded as final outcome of the study.

The method of each index construction followed 4 general steps: (1) selection of variables, (2) probing the empirical relationships of variables (3) weighing the variables and combining them into an index, (4) validating the index by examining the scores with the socio-demographic variables as well as the evidence from literatures.

4.7.1. WaSH Provisions Index (WPI)

Using the ward wise frequencies of water provision based on the Survey and Census data of India (2011), a WaSH provisions (WP) index of a ward as a normalized weighted average was applied, defined as follows:

$$WP\ index(non-normalized) = \frac{\frac{l}{p}}{2} + \frac{\left(\frac{s}{p} + \frac{d}{p} + \frac{t}{p}\right)}{6}. \quad (9)$$

$$WP\ index(normalized) = \frac{index - min(index)}{max(index) - min(index)} \epsilon[0,1]. \quad (10)$$

with l/p= latrines person^{-1}, s/p= standposts person^{-1}, d/p= dugwells person^{-1} and t/p= tubewells person^{-1}.

The variable "latrines person^{-1}" was considered as a representative of sanitation provision, while the remaining variables represent water sources. Therefore, total number of latrine person^{-1} (l/p) was given same weight as the sum of the remaining three WaSH provisions (s/p= standpost person^{-1}, d/p= dugwells person^{-1} and t/p= tubewells person^{-1}). Normalization to WP index values between 0-1 allows to assess inter-ward-variability in water security provisions.

4.7.2. Urban Environmental Water Security Index (UEWSI)

The Urban Environmental Water Security Index (UEWSI) has been calculated based on results of LULC change analysis between 2009, 2014 and 2019, and Intensity indices (Tate et al., 2005; Su et al., 2011; Suja et al., 2013; Zhou et al., 2014) which explain the degree of change in average ecosystem services value (ESV) in each borough (an administrative block comprising several lowest administrative units called ward) of Kolkata Municipal Corporation and East Kolkata Wetlands for the given period of time.

The temporal and spatial variation of the UEWSI was prepared using the following equations:

Pre-Monsoon Ecosystem Services Valuation Index:

$$ESVI_{prm} = \sum(\Delta ESprmx * 100)/AT \ * \ \Delta t \ ) \quad (11)$$

Post-Monsoon Ecosystem Services Valuation Index:

$$ESVI_{pom} = \sum(\Delta ESpomx * 100)/AT \ * \ \Delta t \ ) \quad (12)$$

Pre-Monsoon LULC Intensity Index:

$$PRM\ II = \sum(\Sigma\Delta C1 * 100)/AT \ * \ \Delta t \ ) \quad (13)$$

Post-Monsoon LULC Intensity Index:

$$POM\ II = \sum(\Sigma\Delta C2 * 100)/AT \ * \ \Delta t \ ) \quad (14)$$

Urban Environmental Water Security Index:

$$UEWSI = \sum_{-1}^{1}[(ESVIprm + ESVIpom + PRMII + PPOMII) + SuplWQI] \quad (15)$$

where, $\Delta ESprm_x$ and $\Delta ESpom_x$ denote the change of the borough wise average ESV in US$ between 2009-2019 during pre-monsoon or post-monsoon seasons; x is the individual borough of KMC; ΔC1 and ΔC2 are the change in area (ha) for all LULC classes over the total study period during pre- and post-monsoon seasons respectively; AT is the total area (ha) of the borough; and Δt is the time (Year) span of the study period between 2009 and 2019.

Weightage for Supplied Water Quality Index ($SuplWQI_x$) is a value assigned to tested supplied water's (or main source of drinking water's) category in the Canadian Council of Ministers of the Environment (CCME) water quality index (WQI) scheme for each borough (example: 1 for poor, 2 for marginal, 3 for fair, 4 for good and 5 for excellent) where the supplied water is considered as the main source of water for drinking purpose.

Normalization of UEWSI values (-1 to 1) allowed assessing inter-borough variability in environmental water security displayed in a map using ArcGIS 10.6 (ESRI, Redland, CA, USA).

4.7.3. Urban Water Security Index (UWSI)

The Urban water security index at the borough level was calculated based on Survey data, as:

UWSI = (Avl*w1) + (Acs*w2) + (Wqt*w3) + (Wrh*w4) (16)

where,

Avl = Score for *Water Availability* variables

Acs = Score for *Water Accessibility* variables

Wqt = Score for *Water Quality* variables

Wrh = Score for *Water Risk and Hazards* variables, and,

w1, w2, w3, w4 are the weights assigned (determined by the ''loadings'' of PCA) for each factor.

Then, the UWS Index scores were used to categorize each borough on the 0-10-point scale (Category of security status) classifying the status of urban water security, as follows:

8-10: Very Secured

6-8: Secured

4-6: Around acceptable threshold

2-4: Insecured

0-2: Very Insecured

4.7.4. Integrated Urban Water Security Index (IUWSI)

Integrated Urban Water Security Index (IUWSI) comprises all the indices mentioned in the previous chapters. It can then be calculated as:

IUWSI = (WPI + UEWSI + UWS) $\epsilon[0,1]$ (17)

where,

WPI is WaSH Provisions Index,

UEWSI is Urban Environmental Water Security Index, and

UWS is Urban Water Security Index.

5. Assessments: Case studies

5.1. Case study 1

Assessment of water security in socially excluded areas in Kolkata, India: An approach focusing on water, sanitation and hygiene[3]

Abstract

Water security is essential not only to ensure the availability and accessibility of water for drinking, producing food, washing, but also to maintain both human and environmental health. The 2011 Census of India reveals that 17.4% of urban households in India live in deprived areas in urban landscapes which are designated as slums in the Census dataset. The increasing number of people living in these areas poses serious challenges to the provision of basic urban water, sanitation, and hygiene (WaSH) services. Perceived susceptibility of risks from contaminated water and lack of proper sanitation and hygiene will be addressed in the light of social exclusion factors. This study attempts to assess the present situation of water, sanitation and required hygiene provisions within the areas defined as slums by the Census of India 2011 in Kolkata, India. Based on the results obtained from the datasets from the census, and a household survey, we identified a lack of supplies associated with WaSH provisions in these areas of Kolkata. The WaSH provisions in the slum areas of Kolkata city are facing various issues related to regularity, quality, and quantity of supplied water. Additionally, there is poor maintenance of existing WaSH services including latrine facilities and per capita allocation of a sustainable water security among the slum dwellers. By adding to our understanding of the importance of factors such as gender, religions, and knowledge of drinking water in deprived areas, the study analyses the links between both physical and social issues determining vulnerability and presence of deprivation associated with basic WaSH provisions as human rights of slum communities.

Keywords: WaSH; human rights; gender; urban deprived areas; slums; water security

[3] Mukherjee, S., Sundberg, T. and Schütt, B., 2020. Assessment of water security in socially excluded areas in Kolkata, India: An approach focusing on water, sanitation, and hygiene. *Water*, 12(3), p.746. https://doi.org/10.3390/w12030746

5.1.1. Introduction

At the turn of the millennium about half of the global population lived in 'mega-cities' (Massey et al., 1999). These large cities are predominantly located in the developing world (Ilesanmi, 2010). There are well-known environmental problems of and in megacities, and this article focuses on one major dimension of these environmental problems—water, sanitation, and hygiene (WaSH)—here seen to represent a major part of the overall concept of water security. Provisioning of sustainable WaSH services is now increasingly considered as water security (Wetlands International, 2017). Water shortage is a rapidly growing problem and delivery of safe drinking water cannot be ensured in many mega-cities. The present-day situation with respect to pollution of air, land, and water, as well as the lack of basic water and sanitation facilities in mega-cities, creates difficult living conditions, with women and children suffering most (Niemczynowicz, 1996). Attaining universal and equitable access to safe and affordable drinking water for all by 2030 (UN Sustainable Development Goal 6) will be a major challenge, particularly in deprived areas of large cities and mega cities.

Water security ensures the access to safe and enough drinking water at an affordable cost in order to meet basic needs, which includes sanitation and hygiene (UN, 2012), and the safeguarding of health and well-being (Wetlands International, 2017). Hence, this article uses water security as a framework to understand WaSH- related issues in mega-cities, here Kolkata (India), and the complex web of factors influencing these issues. We study WaSH indicators, which we understand as key provisions to achieve water security. We combine human-oriented and environmental perspectives through analyzing slum data and data of a pilot survey—and combining bio-physical and social data as discussed in Mukherjee et al. (Mukherjee et al., 2018). Although there is no consensus on the concept of water security, most authors agree on some commonalities seen as fundamental to water security, including adequacy of water and sanitation (see for example (Sommer et al., 2015; Brears, 2017). Securing access to clean water, and ability to adequate hygiene and sanitation is here seen as crucial to secure basic human rights, and sustainable development (Brears, 2017).

When analyzing water security in urbanized areas most recent studies seek to focus on complex sets of factors including unrestricted population growth (Falkenmark and Widstrand, 1992; Ravell, 2014), poor governance (Cook and Bakker, 2012; Bakker and Morinville, 2013; Biggs et al., 2013) and mismanagement of the water supply system (Piesse, 2015) as well as social inequality (UN-Habitat, 2008; Goff and Crow, 2014; Blanca, 2017; Jepson et al., 2017;). Our study aligns itself with studies focusing on the multidimensional and complex set of factors related to WaSH to create an improved quantitative assessment framework. By analyzing data on slums and a pilot survey in Kolkata and combining both data sets we will show variations in bio-physical and socio-economic data—and how these factors need to be considered when we want to understand WaSH related vulnerabilities. By analyzing WASH provisions, we want to identify inequalities in water security among the socially excluded groups in Kolkata.

For an in-depth discussion on the connotations and history of the concept of slums see Mayne (Mayne, 2017). In his work he understands slums as a 'place to be ministered to, a place to be cleaned up, a place to be cleared out'. In 2012, globally more than 8 million people — about a third of the urban population of developing countries—lived in slum areas (Subbaraman and Murthy, 2015; Mukherjee et al., 2018). The primary barriers to access water in these areas are not solely monetary or technical but legal, institutional, and political (Subbaraman and Murthy, 2015). Urban areas with high levels of deprivation i.e., slums, constituted almost 1 billion people or 32% of the global urban population in 2003 (UN-Habitat, 2003). Moreover, the locus of global poverty is moving to the cities, a process now recognized as the 'urbanization of poverty' (Ravallion et al., 2007). Without concerted action on the part of municipal authorities, national governments, civil society actors and the international community, the number of people living in highly deprived areas in these cities is likely to increase in most developing countries and is projected to rise over the next 30 years to about 2 billion (UN-Habitat, 2003). In the United Nations Millennium Declaration, world leaders pledge to tackle this challenge, setting the specific goal of achieving 'significant improvement in the lives of at least 100 million slum dwellers by the year 2020′ (UN-Habitat, 2003). This includes to address the needs for shelter as well as overarching problems of urban poverty, especially unemployment, low incomes, and a lack of access to basic urban services, such as access to water and sanitation. At present, 785 million people lack even basic drinking-water service and 2.0 billion people still do not have basic sanitation facilities such as toilets or latrines (UNICEF/WHO, 2019). The question arises: why the interventions to ensure safe water and sanitation to everyone is insufficient? It is our hypothesis, that part of the answer lies within the issue of socio-cultural dimensions. These aspects are often only considered superficially, and there is inadequate knowledge to be able to ensure suitable and sustainable WaSH provision for everyone.

In this study we want to analyze water security in socially excluded areas in Kolkata mega city as a case study along social, political, economic, and cultural dimensions combined with bio-physical characteristics. As a social measure of vulnerability to water security we focus on data from areas defined as slums by the data gathering institutions, here the Census of India 2011, to analyze the trends in water security among households that are socially excluded. These socially excluded areas or ‘slums’ are defined as a group of individuals living together under the same roof and lacking one or more of the following conditions: access to improved water, access to improved sanitation, structural quality/durability of dwelling, sufficient living space that is not overcrowded, and security of tenure (Mayne, 2017). Referring to various desiderata, this study aims to determine the role of social factors and culture as dimensions of water security by analyzing in the context of Kolkata’s deprived areas, to assess WaSH program’s failure or success. We explore to what extent social, cultural, economic, political, and institutional factors influence individuals’ and specific groups’ (groups in vulnerable positions from an intersectional point of view) water security in a city, with the objective to create indices that can reliably measure water security. This will help to develop sustainable solutions to fight water insecurity. Summarizing, this article aims to:

1) Provide a new understanding of water security in socially excluded areas in Kolkata using ‘Slum Data’ extracted from the 2011- Census of India report.

2) Show the variation in water security across and within areas defined as slums, by focusing on WaSH and identify the key socio-economic factors affecting urban water security of socially excluded population in Kolkata based on primary data collected in the frame of this study.

This article provides an analysis of biophysical and social data with the aim of enhancing our understanding of water security issues in socially excluded areas, often referred to as slums.

5.1.2. State of the art

Geographical areas with high levels of social exclusion and deprivation are often referred to as slums (Begum and Moinuddin, 2010). These areas are expected to have particularly high levels of water insecurity (Webb and Iskandarani, 1998). The populations within these areas are growing due to net migration gain and high birth rates (Martine, 1972; Marx et al., 2013). For Kolkata (and India), the general term slum can refer to both *bastis* (or Bustee) and squatter settlements (Schenk, 2010). Bastis are legally recognized settlements that the Kolkata

Municipal Corporation supplies with services such as water, latrines, trash removal, and occasionally electricity. *Basti* huts typically are permanent structures that the government will not demolish, which allows *basti* communities to develop a sense of permanency and to focus on issues of poverty beyond shelter availability (Schenk, 2010). In contrast, squatter settlements are illegal clusters of temporary houses mostly located along canals and railways (Levitas et al., 2007; Ghosh, 2013). The Kolkata Municipal Corporation (KMC), responsible for the civic infrastructure and administration of the city of Kolkata, usually does not supply squatters with basic conveniences (UN-Habitat, 2003; Ghosh, 2013). Moreover, people in squatters live in anticipation, though of different degrees depending on settlement location and political affiliation, of their potential evictions (UN-Habitat, 2003; Schenk, 2010).

The term social exclusion in the sense of the UN-Habitat Programme is a ‘a complex and multi-dimensional process (… that) involves the lack or denial of resources, rights, goods and services, and the inability to participate in the normal relationships and activities, available to the most people in a society, whether in economic, social, cultural or political arenas. It affects both the quality of life of individuals and the equity and cohesion of society as a whole’ (UN-Habitat, 2003, p. 9). Social exclusion as a concept focuses on both the processes by which social and economic institutions exclude groups, and the multidimensional nature of the adverse consequences experienced by those who are excluded (Thorat, 2007). Gender is one of the most important factors related to social exclusion and is also the most dominating in the context of cultural dimension of WaSH and water security (WSP, 2010). It controls the roles and vulnerabilities in relation to WaSH and the hegemonic role of male gender over others, especially in developing countries. As an example, the provision of hygiene and sanitation are often considered as women’s tasks, resulting in women being more exposed to WaSH-related problems. Despite this, women’s concerns are rarely spoken properly due to societal or cultural blockades (SuSanA, 2009) and other gendered people are not even recognized when designing solutions to WaSH issues (Benjamin and Hueso, 2017).

For Kolkata, few studies exist that have researched water and sanitation issues in specific wards (= administrative units) defined as slums (Schenk, 2010; Das et al., 2012; Ghosh, 2013). Ghosh observed that slum dwellers of Bibi Bagan Lane (within Kolkata city, ward no. 56) are greatly unhappy with water and sanitation provision; among the most crucial issues they highlighted were dirty, filthy conditions of the toilets for females (Falkenmark and Widstrand, 1992). Beyond, overflowing toilets, shortage of baths and drainage problems were common problems in the ward, and the study also reports a demand for provision of tap water. A socio-economic survey of the Dasnagar slum within the Kolkata Metropolitan area (KMA) describes not only poor but also deteriorating conditions out of which the authors identified a set of social indicators of social exclusion combined with poor sanitation in the area (Das et al., 2012). Schenk argues that religion and language have a greater influence on the social, economic, and physical characteristic of deprived areas than caste (Schenk, 2010). He points out that to improve the living conditions we need to understand the factors that led to emergence of slum areas, the population that inhabit them and the constraints imposed by the politics of slums and settlements. Lessons must be learned from the shortcomings of past policies (Ray, 2017), and Schenk suggests that new policies must consider ethnic diversity, disparate occupation and the social and political scenario of the slums that are critical for its existence (Schenk, 2010).

Looking at official data (Census of India, 2011) growing numbers of deprived areas defined as slums by the official bodies in Kolkata and Bengal can be observed (Census of India, 2011). According to the ‘Primary Census Abstract for Slum’ (Census of India 2011) West Bengal state counted 6.4 million slum dwellers—0.48 million in notified slums, 3.7 million in recognized slums and 2.6 million in identified slums. The share of slum population in West Bengal state has risen from 8.9% in 2001 to 9.8% in 2011. In Kolkata (capital city of West Bengal state), the proportion of slum households to total urban households amounts 29.6%. 80–85% of the slum population in West Bengal are literate.

i. Water security and human rights

For squatter/semi-permanent settlements state water insecurity is stated as ‘a lack of access by all people, at all time, to adequate water for an active and healthy lifestyle’ (Wutich and Ragsdale, 2008, p. 2117). Various studies emphasize the dimensions of quantity, quality, and accessibility as crucial dimensions (Gleick , 1998; Satterthwaite, 2003; Hadley and Amber, 2009). The *human right to water* entitles everyone to enough, safe, acceptable, physically accessible, and affordable water for personal and domestic (household) use. Sanitation is defined as a system for the collection, transport, treatment, disposal, or reuse of human excreta and associated hygiene (UNICEF/WHO, 2014a). The human right to sanitation entitles everyone to sanitation services that are safe, socially, and culturally acceptable, secure, hygienic, physically accessible, and affordable, and that provide privacy and ensure dignity (UN, 2014). ‘Human rights are inherent in all human beings, whatever their nationality, place of residence, sex, national or ethnic origin, color, religion, language, or any other status’ (UN-

Habitat, 2003). In 1977, the United Nations Water Conference for the first time recognized the 'right to water'. The conference's action plan stated that all people have the right to have access to drinking water in quantities and of a quality equal to their basic needs (Chenoweth et al., 2013; UN-Water, 2013). In 2000, the 'right to clean water' was affirmed by the United Nations General Assembly in its resolution A/Res/54/175. However, the rights to water and sanitation were not recognized as a fundamental human right until July 28, 2010 in resolution 64/292 made by the United Nations General Assembly (UN, 2010). The formal recognition of the 'Human Right to Water and Sanitation' (HRWS) in 2010 by UN member states was the most recent step in a decades-long discussion about the contents and implications of these rights (Boelens, 2013, p. 238). Securing human rights to clean water and sanitation is central in water security with both aspects being intrinsically linked. Consequently, water security can be defined as 'the secure, adequate, and sustainable access that people and ecosystems have to water, including the equitable distribution of advantages/disadvantages related to water use and development opportunities, the safeguarding against water-based threats, and the ways of sharing decision-making power in water governance' (Grey and Sadoff, 2007, p. 20). Gutierrez advocates for an approach to water security that embraces the notion of 'access' (Gutierrez, 1999). This implies bringing individual rights, equity and justice and affordability to the first place (UN, 2010; Leb and Wouters, 2013). These principles of water security comply with the Human Right to Water and Sanitation (HRWS) ensuring all people to have access to enough water (UN, 2010; UNESCO, 2019). Recognizing this coupling of the HRWS and water security concepts, it is helpful to consider five main dimensions of the rights in practice, in order to maintain household water security:

- ***Availability***, corresponding to sufficient and continuous water supply for personal and domestic uses, including drinking and food preparation, personal hygiene, washing of clothes, cleaning, and other aspects of domestic hygiene, as well as facilities and services for the safe disposal of human excreta (i.e., urine and faeces) (Gleick, 2004).

- ***Accessibility***, implying that water and sanitation facilities must be located or constructed in such a way that they are always accessible to everybody. Safe access is particularly important regarding to sanitation both for people with constrained physical movement and particularly women, girls and trans* who may face safety risks (UN, 2004; WHO, 2018).

- ***Quality and safety***, implying that water quality must be safe for human consumption (i.e., drinking and food preparation) and for personal and domestic hygiene. This means it must be free from microorganisms, chemical substances, and radiological hazards that constitute a threat to a person's health both short term and over a lifetime of consumption. Sanitation facilities must be safe to use and prevent contact between people and human excreta (Gleick, 2004).

- ***Acceptability***, meaning that water and sanitation facilities must meet social or cultural norms from a user's perspective, i.e., regarding the odor or color of drinking water, or the privacy of sanitation facilities. In most cultures, gender-specific sanitation facilities will be required in public spaces and institutions (UN, 2004; WHO, 2018).

- ***Affordability***, including that individual and household expenditure on water and sanitation services, as well as associated hygiene, must be affordable for people without forcing them to resort to other, unsafe alternatives or limiting their capacity to acquire other basic goods and services (such as food, housing, or education) guaranteed by other human rights (Smets, 2009; Teodoro, 2018).

Almost all United Nations members agreed with HRWS as a universal right, but the implementation of the standards varies in practice. The United Nations International Children's Emergency Fund (UNICEF) and World Health Organization (WHO) specified 20 L of water per capita per day as the minimum amount required for a person (UNICEF/WHO, 2012). Only then that person would be considered to have access to improved water supply in their global assessment of water supply according to WHO/UNICEF Joint Monitoring Programs for Water Supply and Sanitation, 2011 (UNICEF/WHO, 2012). However, this does not provide enough water to ensure other basic human rights which are fundamental to maintain water security at a household level (Boelens, 2013; Chenoweth et al., 2013). Chenoweth argues for 85 L per capita per day as minimum requirement for basic domestic water usage (mainly drinking, cooking and washing) at the household level, and 120 L per capita per day as the least necessity if economic activities are involved on top of that (Chenoweth et al., 2013). Therefore, it gets clear that the standard of minimum access level of per capita water requirement set by WHO/UNICEF is too low for achieving household water security to fulfill the HRWS (Chenoweth et al., 2013).

For vulnerable societal groups, water insecurity and deficient WaSH provisions commonly reflect unequal distribution of water volumes, quality, and sanitation services within unequal power structures (Bradley and Bartram, 2013; UNESCO, 2015). Policy debates tend to naturalize and de-politicize the definition of water security (Boelens, 2013). Instead of recognizing that water security and distribution are a result of political choices, negotiation, and power plays, they are often represented as following universal economic, legal, and natural-scientific rules (Boelens and Seemann, 2014). In this context, there is a widespread policy assumption that formally recognizes that local, customary HRWS is an important element to grant water security for marginalized user groups (UN, 2010).

Water in-security, as it is increasingly perceived in recent policy notions, is not so much associated with hazardous or absolute scarcity of sufficient fresh and clean water only, but the ways the water and water-services are distributed and, essentially, the unequal power structures within the society (UN, 2010; Bradley and Bartram, 2013; UNESCO, 2015). Therefore, *equity in distribution of water* services is more crucial in limiting water security in the context of unequal power than *sufficiency* of availability of safe and clean water (Bradley and Bartram, 2013). According to the 2006 United Nations Human Development Report, poverty, power, and inequality create the water crisis, not the water scarcity itself (UN, 2010, p. 238).

The right to water ensures that every human is provided with safe, accessible, and affordable universal access to water which is also reflected in the WHO approach to categorizing access to water (WHO, 2008). In developing countries, access to urban services often differs widely between the rich and the poor dwellers, and between men and women (Duflo et al., 2012). The slum dwellers experience variable deficiencies and risks associated with urban water insecurity, including lack of durable housing, overcrowding, insufficient access to clean water, poor sanitation and hygiene facilities and threats of forced evictions (UN-Habitat, 2003). In water, sanitation and hygiene, women's concerns are rarely addressed appropriately due to societal or cultural barriers (Schelwald-Van Der Kley and Reijerkerk, 2009; Warner et al., 2008). Women and girls in slums or poor informal settlements typically take responsibility for fetching water when supply is poor, and this can take hours out of their day, reducing time for education, employment, childcare etc. (Winter et al., 2019). When relatives become sick because of poor hygiene, it is also women and girls who bear the greatest burden of care (UN-Women, 2018). Because women tend to spend more time than men in the home and neighborhood, they are also more directly exposed to environmental hazards of poor sanitation—such as diseases caused by poor drainage, contact with human faeces and decomposing rubbish (Winter et al., 2019).

ii. Water security in Kolkata's deprived areas

Water security provision in Kolkata's deprived areas (slums) has been a contested topic since the foundation of the city. Various political forces have debated the issue of slum improvement versus slum demolition since the Colonial Period (Doshi, 2011). The post-independence Indian government emphasized slum improvement but with the goal of slum demolition and relocation. The colonial government refused to take financial responsibility for improving slums because they existed on private lands (Furedy, 1982, p. 31). The municipal corporation only acted initially out of concern for public health and fire hazards (Furedy, 1982). Prioritization of street construction over slum improvement grew during the 1890s and early twentieth century as power was allotted to the Calcutta Building Commission and the Calcutta Improvement Trust (Schenk, 2010; Furedy, 1982, pp. 39–41). Slums were cleared in the early twentieth century to make room for British colonizers (Dutt, 1944). There is no indicator that the authorities showed concern for the welfare of displaced slum dwellers, but rather a political emphasis on 'commercial viability' by colonial British policies (Schenk, 2010, p. 104).

In Kolkata local water security is deeply anchored in local water control rights (Boelens and Seemann, 2014). Diverse interest groups encounter and negotiate with rights definitions and normative codes that regulate day to day water uses. HRWS is co-determined also by bio-physical conditions, but in a mega-city like Kolkata the water rights are interwoven with society's socio-cultural norms and perceptions related to WaSH as well as political and economic histories (UN, 2010). Religion, language, and caste are diverse among the population in Kolkata's deprived area, which is reflected in the wide spectrum of their social and economic features as well as in water and sanitation. Also, religion, ethnicity and language are included to understand deprived areas (Schenk, 2010). Currently, and despite the *Bustee Improvement Programme* implemented by the Calcutta Metropolitan Planning Organization (CMPO) and a variety of activities by different NGOs and efforts of slum dwellers themselves, there has not been any significant improvement in the physical living conditions of the slums in Kolkata (Bose and Ghosh, 2015).

5.1.3. Study area

Kolkata Municipal Corporation (KMC) is located between 22° 28′ 00″–22°37′ 30″ N and 88° 17′ 30″ E–88°25′ 00″ E with its northwestern boundary along the main branch of river Ganga, the Bhagirathi Hooghly (Figure 5.1.1). The city Kolkata is the capital of the state West Bengal and is well connected by rail, road, and air network. The Kolkata Municipal Corporation covers an area of 187.3 km² and comprises of 141 wards reassigned to 15 boroughs (currently, three new wards have been added and boroughs are rearranged in 16 wards, but official data for this rearrangement are still not available) having 21 assemblies and three parliamentary constituencies. As per provisional reports of Census of India (2011), population of KMC in 2011 totaled 4,496,694 capita of which 52.4% were male (Census of India, 2011). As per 1901 census population of Kolkata counted 933,754 capita and increased to 2,698,494 capita in 1951, 4,572,876 in 2001 (Census of India, 2011) and most recently it is estimated to be 5,302,880 capita (https://indiapopulation2019.com/population-of-kolkata-2019.html). In 2001 approximately 40% of Kolkata's population lived in 5500 overpopulated slums (Census of India, 2011), while according to census data from 2011 there lived approximately 25% Kolkata's population in 5600 different slum areas (c. 1.141 million city residents) (Census of India, 2011). The population growth of Kolkata city is increasing rapidly which also enhances the demand of ground water in the city and ultimately imposes stress on ground water regime in the area (McArthur et al., 2018). Hinduism is the predominant religion in Kolkata city with 76.51% followers, while Islam has about 20% followers. Beyond, in Kolkata city Christianity is followed by 0.88% of its population, Jainism by 0.47%, Sikhism by 0.31% and Buddhism by 0.31%; around 0.03% of the city residents stated to follow an 'Other Religion', approximately 1.09% stated to belong to 'No Particular Religion' (Census of India, 2011). Daily water demand within the KMC area totals about 969×10^6 L with two major water sources to cover the water demand: (a) Surface water from the river Hooghly through piped supply as standposts and (b) ground water made accessible through tubewells and dugwells (Mukherjee et al., 2018).

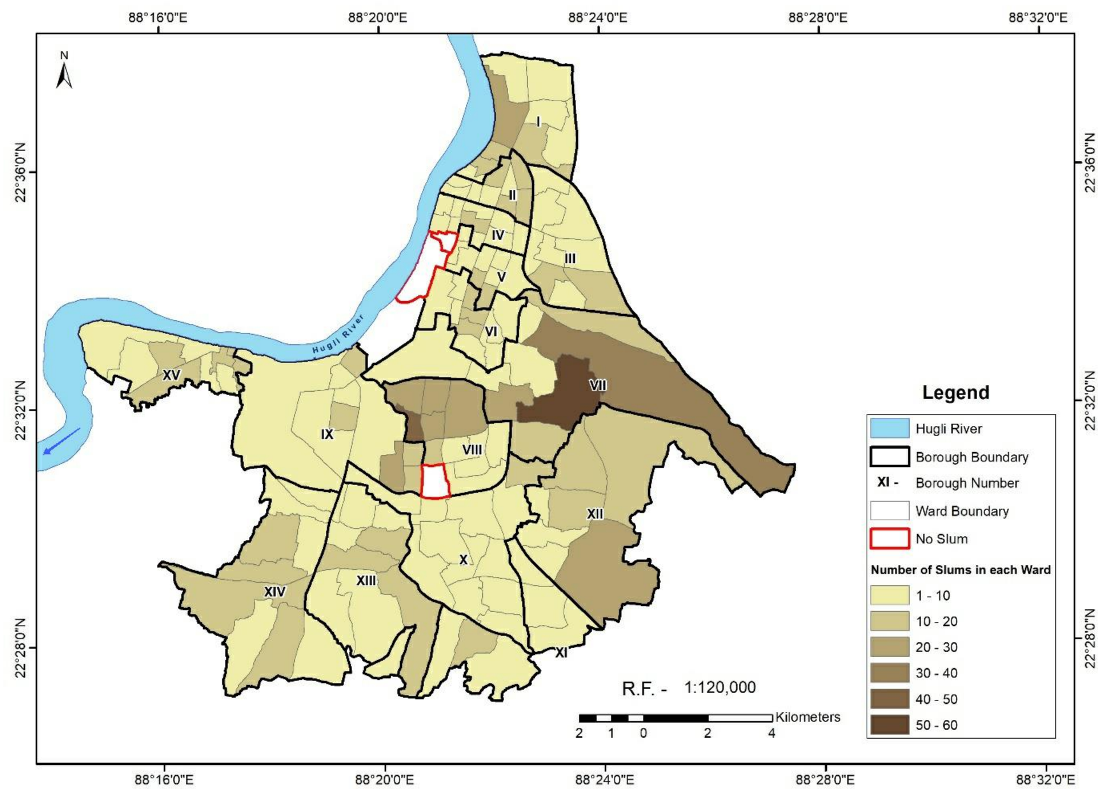

Figure 5.1.1. Borough map of Kolkata Municipal Corporation (KMC) area featuring the wards associated in a borough. Roman numbers mark the borough numbers. Data source: Census of India, 2011; Mukherjee et al., 2018.

5.1.4. Methods

i. Data

The primary data base on a survey using (i) Stratified Random Sampling collection of data from 45 households from each borough of KMC and (ii) two LGBTQ focus groups consisting of 35 respondents were conducted in November-December 2018. Total respondents were 755. Furthermore, Census Data of India (2011) was used to extract the detailed slum data (Census of India, 2011). The survey included the presence of drinking water provisions and toilets in the house. The respondents were a mixed from slum and non-slum areas of the entire KMC. The 2011 Census Data of India dataset on slums provides detailed information on household level in each ward of the KMC area. It includes information on socioeconomics such as condition of the slum housing, income, literacy as well as water provisions in term of latrines, dugwell, tubewell and standposts; data on gender, religion and language statistics were also obtained from this data set.

This article reports on interdisciplinary analysis using the data in an innovative way, combining it with biophysical data and complementing it with survey data. As the aim of the research is to for the first time combine social and biophysical data to start exploring the new understanding such approaches can yield in the area of water security—and this aims to highlight this through bivariate analysis, with robustness and significance testing and the use of data from satellite images. This follows in the tradition of landmark studies within the area of water security, where simple indicators and analysis form the basis for crucial contributions to the field (Webb and Iskandarani, 1998; Grey and Sadoff, 2007; Cook and Bakker, 2012; Bakker and Morinville, 2013; Boelens, 2013; Bradley and Bartram, 2013; Blanca, 2017; Jepson et al., 2017; Brears, 2017; Mukherjee et al., 2018). The article is a first step in a larger project, which will make use of advanced techniques such as multilevel modelling and GIS combining social and biophysical data, and argues that simple, strong findings found in the analysis carried out here is crucial and sufficient to show important dimensions to consider in water security, as can be seen in our findings.

The survey focused on water security issues comprehensively as defined by Grey and Sadoff (2007). According to them, water security is 'the availability of an acceptable quantity and quality of water for health, livelihoods, ecosystems, and production, coupled with an acceptable level of water-related risks to people, environments and economies' (Grey and Sadoff, 2007, p. 548). The survey was based on a questionnaire consisting of 35 questions divided into four segments, differentiating issues of pressure (availability and accessibility), state (water quality) and impact of water security (water related risks/hazards) on the households. The fourth segment included demographic data assemblage to reflect the social aspects of water security in the city's neighborhood.

The article used the variables focused on WaSH issues of availability, accessibility, quality, and risks related to water experienced in the respondent's everyday life. Due to the ethnic and linguistic diversity of Kolkata interviewers speaking the local languages were recruited providing access to respondents of different socio-economic, ethnic and caste background. The Interviewers undertook training to ensure they learnt about the crucial social and biophysical dimensions of water security as well as to ensure they were fully trained both on interviewing skills, how to avoid bias as well as ethical issues that may arise during an interview. Survey training activities were also especially important to maintain survey quality, as well as gender sensitization because our survey included the entire gender spectrum to be notified on record.

Interviews were conducted based on the availability of respondents, which might affect how representative the sample is. The average survey response rate across the city was about 70% varied across the study area.

The research also incorporated analysis of satellite images to extract the information on existing waterbodies within the city in 2010 (as the Census survey was performed mainly in 2010) as a basis to compare the status of WaSH provisioning and the availability of surface waterbodies. For this study we used Indian Remote Sensing (IRS) Resourcesat-1 Linear Imaging Self-Scanning Sensor (LISS) III image (path 108, row 56; DoA: 03.02.2010).

It is focused on source and access to water as well as access to and place of toilets. The provisions of WaSH are defined in each slum as access to latrine and drinking water supply facilities i.e., standposts, dugwells and tubewells. A standpost is a tap-stand which provides water from a piped water distribution system for local communities. Dugwells and tubewells are both vertical drilled wells receiving water from an aquifer. Dugwells are holes in the ground dug by shovel or backhoe and cased with stones, brick, tile, or other material to prevent collapse, while tubewells are cased with stainless steel tube or pipe (US-EPA, 2019).

ii. Data processing

Data processing and analyzing were divided into four sections according to the source of the data.

- Survey data processing.

All survey data were collected by questionnaire which were transferred into MS-Excel data sheets. The answers were coded and cleaned for further analyses. Data cleaning involved the detection and removal (or correction) of errors and inconsistencies in a data set or database due to the corruption or inaccurate entry of the data. Incomplete, inaccurate, or irrelevant data is identified and then either replaced, modified, or deleted.

- Census data processing.

The slum data obtained from the Census of India (2011) were first extracted from the District Census Data Handbook—Kolkata and transferred into a MS-Excel data sheet. Data was cleaned and sorted based on wards and boroughs, respectively. On this base per capita availability of water provision (no of latrine, standposts, dugwell and tubewell) in each ward was calculated. Each of the per capita allotment of water provision was further related to each category of gender (male, female, children), language spoken (Bengali, Hindi, Urdu) and religions (Hindu, Muslim, other) to get the category-wise distribution of water provision in the slums in each ward. Deductive statistics is applied to analyze the distribution of water provision in regard to the different population categories.

- Outlining surface waterbodies and WaSH provisioning in the slums, optical bands were considered to map surface waterbodies and WaSH provisioning in the slums within KMC areas.

In the first step, standard image (LISS III Satellite Image 2010 from ISRO, Bengaluru, India) was geometrically and radiometrically corrected, thereupon image was co-registered to match the overlay with sub-pixel accuracy (RMS errors ≈ 0.21). For re-sampling, nearest-neighborhood technique was performed for the classification to retain the original pixel values. The maximum likelihood based supervised classification was employed to detect the changes in wetlands areas within the Kolkata Municipal Corporation area (KMC) for 2010. Classification of wetland areas was performed on co-registered images using a non-parametrical feature-space classifier on ERDAS Imagine software (v. 2015, Hexagon Geospatial, Madison, AL, USA). Surface waterbodies (excluding the river Bhagirathi Hooghly in the west) were mapped. For the assessment of the accuracy level of the classification procedure topographical maps (scale 1:50,000 surveyed in 1975-76 by the Survey of India), complemented by ground-truth data obtained from field surveys between 2008–2018 and analysis of secondary data collected within 2008-18 were compared with the classified satellite imagery. The overall accuracy obtained was 85%. Finally, the extracted surface waterbody class was overlaid on the displayed slum data with various water provisioning in the study area.

- Calculation of ward wise distribution of WaSH provisions (WP index).

Using the ward wise frequencies of water provision, a WP index of a ward as a normalized weighted average was applied, defined as follows:

WP index (non-normalized) = (l/p/2) + {(s/p + d/p + t/p)/6}

WP index (normalized) = {index – min(index)}/{max(index) – min(index)} $\in [0,1]$

with *l/p* = latrines person^{-1}, *s/p* = standposts person^{-1}, *d/p* = dugwells person^{-1} and *t/p* = tubewells person^{-1}.

The variable "latrines person^{-1}" was considered as a representative of sanitation provision, while the remaining variables represent water sources. Therefore, total number of latrine person^{-1} (l/p) was given same weight as the sum of the remaining three WaSH provisions (s/p = standpost person^{-1}, d/p = dugwells person^{-1} and t/p = tubewells person^{-1}). Normalization to WP index values between 0–1 allows to assess inter-ward-variability in water security provisions. The results were displayed in maps using ArcGIS 10.6 (ESRI, Redlands, CA, USA).

5.1.5. Results

The ward wise distribution of the WaSH provisions in relation to gender (male, female), ethnicity based on language spoken (Bengali, Hindi, Urdu, and other languages) and religions (Hindu, Muslim, and other religious groups) is analyzed applying deductive statistics supported by maps documenting spatial distribution.

i. Social exclusion and WaSH provisions in slums

Pearson product-moment correlation coefficient was applied to assess the linear correlation between all WaSH provision variables and the social categories (Table 5.1.1); analysis base on the 2011 Census data of slums within the KMC area.

There is a statistically significant correlation in the data between all the dependent variables with *number of families, male dwellers, female dwellers and literate dwellers* in slums of KMC ($\alpha < 0.01$). *Number of Bengali speakers* show statistically significant correlations with both latrine person^{-1} and sources of water (*standposts person^{-1}, dugwells person^{-1} and tubewells person^{-1}*) ($\alpha < 0.01$).

At the same time, the number of *Hindu* as another majority group correlates with the number of *latrines person*$^{-1}$ ($\alpha < 0.01$) and sources of waters (*standposts person*$^{-1}$, *dugwells person*$^{-1}$ *and tubewells person*$^{-1}$) ($\alpha < 0.05$). The data do not provide statistically significant relationships between the dependent variables *dugwells person*$^{-1}$ and *tubewells person*$^{-1}$ and the independent variables *number of Muslim* and *other religious groups* as well as number of Urdu and other language speakers ($\alpha > 0.05$).

Table 5.1.1. Pearson correlation coefficient (r) to assess the linear correlation between per person access to sanitation and drinking water provision in slums within Kolkata Municipal Corporation (KMC) area (n = 138). Data source: Census of India (2011). * marking 95% confidence level, ** marking 99% confidence level.

		Latrines person^{-1} Pearson's r	Latrines person^{-1} Sig. (2-tailed)	Latrines person^{-1} N	Standposts person^{-1} Pearson's r	Standposts person^{-1} Sig. (2-tailed)
	Families	0.781**	0.000	138	0.871**	0.000
Gender	**Male Dwellers**	0.718**	0.000	138	0.830**	0.000
	Female Dwellers	0.707**	0.000	138	0.817**	0.000
Literacy	**Literate Dwellers**	0.733**	0.000	138	0.815**	0.000
Ethnicity (Based on Language Spoken)	**Bengali Speakers**	0.795**	0.000	138	0.807**	0.000
	Hindi Speakers	0.323**	0.000	138	0.482**	0.000
	Urdu speakers	0.178*	0.037	138	0.254**	0.003
	Other Language Speakers	0.213*	0.012	138	0.375**	0.000
Religion	**Hindu**	0.734**	0.000	138	0.856**	0.000
	Muslim	0.192*	0.024	138	0.192*	0.024
	Other Religions	0.261**	0.002	138	0.409**	0.000

N	138	138	138	138	138	138	138	138	138	138	138
Dugwells person^{-1}											
Pearson's r	0.403**	0.340**	0.364**	0.381**	0.452**	0.202**	-	-	0.455**	-	-
Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000	0.018	0.892	0.079	0.000	0.819	0.058
N	138	138	138	138	138	138	138	138	138	138	138
Tubewells person^{-1}											
Pearson's r	0.369**	0.369**	0.337**	0.349**	0.509**	-	-	-	0.410**	-	-
Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000	0.883	0.659	0.979	0.000	0.503	0.820
N	138	138	138	138	138	138	138	138	138	138	138

* Correlation is significant at the 0.05 level (2-tailed). ** Correlation is significant at the 0.01 level (2-tailed).

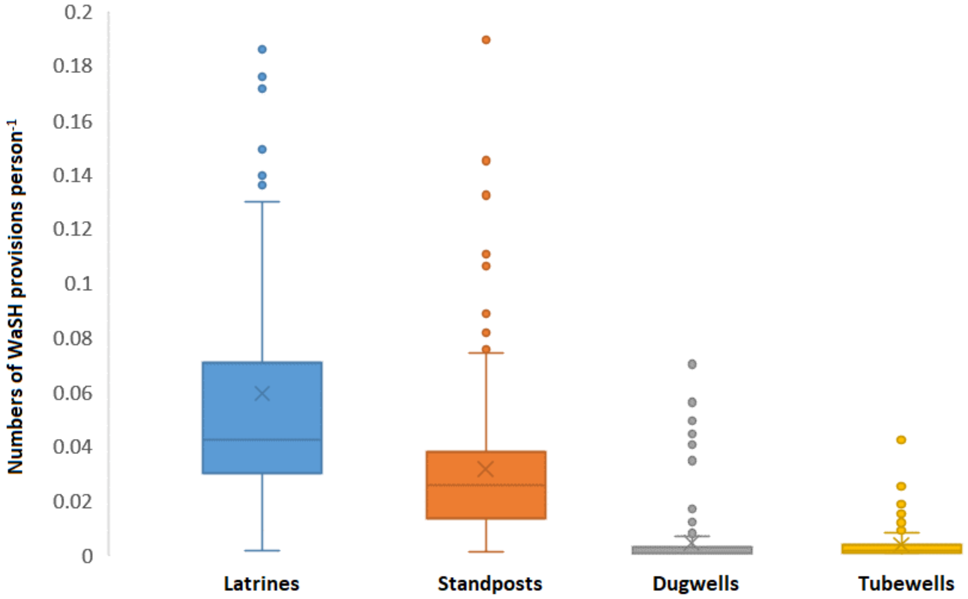

Figure 5.1.2. Boxplot showing distribution of the *WaSH provisions (Latrines, Standposts, Dugwell, Tubewells)* per person in Slums of Kolkata Municipal Corporation (KMC) area. Data source: Census of India (2011).

In about 75% of the slum areas less than 0.07 latrines person^{-1} (median = 0.042; n = 138) are available, and in about 50% of the slums, this value decreases to less than 0.04 latrines person^{-1} (Figure 5.1.2). In comparison, the availability of standposts is even sparser: in 50% of all slum areas, the number of standposts person^{-1} available range between 0.02–0.04 (median = 0.026; n = 138). In contrast, the availability of dugwells person^{-1}and tubewells person^{-1} are in general low in numbers. In case of the numbers of dugwells person^{-1} (median = 0.00, n = 138) and tubewells person^{-1} (median = 0.001, n = 138), the median is either zero or close to zero, which points out that there are many slum pockets which did not have either dugwell or tubewell.

ii. WaSH provisions in slum and non-slum areas of Kolkata city

Survey data from 2018 consists of samples from both slum and non-slum areas of KMC. Chi-Square Test was run to determine the relationship between the location variables *ward* and WaSH provisions ("*Direct piped water supply to the house*" and "*Presence of toilets in the house*") and between "*Presence of toilets in the house*" and "*Gender characteristics*" using survey data (Table 5.1.2). The location variable *ward* shows significant statistical correlation to the variables *direct piped water supply to the house* (p = 0.000, n = 755, $p < 0.01$) and *presence of toilets in the house* (p = 0.000, n = 755, $p < 0.01$). Also, a statistically significant correlation occurs between *presence of toilets in the house* and *gender characteristics* of the houses surveyed ($p < 0.01$). The survey data show (see Appendices) that 81% of the total respondents depend on piped water supply in their houses for drinking purpose; among these respondents only 8% use the piped water supply for household works (toilet flushing, washing clothes etc.). 43% of the total respondent depend on the water from standposts outside their houses for household works (see Appendices). Piped water in the houses as well as standposts are supplied by the government (KMC authority).

Table 5.1.2. Statistical measure (Chi-Square Test) for testing relationships between location variable *ward*, WaSH provisions (*direct piped water supply to the house* and *presence of toilets in the house*) and *gender characteristics*. Data source: Survey data (2018-19).

WaSH Provisions and gender characteristics	Statistical measure	Value	df	Asymptotic Significance (2-sided)
Ward and Direct piped water supply to the house	Pearson Chi-Square	670.72	372	0.000
	Likelihood Ratio	279.66	372	1.000
	Linear-by-Linear Association	0.06	1	0.801
	N of Valid Cases	755		
Ward and Presence of Toilets in the house	Pearson Chi-Square	764.73	124	0.000
	Likelihood Ratio	719.22	124	0.000
	Linear-by-Linear Association	42.50	1	0.000
	N of Valid Cases	755		
Presence of Toilets in the house and Gender characteristics	Pearson Chi-Square	239.75	8	0.000
	Likelihood Ratio	259.28	8	0.000
	Linear-by-Linear Association	32.13	1	0.000
	N of Valid Cases	755		

The survey data reveal the differences in WaSH provisions in the city (both slum and non-slum areas) in terms of having direct piped sources of drinking water (Appendices 5.1A–5.1F) and the presence of water flushed toilets in the houses (Appendices 5.1G–5.1K). 82.3% (n = 755) respondents are of general (upper) caste and have direct water supply in the house, while 73% of the scheduled caste or scheduled tribes (SC/ST; 17.7% of the respondents) or other backward castes (OBC) have direct water supply in the houses. Within total respondents, the majority are the Bengali speakers (83.7%), among them almost 83.4% have direct water supply in their houses. In contrast, among the non-Bengali speakers 15.9% have direct water supply facilities in their houses. In case of religions, among the Hindu respondents 86.6% have direct water supply facilities in their houses. Differentiating by gender, 34.9% of the Cis-male and 25.2% of the Cis-female have direct piped water facilities in their houses, while 17% of the transsexual and 11% of the intersex respondents have direct water supply facilities in their houses. Of the respondents who work in the unorganized sector of business (it includes activities carried out by small and family enterprises, partly or wholly with family labor without any legal registration) only 2.3% have direct water supply facilities in their houses, and workers from the unorganized sectors have in 1.8% direct water supply facilities within their houses.

Analyzing the presence of flush toilet(s) in the houses of the respondents, survey findings show that c. 86% of the respondents from the general (upper) caste category have at minimum one toilet in their houses, while in the case of the lower caste people (SC/ST/OBC) only 13.6% have at minimum one toilet in their houses. 25.6% of the Cis-male and 33.7% the Cis-female have at least one toilet in their houses while only 15.9% of the transsexuals and 13.1% of the intersex respondents have at minimum one toilet in their houses. 82.8% of the Bengali-speakers and 17% of the other Indian language speakers, 86.2% of the Hindu and 10.8% of the Muslims have at least one toilet in their houses. 38% of the respondents who work in unorganized business and 69.2% of the respondents who work in the unorganized sectors do not have any toilet in their houses.

iii. WaSH provisions in slums: ward wise variation

In Figure 5.1.3 the per capita WaSH provisions in slums of KMC are shown. The numbers of per capita WaSH provision vary in the slums within KMC area. Most of the slums within boroughs X-XIV have the highest number of per capita latrines. These slums are concentrated in the south and east of KMC.

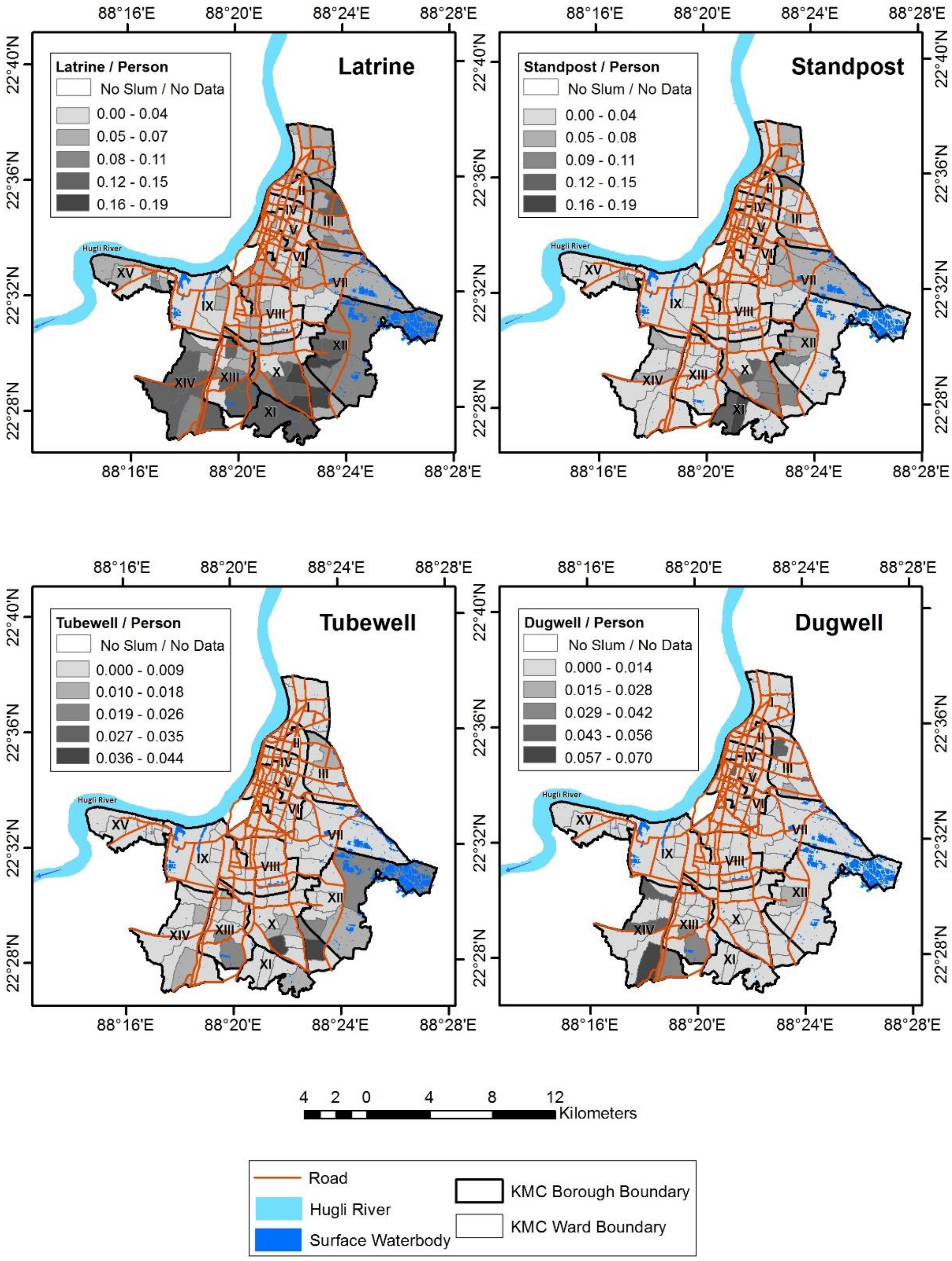

Figure 5.1.3. Ward wise distribution of per capita WaSH provisions in slums in terms of latrine, standpost, dugwell and tubewell within Kolkata Municipal Corporation (KMC) area. Data Source: Census of India, 2011 and Kolkata Municipal Corporation, 2016; LISS III Satellite Image 2010 (ISRO, India).

The intra-borough variation in number of per capita WaSH provisions can be mainly observed in the slums of borough XII, which is located at the south-eastern corner of the city and in the slums of borough VIII, which stretches from the city center to its eastern border. In contrast, the slums located in the central and northern boroughs have lower numbers of per capita latrines than the boroughs in the south. A similar relation can be seen in the number of standposts per person (Figure 5.1.3). Additionally, intra and interborough variations of the number of standposts per person can be observed. Relatively high numbers of standposts per person mainly occur in the slums of the southern and eastern boroughs. Some wards in the center of the city show extremely low numbers of dugwells and tubewells but assessing this phenomenon the in total small number of dugwells and tubewells must be considered (Figure 5.1.3). It is evident, that in slums where relatively high numbers of dugwells were observed, relatively low numbers of tubewells per person were detected. Albeit insignificant in terms of number, dugwells and tubewells are still the only sources for drinking water in many slum areas within KMC area. Their distribution, hence, shows the variability of slums' total water provision and access to sanitation and hygiene.

The spatial share of wetlands in each ward is mapped in Figure 5.1.4. Only four wards (wards 6, 45, 108 and 141) are covered by more than 50% by wetlands, another five wards (wards: 1, 21, 22, 58, 80) are covered by 10–50% by wetlands. In all other wards less than 10% of their area is covered by wetlands.

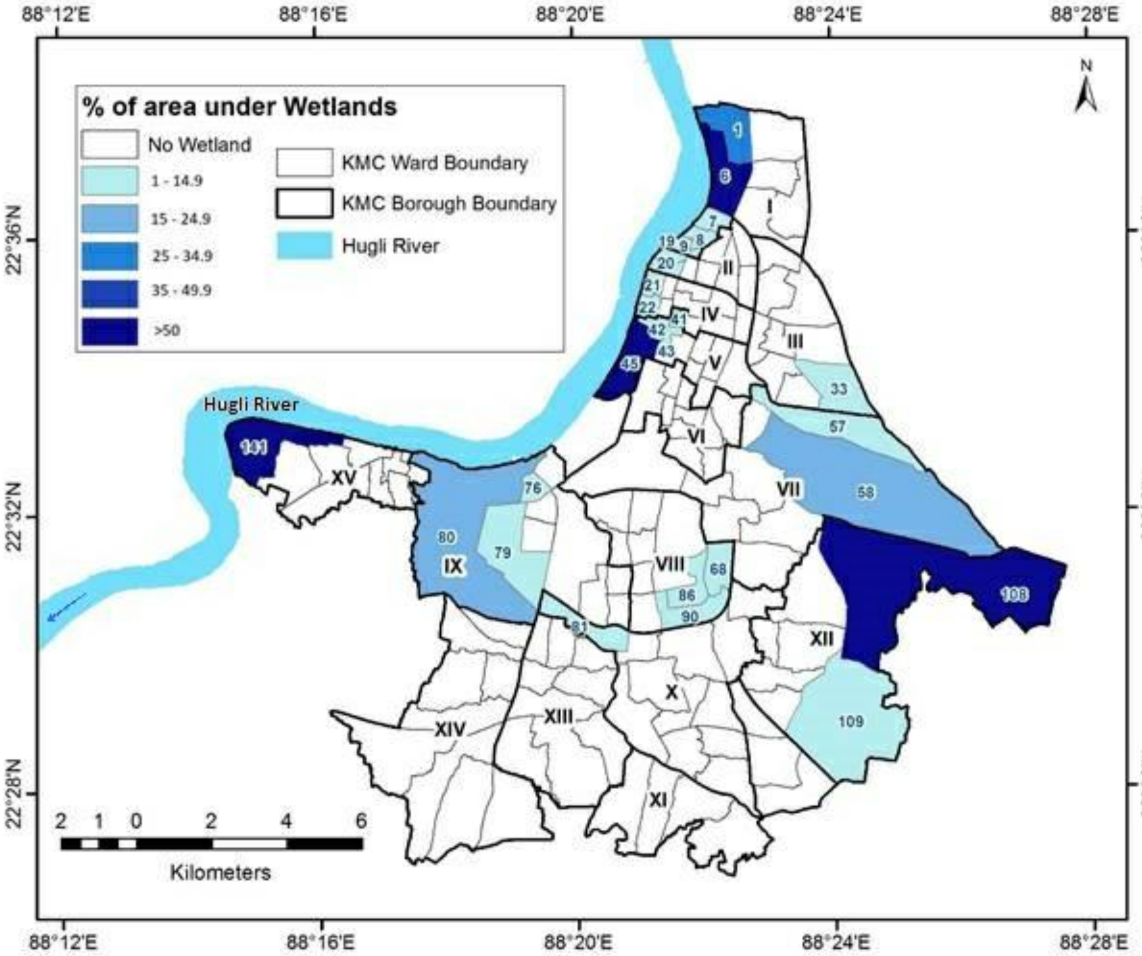

Figure 5.1.4. Ward wise percentage (%) of areas covered by wetlands within Kolkata Municipal Corporation (KMC) area. Data Source: Census of India, 2011 and Kolkata Municipal Corporation, 2016; LISS III Satellite Image 2010 (ISRO, India).

iv. Ward wise distribution of WaSH Provision (WP) Index for slums

The application of the WaSH provision (WP) Index shows that the slums in the peripheral boroughs of the KMC area have higher per capita WaSH provision than the centrally located boroughs. Most wards (58 out of 141) show WaSH provision (WP) Index between 0.00–0.12, which corresponds to almost zero access to WaSH provision in slums (Figure 5.1.5). Hence, the slums within 11 wards are characterized by WaSH provision (WP) Index of 0.66–1.00, which corresponds to more access to WaSH provision than the other wards within the city (Figure 5.1.5). The majority of the KMC wards show WaSH provision (WP) Index of less than 0.4. The slums located in the center of the city have the lowest WaSH provision (WP) Index.

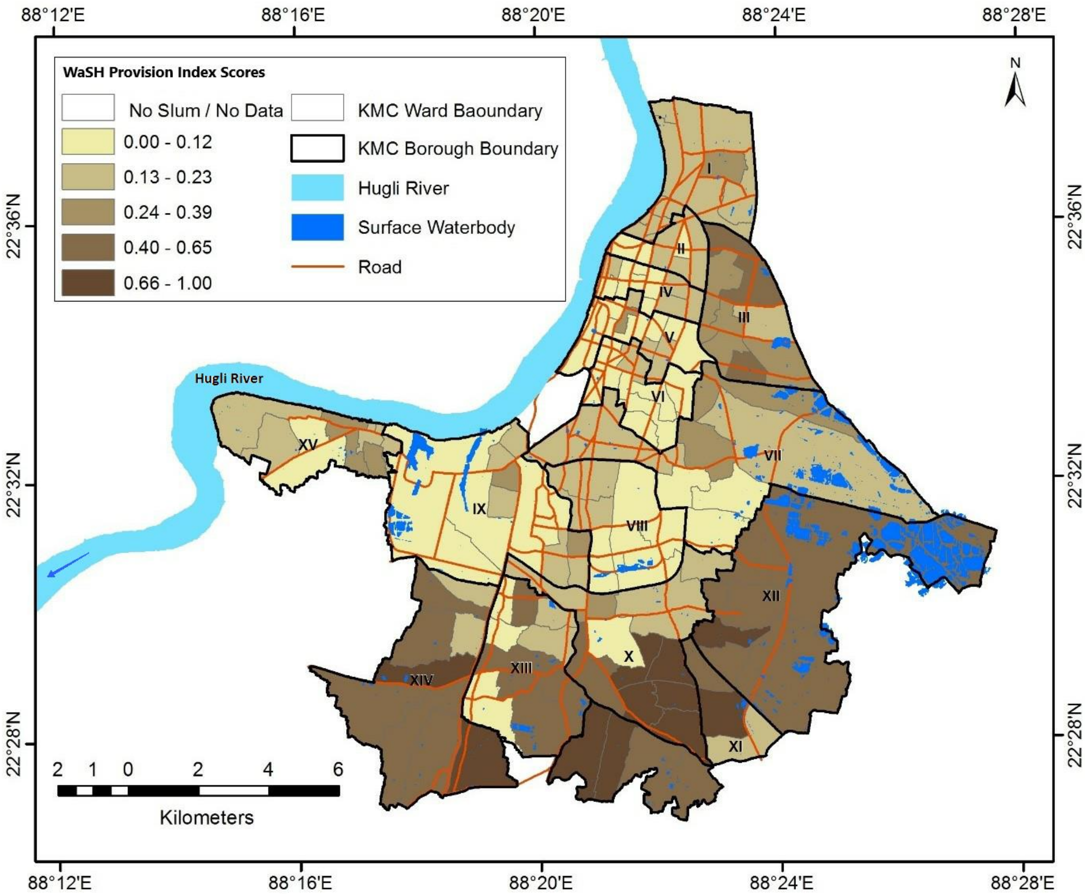

Figure 5.1.5. Ward wise distribution of per person WaSH provision Index for the slums within Kolkata Municipal Corporation (KMC) area. Higher scores represent more WaSH provision per person in slums within a ward.

5.1.6. Discussion

Water is a resource that activates extreme tensions and fierce struggles. In this *struggle for water* those people living in deprivation and who are excluded socially, economically, and politically suffer most (Harvey, 1996; Escobar, 2006; Perreault et al., 2011; Crow et al., 2014; Boelens and Vos, 2018). Socio-political exclusion results in a 'continuum of inclusion/exclusion characterized by unequal access to resources, capabilities and rights which leads to health inequalities' (Popay et al., 2008, p. 2). It is a complex and multi-dimensional process that involves the lack (or denial) of resources, rights, goods, and services. Provision of water for human domestic use is a fundamental part of water security (Bradley and Bartram, 2013). Rapid urban expansion is a major concern for water security (Boelens and Vos, 2018), and many developing, and less developed countries often lack the infrastructure and basic services to ensure WaSH for the increasing number of citizens (Cohen, 2006; Montgomery, 2008). Unable to adequately meet the demands of the growing population, deprived areas have emerged and continue to grow in developing and less developed countries (Mahabir et al., 2016).

i. Variation in water security across and within areas defined as slums in Kolkata

We have applied a water security perspective to the problems of domestic water, sanitation, and hygiene (WaSH) provision in poorer or deprived areas (notified as slums) in Kolkata, using the status of WaSH provisions as the condition of water security. The results show that intersecting factors of social exclusion, social characteristics and biophysical factors influence water insecurity. Inequalities in WaSH provision along both social and biophysical dimensions are closely interrelated with and influence access, use, and control, and often translate to varying degree of lack of adequate and affordable water services for urban citizens. Urban water services do not just reflect urban inequalities present in the society, but they are also a key in reproducing socio-political, economic, and spatial exclusions from water security. Inherent to this are also questions about inclusivity and equity of service provision of WaSH, and the extent by which these relate to urban dwellers' needs and aspirations. Water deprivation and water insecurity affect marginalized urban subgroups at various scales (Boelens and Vos, 2018). Mapping the geographical distribution of WaSH at ward level scales help to identify deprived subgroups that would otherwise be hidden within national or state statistics. The current monitoring frameworks for the water security in terms of WaSH, internationally and Indian nationally, collect and disaggregate data by urban and rural areas. However, intra-urban inequalities, and particularly data and information on people living in deprived areas or informal settlements, deserve more attention (Kilroy, 2007; Martinez et al., 2008; Hawkins et al., 2013; Mosello et al., 2017). Another categorization to consider is smaller administrative units, such as wards in Kolkata to understand variations in poverty - especially within wards with high levels of poverty (UNICEF/WHO, 2014b). As our results show, it is crucial to understand both inter-city and inter-ward variations to fully capture the complex issues of urban water security at play.

The Census Data of India (2011) on deprived areas (denoted as slums) of Kolkata (KMC area) reveals that almost one-third (31.35%) of the urban population live in these deprived areas of the city (Census of India, 2011) where the income gap has widened sharply during the past three decades (Schreiber and Carius, 2016). The most deprived areas are concentrated in the eastern and northern peripheral areas. The central areas (especially business districts) of the city either do not have *slum* pockets or one or two informal settlements only. The number of families vary within *slums* in a ward.

According to Census of India (2011) most of the households in slums within KMC use standposts (82%) for collection of water for both drinking and domestic purposes, while some use tubewell (13%) to collect drinking water mainly. Among the other sources of drinking water are dugwells located nearby the houses mostly outside their premises. These data show the sources of proliferating problems of material and social “water injustices” which prohibit the equal distribution of access water rights and water-related decision-making for the marginalized subgroups in slum areas. For example, in our study we found that the inter-ward variation of different water sources, such as standposts, tubewells and dugwells are all controlled and maintained by the KMC Authority to supply treated surface water (standposts) or direct extraction of groundwater (tubewells and dugwells).

ii. Assessing water insecurity from an exclusion perspective for socially excluded areas in Kolkata

Socio-political exclusion affects both the quality of life of individuals and the equity and cohesion of society (Levitas et al., 2007, p. 9). Due to the lack of proper WaSH provision, inequality in urban water services is argued to be a crucial factor in socially deprived areas of KMC (Census of India, 2011). The present study indicates that intra-city inequality in slums is a major challenge and is related to who has access too adequate WaSH provision. It suggests that the existing inequality in WaSH provisions is regardless of areas defined as slum and non-slum households, highlighting the need to move away from simple understandings of slums, towards more complex analyses that also explores the multitude of demographic and socio-economic characteristics that are related to water insecurity, as well as the variations of these in socially deprived areas often referred to as slums.

Similar to our findings, other studies also report that WaSH service deliveries vary across populations in deprived areas, and are differentiated by gender, religions, languages (Hegde, 2013; Bhan and Jana, 2015; Sidhwani, 2015; Haque, 2016; Mahabir et al., 2016). Further to those characteristics, most of the labors who work in unorganized sectors are forced to live in the slums (Saroj et al., 2017), which are characterized by poor WaSH provisions due the lack of contributing in city's overall economies (Giles and Brown, 1997; Smith, 2001). In 2011, within the KMC area, 21% of households defined as slum households were without a bathing facility. The rest of them had bathing facility within a semi-permanent or temporary enclosure (sometimes without a roof) (Census of India, 2011). In consequence dwellers are exposed to hygiene issues, particularly for many adolescent girls and women (Chant et al., 2017; Corburn and Hildebrand, 2015; Mohite and Mohite, 2016). Additionally, poor sanitation contributes to high levels of water-borne diseases like jaundice and diarrhea among the children living in the slums (Parvez et al., 2019).

Our findings confirm previous studies' findings arguing that achieving availability and accessibility of WaSH is linked to equitable distributions of WaSH services. These services demand considerable and equitable financial allocation to the governing urban bodies. The specific allocation and expenditure of WaSH provisions as basic amenities and services are almost negligible compared to the capital-intensive big projects on urban transportation system (Kundu, 2014; Mahadevia, 2007). Lack or poor WaSH service facilities result in unhealthy practices within and around the households defined as slum households in the cities. Social exclusion and spatial segregation of city dwellers based on socio-economic, cultural (sometimes political too) status is a primary factor related with intra-city inequality (Goli et al., 2011; Murthy, 2012; Goli et al., 2013; Bhan and Jana, 2015). This is a crucial dimension to explore in future studies, as our findings show both intra- city and ward variation.

Another crucial finding in our study is that wetlands are needed in a city to secure water security. This requires combining environmental and socio-economic dimensions to fully understand urban water security. Our analysis reveals that only 6.5% of the wards have more than 10% of their areas covered by wetlands. The lack of wetlands correlates in environmental water insecurity which ultimately results in water poverty for both human and environment (Webb and Iskandarani, 1998; Kumar et al., 2011). In consequence, water poverty is a multi-dimensional state of deprivation, of which lack of access to adequate water of safe quality is a key characteristic (Mayer et al., 2009). Wetland ecosystems provide cultural, provisioning, regulating, and supporting services that contribute directly and indirectly to human well-being

(Aylward et al., 2005). Wetlands in a city can also provide water for the people who are otherwise deprived of having a latrine or other sanitation facilities (for examples: bathing, washing clothes and cooking utensils etc.) within their premises (Nawab et al., 2006; Schenk, 2010; Kundu, 2014).

Monitoring of disadvantaged groups can be challenging when they form a small proportion of the population and/or if they are difficult to reach through conventional household surveys or by census data. In many less developed countries, this shortage of data is linked with the use of rigid and often outdated urban planning regulations, which are usually ignored by the slum dwellers to meet their housing needs due to the poor urban governance (Chiodelli and Moroni, 2014). Although, many local and national governments in developing and less developed countries are unable to implement planning regulations due to the lack of resources (Tsenkova et al., 2009). In addition, responses are made at the level of the household, which makes it impossible to accurately measure intra-household inequalities such as gender, age or disability (UNICEF/WHO, 2014a). In our survey we consciously included questions and training of interviewers that helped us to understand intra-household inequalities, which are frequently missing in survey and census data. To further research on water insecurities, studies need to focus on the barriers to WaSH access met by people along a multitude of constraining characteristics including people with disabilities, chronically ill and elderly people. Indicators measuring WaSH issues are one dimension of water security data analyses. Significantly, while common taps or standposts are the sources of water in all areas defined as slums, there is no report on water scarcity in metropolitan Kolkata, except at E.M. Bye Pass area (Mukherjee et al., 2018). On the other hand, as far as sanitation is concerned, there is no information on the Census of India (2011) dataset but according to literature and government reports conditions in the slums are poor (Bose and Ghosh, 2015). The ratio of the number of latrines to number of slum dwellers is extremely low, a situation that creates water insecurity in the everyday life.

In developing countries, access to urban services often differs widely between the rich and the poor citizens, and across genders. The gender and social inequalities violate the basic human rights associated with water in urban slums of KMC. According to the Census Data of India (2011), though the majority of what is defined as slum households in KMC areas have bathing facilities (almost 80%), the enclosure is sometimes without a roof. A large section of households (21%) lacks bathing facilities (Census of India, 2011)—in consequence the dwellers are forced to bath and wash in public bathing facilities, which can lead to difficulties maintaining hygiene for certain groups, i.e., during menstruation, and this may be related to increased levels of infection and other diseases. Despite of having latrine facilities in 59% of these households (within KMC area), an exceedingly high percentage (41%) still lacks this provision (Census of India, 2011). Most of the slum dwellers (30%) are either forced to use the public latrines or must go to the open areas (11%). The lack of toilets exposes the dwellers of these poorer parts of the city to physical and emotional danger (UN-Habitat, 2003). For example: bathing in open ponds and rivers also exposes them to risks, such as sexual harassment (UN-Habitat, 2003). Special situations like pregnancy and illnesses exacerbate the problem (UNHRC, 2010; Mishra, 2017). The slum dwellers experience varying deprivations and risks associated with urban water insecurity, which can include a lack of durable housing, overcrowding, insufficient access to clean water, poor sanitation and hygiene facilities and threats of forced evictions (UNHRC, 2010; Uddin, 2018).

Another vulnerable group living in areas defined as slums are trans* people. Although, none of these groups are mentioned in the Census Data of India (2011). We therefore used our survey data where we found that trans and intersex people are vulnerable to WaSH issues, whilst at the same time being understudied. Making it crucial to focus on these populations in future studies Recent studies (Dhall and Boyce, 2015; Boyce et al., 2018) show that they also experience daily harassment, discrimination, prejudice, and violence in relation to water and sanitation. Denial of accommodation forces them to live in remote, socially deprived areas, where WaSH provision is poor. Trans* people face a dilemma every time they must use a public toilet. Public toilets are either for men or women and transgender people are not welcome in either, since it is commonly alleged that they are seeking sex work when they visit public toilets. Also, most of the time it is reported that when they use the men's toilet, they are subjected to sexual harassment and sexual violence. Therefore, most transgender women prefer to use the ladies' toilet; however, they report both abuse and issues with cis women when doing so. Studying water security using gender characteristics on a gender continuum is crucial to help address gender and social inequalities related to water which violate the basic human rights associated with water. Our survey data is valuable as it helps to address the shortage of multidimensional data on water security and WaSH. This highlights a gap in data provided through national household surveys and censuses for the collection of WaSH data.

We found that gender is crucial to social exclusion and WaSH in our survey data given in the appendices (Appendices 5.1D and 5.1J), where we see that women, trans*, intersex and other are more insecure in terms of both sanitation as well as source of water. This study is the first of its kind to transgress the binary definition of gender in a representative survey combining more diverse gender indicators with biophysical and WaSH indicators—and these findings underline the importance of doing so. Thus, this study shows the relevance of a multidimensional approach, underlining that social exclusion correlates with WaSH issues within and across the city of Kolkata. An individual's social position also is important when analyzing water insecurity (Sasidevan and Santha, 2018; Shrestha et al., 2018), again highlighting a need for further and more complex studies combining social and biophysical data. Importantly, all of this shows us that social exclusion and water insecurity goes hand in hand, and that we need to analyze how these factors vary across and within cities and wards when we analyze urban water security, addressing and finding solutions to water and sanitation for all.

5.1.7. Conclusions

Water insecurity is a multidimensional issue along social, cultural, and economic characteristics. This article forms part of a critique of those applying the concept of slum, in general, and as a fixed entity. It has been shown that social, economic, and political exclusion vary within and across both, wards defined as slums as well as other wards within and across the city. Previous literature has analyzed discreet issues of water injustices in areas defined as slums, focusing on socio-economic and physical characteristics, frequently leading to a partial view of slums and related policies. However, these different issues are all interrelated at various spatial levels. Therefore, the interdisciplinary and intersectional approach applied in this article is required to fully understand the multifaceted issues influencing and shaping water security in these areas. This will help to develop appropriate policies and to improve the livelihoods of those living in deprived areas.

The article shows that there are vulnerabilities to water security in terms of WaSH in socially deprived and excluded areas; however, there are also variations within these geographical areas. We identified that within areas characterized by deprivation and social exclusion, based on ethnicity, religion, socio-economic standing, and gender matters, in determining who is more water insecure. In consequence, water and sanitation experts should take not only bio-physical factors into account conducting the WaSH infrastructure planning, but how they are associated with socio-economic, cultural, and demographic characteristics. Therefore, we observe multi-dimensional vulnerability to water insecurity—which should be considered in water security research.

We use social exclusion as an overarching concept to understand vulnerabilities and exposure to water insecurity in what has been defined as urban slum areas. Our findings show that we can explicate some of the variabilities in the provision of WaSH from the context of urban water security within and across areas defined as socially deprived areas within Kolkata. Water Security solutions exist that can make significant strides in combating disease and mortality, and further research should be done with an interdisciplinary, intersectional approach to understand how we can change policies, management, and behavior to secure water security. Further, creating community groups for women and other marginalized community members to learn about using point-of-use water treatment methods, decreasing pathways of contamination, and mobilizing communities to work towards sustainable clean water systems would be suggested.

Our results indicate that we need to analyze and address water security issues with a lens that appreciates across and within city and ward variations to understand water and sanitation issues. Research in water security (particularly for urban areas) needs to be focused on understanding the link between this spatial heterogeneity and water accessibility issues. This understanding is crucial for the management of current urban water systems as well as for the planning of future sustainable development. It also may help us to understand the influence of policy interventions on urban system structure and function. Cities function as a melting pot for people with differing cultural backgrounds, religions, interests, and social statuses. As our results show that ethnicity, religion, and language are crucial in influencing and understanding who water-insecure, more research is needed on these aspects to fully understand the complex interactions. This is important as cities are not only growing in population but are also becoming increasingly diverse.

Our findings are crucial in showing the importance of interdisciplinary approaches to enhance understanding of the complexity of water security on the one hand. On the other, they shed important knowledge to be incorporated into to water security management and policies. It is clear that solving WaSH issues needs to address and include policies that can support marginalized groups across the gender continuum, ethnicity, and religion as they are particularly vulnerable to WaSH issues. Furthermore, it also shows the importance of understanding within city and within ward variations, so that policies do not solely target specific areas defined as slums but incorporate flexible and intelligent solutions which looks at urban water security in the city as an organism, with complex divisions and relations, which cannot be solved by solving issues in only one area**.**

5.2. Case Study 2

Assessment of environmental water security of an Asian deltaic megacity and its peri-urban wetland areas[4]

Abstract

Achieving urban water security requires sustaining the trade-offs between the exploitation of water/environmental resources and ecosystem services. This achievement not only reduces the pollution and contamination in the environment, level of water stress, but also secures good ambient water quality and future for people's well-being and livelihoods. Changes in land use and land cover and growth of impervious structures can immediately generate severe ecological and social issues and increase the level of natural or manmade risks, affecting the condition of ecosystem services within and in the vicinity of an urban region. As a result of these transformations and further exploitation, due to the growing anthropogenic pressure, surface water and groundwater quality can be deteriorated compared to ambient water quality standards (for both chemical and biological pollutants). Based on land use and land cover (LULC) data retrieved from remote sensing interpretation, we computed the changes of the ecosystem service values (ESV) associated with the LULC dynamics, water quality and, finally, urban water security during the pre- and post-monsoon periods of 2009, 2014 and 2019 in Kolkata, an Asian deltaic megacity, and its peri-urban wetlands named East Kolkata Wetlands (EKW). The area under wetlands reduced comprehensively in 2009–2019 due to the conversion of wetlands into various other classes such as urban settlement, etc. The quality of surface water bodies (such as rivers, lakes, canals and inland wetlands) deteriorated. The groundwater quality is still under control, but the presence of arsenic, manganese and other metals are a clear indication of urban expansion and related activities in the area. As a result, there was a change in the ESV during this timeframe. In the pre-monsoon period, there was an increase in total ESV from US$53.14 million in 2009 to US$53.36 million and US$59.01 million in 2014 and 2019, respectively. In the post-monsoon period, the ESV decreased from US$67.42 million in 2009 to US$64.13 and US$61.89 million in 2014 and 2019, respectively. These changes can be attributed to the peri-urban wetlands and the benefits or services arising out of them that contribute more than 50% of the total ESV. This study found that the area under wetlands has reduced comprehensively in the past 10 years due to the conversion of wetlands for various

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[4] Mukherjee, S., Sikdar, P.K., Pal, S. and Schütt, B., 2021. Assessment of environmental water security of an Asian deltaic megacity and its peri-urban wetland areas. *Sustainability*, 13(5), p.2772. https://doi.org/10.3390/su13052772

other uses such as urban expansion of the Kolkata City, but still, this peri-urban wetland supports the urban water security by providing sufficient ecosystem services. In conclusion, the transformation in extent of the water-related ecosystem is a crucial indicator of urban water security, which also measures the quantity of water contained in various water-related ecosystems. Quantitative analysis of the LULC change, hence, is important for studying the corresponding impact on the ecosystem service value (ESV) and water quality that helps in decision-making in securing urban water future and ecosystem conservation.

Keywords: urban ecosystem services; valuation of ecosystem services; land use and land cover; water quality index; remote sensing

5.2.1. Introduction

Water security is widely regarded as the key natural resource challenge facing humanity. The availability of water in the appropriate quantity (including avoiding scarcity and overabundance) with the appropriate quality and at the appropriate time for both human consumption and ecosystems is a basic requirement for sustainable development (Grey and Sadoff, 2007). Water insecurity results in water poverty for both people and the environment, which is a multi-dimensional state of deprivation with lacking access to adequate water of safe quality as a key factor (Mayers, 2009). Ecosystems provide cultural, regulating and supporting services that contribute directly and indirectly to human well-being through recreation, scenic values and maintenance of fisheries (Aylward et al., 2005). Fresh water is a provisioning ecosystem service as it provides water for human use including domestic use, irrigation, power generation and transportation. Fresh water and the hydrological cycle also sustain inland water ecosystems, including rivers, lakes and wetlands. Provisioning of fresh water also plays a role in sustaining freshwater-dependent ecosystems such as mangroves, inter-tidal zones and estuaries, which provide another set of services to local communities and tourists alike (Aylward et al., 2005).

Under continuous urban expansion and redevelopment, rural–urban linkages are transformed (Steinberg, 2014; Akkoyunlu, 2015). Changing ecosystem services (ES) are central to this transformation as they arise from the interaction of people and ecosystems and are most prominent in areas where the rural is increasingly influenced by the urban (Mngumi, 2020). The ecosystem services generated by peri-urban ecosystems play a significant role in urban sustainability and resilience, spanning from food security to disaster risk management

(Marshall et al., 2017). Urban and peri-urban wetlands provide ecosystem services seen and unseen to millions of people and to the environment on which we rely (Marshall et al., 2017). Especially wetlands provide vital water-related ecosystem services at different scales (e.g., clean water provision, wastewater treatment, groundwater replenishment, flood control), which are relevant for livelihood and well-being (UNEP, 2009). Thus, wetlands are crucial in maintaining the water cycle which, in turn, underpins all ecosystem services and therefore sustainable development and water security (UNEP, 2009). However, wetlands face serious risks as they are confronted by a range of threats such as urban development, pollution and agricultural use (Amerasinghe and Dey, 2018).

Ecosystem-based management is defined by the United Nations Convention on Biological Diversity (CBD) as a "strategy for the integrated management of land, water and living resources that promotes conservation and sustainable use in an equitable way" (WWAP, 2015). Ecosystem services (ES) research has gained momentum and the science and policy of valuing ES has experienced rapid growth since the Millennium Ecosystem Assessment (MEA, 2005). The economic valuation of ES is becoming a regular practice in ecological economics to improve the basis for political and planning decisions and to establish more profound knowledge of the economic importance of ES. This includes the assessment of opportunity costs of land degradation or restoration as well as the assessment of developing policy tools and incentive mechanisms such as payments for ecosystem services (PES). However, monetary valuation of ES does not imply that they have exchange values and that all ES can be commodified or exchanged in the market as a substitute to other market commodities. Thus, the valuation is instead an estimate of the benefits of ES to the society expressed in units that work as a tool to help raise awareness on ES importance. Pahl-Wostl and Knüppe (2016) argue that the ES concept may serve as a bridging concept to integrate various fragmented development trajectories and human water security without neglecting environmental water needs within a logical integrative framework.

Kolkata is the capital of West Bengal (one of the states of India) with a population of 4.5 million people, situated on the Ganga–Brahmaputra Delta. The climate of Kolkata is a tropical wet-and-dry climate (Aw according to Köppen climate classification system). The city experiences a hot pre-monsoon season from late March to mid-June followed by a monsoon period from mid-June till mid-September and lastly a slightly cooler dry season from mid-October until mid-March (Mukherjee et al., 2018). Since 1690, the approximate year when the British founded Kolkata, it has been expanding randomly without having a proper master plan.

Besides, Kolkata is blessed ecologically because it has the mighty river Ganga flowing at the west, a huge groundwater reserve underneath and a wide wetland area adjacent to its eastern fringe which naturally treats city's wastewater and transforms that suitable for fishery and agriculture (Mukherjee et al., 2018; –15). Despite these advantages, at present, the city is increasingly running into water insecurity (Mukherjee et al., 2018).

Thus, the main objectives of this study are to investigate the spatial and temporal land use and land cover (LULC) changes, their influence on different urban ecosystem services (UES) through an ES valuation approach and analyze the trade-offs between urban environmental water security (UEWS) and its peri-urban wetland area as an example for an Asian deltaic megacity—Kolkata, India.

Therefore, the overall aim of this article is to investigate the spatial and temporal LULC changes and their influence on different urban ecosystem services (UES) in Kolkata City's UEWS. The following research questions shall be answered by the study:

- To what extent have LULC and their impact on ecosystem services changed over time within Kolkata City and its urban and peri-urban wetland (named East Kolkata Wetlands, or EKW) areas during the pre- and post-monsoon seasons in the last decade (2009–2019)?
- To what extent are the availability and quality of surface and groundwater impacted with the changes in LULC in the Kolkata Municipal Corporation area?
- How do these changes ultimately affect spatial distribution of UEWS in Kolkata City?

5.2.2. Methodology

i. Study area

The total study area comprises 330 km^2 and includes the Kolkata Municipal Corporation (205 km^2) and the East Kolkata Wetlands (125 km^2) (Figure 5.2.1). The Kolkata Municipal Corporation (KMC) currently has 144 wards (three of which were added in 2015). These wards are then clustered into 16 boroughs or administrative blocks (Mukherjee et al., 2018). The area is part of the lower deltaic plains of the Ganga–Bhagirathi river system with an elevation ranging between 3.5 and 6.0 m above mean sea level (amsl). The area is drained by the River

Hugli, a distributary of the Ganga, running along its northwestern boundary and by several canals. Due to rapid urbanization of Kolkata, most of the marshy lands have been filled up and covered with buildings and the majority of the canals have been silted. The East Kolkata Wetlands area (EKW) is a peri-urban saltmarsh that has been used to receive city's sewage since the late 17^{th} century (Kundu et al., 2008; Kundu and Chakraborty, 2017). Subsequently, the EKW area was transformed by local people into an extensive land use mosaic of sewage-fed fish farms and agricultural lands about 100 years ago (Kundu et al., 2008). These wetlands serve for the biological treatment of raw sewage coming from the Kolkata Municipal Corporation and other adjacent areas (Kundu and Chakraborty, 2017). East Kolkata Wetlands have been reported to support livelihoods of ~74% of the population of the peri-urban area (Kundu and Chakraborty, 2017; Ghosh and Ghosh, 2018). Beyond that, the East Kolkata Wetlands act as an important habitat for various wildlife, especially birds (Bhattacharya et al., 2012). Traditional pisciculture and cultivation techniques form the basis of ecological security in the region (Kundu and Chakraborty, 2017), providing multiple benefits, including food production, resource recovery, flood reduction, habitat and biodiversity restoration and opportunities for employment. Under the Ramsar Convention, in August 2002, the East Kolkata Wetlands were designated as a "wetland of international importance" (Ramsar Commission Secretariat, 2002). Details on geology, geomorphology, surface water and groundwater hydrology and ecology are given in the publications by McArthur et al. (2018), Sahu and Sikdar (2008; 2009a; 2009b; 2011; 2017), Sahu et al. (2013), Sikdar et al. (2001; 2002), Sikdar (1996a; 1996b), Sikdar and Dasgupta (1997). The research focuses on the KMC area, and the EKW stand for their support to contribute to ecosystem service valuations (ESVs).

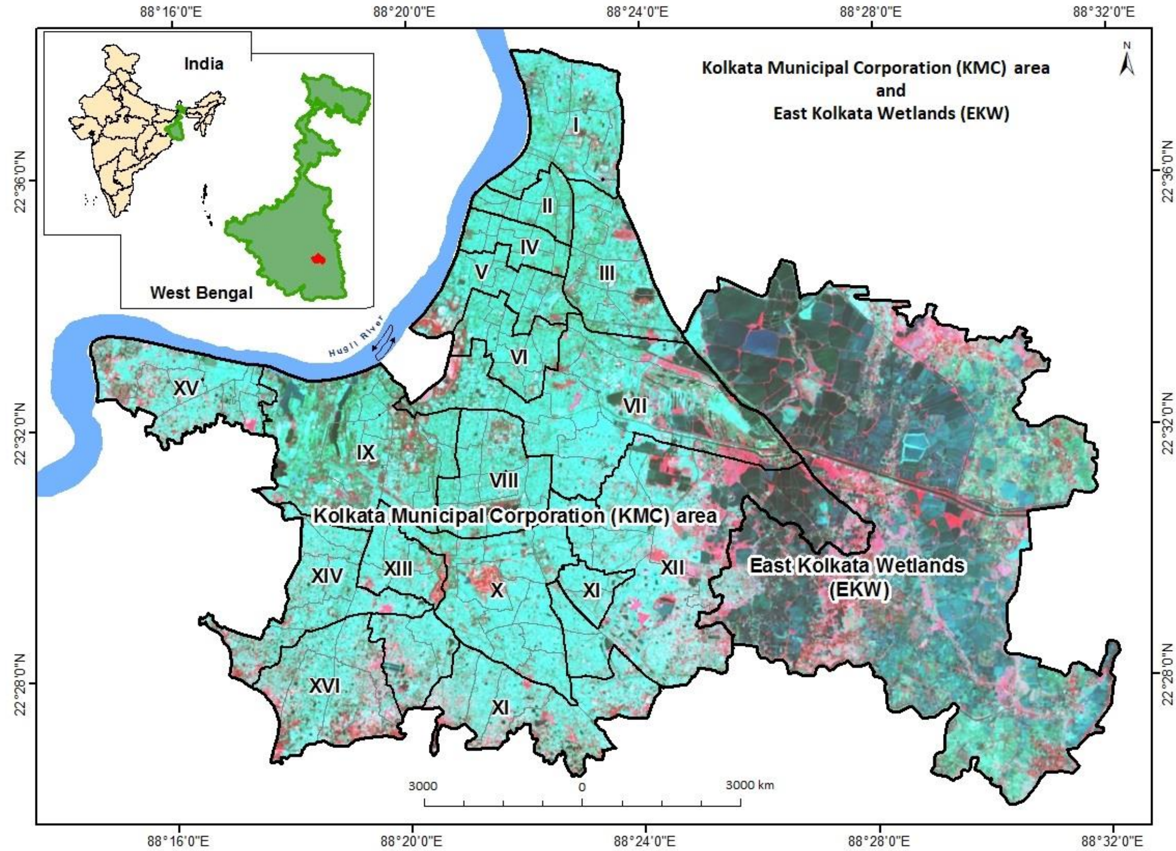

Figure 5.2.1. Map showing Kolkata Municipal Corporation (KMC) boroughs (featuring the wards associated in a borough) and the East Kolkata Wetlands (EKW) area located outside the KMC area. Roman numerals mark borough numbers. Data source: Mukherjee et al., 2018.

ii. Land use and land cover change between 2009 and 2019

Satellite images (Table 5.2.1) were analyzed to detect changes in the distribution of the major land use and land cover (LULC) classes between pre-monsoon (March–May) and post-monsoon (October–December) seasons of 2009, 2014 and 2019. In India, the dry winter season comes after the post-monsoon season (October–November) and is considered different from the pre-monsoon season (April–May) when the temperature is higher than 40 degrees Celsius. This study tries to focus on the pre-monsoon season specifically as we cannot use satellite images during the monsoon months (July–September). In order to avoid the yearly changes to show, we chose two distinct seasons of the year, i.e., pre- and post-monsoon seasons only.

Table 5.2.1. Details of the satellite imagery used.

Serial No.	Sensor	Date of acquisition	Spatial resolution	Spectral resolution	Path/row
1	Landsat 05	10 May, 2009	30 mts × 30 mts (excl. band 6)	Five spectral bands and one thermal band	138/44
2		15 October, 2009			
3	Landsat 08 Operational Land Imager (OLI)	22 April, 2014	30 mts × 30 mts (for visible, Near infrared (NIR) and Shortwave infrared (SWIR))	Nine spectral bands	
4		16 November, 2014			
5		06 May, 2019			
6		30 November, 2019			

In the first step, a reference image was geometrically and radiometrically corrected; thereupon, the remaining images were co-registered to match the overlay with sub-pixel accuracy (RMS errors ≈ 0.21). For resampling, the nearest neighbor technique was applied for further classification to retain the original pixel values. The maximum likelihood-based supervised classification was performed to detect the LULC changes within the study area for 2009–2014, 2014–2019 and 2009–2019 during pre- and post-monsoon periods. Classification of LULC was performed on co-registered images applying the Arc GIS software (version 10.7) using the supervised (maximum likelihood) image classification technique (SICS). Five broad classes representing urban settlement, vegetated areas, lakes, inland wetlands, open spaces and agricultural lands were mapped (Table 5.2.2). It needs to be mentioned that there are two designated surface water bodies within the KMC area referred to as lakes (Government of West Bengal, 2006; Government of West Bengal, 2007; Mistry and Basu, 2014); correspondingly, we considered only the water-filled parts of them as lakes, while the other surface water bodies (except the River Hugli) were classified as inland wetlands supporting the presence of hydrophytes in them.

More than 50 spectral signatures were taken as representative signatures for each LULC type. Overall accuracy of the classification process was computed for the classified images for 2009, 2014 and 2019, respectively, based on representative reference points extracted from images provided by Google Earth. Ground truth data obtained from field surveys in 2008 and 2020 and the analyzed secondary data collected in 2008–2020 were compared with the classified satellite imagery.

Table 5.2.2. Land use and land cover (LULC) classes mapped for the Kolkata Municipal Corporation and East Kolkata Wetlands areas.

LULC class	Description
Urban settlement	Land predominantly covered with houses including residential, commercial, industrial buildings and construction materials as well as transportation facilities such as roads and railway lines
Agricultural lands	Land specially used to produce agricultural crops
Vegetation	Land covered with any type of natural vegetation, including roadside tress and grasses
Lakes	Area with permanent bodies of open water bigger and deeper than wetlands
Inland wetlands	Area with open water including canals, small ponds and wetlands (including aquaculture ponds locally known as bheris), excluding rivers with water measuring up to 2 m in depth
Open spaces	Barren land without grass and manmade constructions

The overall accuracies for the LULC classifications obtained are 89% (for pre-monsoon 2009), 90.1% (for pre-monsoon 2014), 93% (for pre-monsoon 2019), 88.4% (for post-monsoon 2009), 92% (for post-monsoon 2014) and 92.6% (for post-monsoon 2019). Finally, the data generated from the classified imagery were integrated into spreadsheets to calculate the changes in each class over the last decade.

iii. Estimation of value of ecosystem services and changes in value due to LULC changes

Global value coefficient (GVC) for 17 biomes was proposed by Costanza et al. (2014) to estimate the status of ecosystem services globally. In this study, to quantify the ecosystem service value (ESV) for the six land use categories (urban settlement, agricultural lands, vegetation, lakes, inland wetlands and open spaces), the GVCs proposed by Costanza et al. (1997) were used after suitably modified by Mamat et al. (2018). These modified values were used for this study. All estimated monetary values given in US$ are based on the 2018 valuation (Table 5.2.3). For our research, we used GVCs estimated by Mamat et al. (2018) as an indicative value. Therefore, the most representative biomes are used as proxy for individual land use categories such as urban for urban settlement, rivers/lakes/ponds for inland wetlands, crop lands for agricultural or cultivated lands and forests for vegetation, respectively. Accurate evaluation of monetary values for both ecosystem services and land use and land cover depends upon many factors ranging from national/international polices, socioeconomic development criteria, inflation of the local currency to willingness to pay and the supply–demand mechanism of the local people. Therefore, accurate valuation of ES for a specific geographical context is difficult and, to a certain point, vague. Considering this issue, we used the already adjusted valuation based on the benefit transfer method used by Mamat et al. (2018) for their study area. The following equations were applied to quantify ESV:

$$ESV_k = A_k \times GVC_k \quad (2)$$

$$ESV_t = \Sigma A_k \times GVC_k \quad (3)$$

$$ESV_f = \Sigma A_k \times GVC_{kf} \quad (4)$$

where ESV_k is the ecosystem service value (ESV) for individual land use categories, ESV_t is the total ecosystem service value and ESV_f is the individual ecosystem service function (Table 5.2.3), A_k is the area in hectares (ha) and GVC_k is the global value coefficient (US\$ $ha^{-1}year^{-1}$) for land use category k. GVC_{kf} is the global value coefficient (US\$ $ha^{-1}year^{-1}$) for land use category k and ecosystem service function type f (Mamat et al., 2018) (Table 5.2.3).

After estimation of total ecosystem service values (ESV), the average ecosystem service value (ESV_{avr}) was computed applying the following equation:

$$ESV_{avr} = ESV_t/U_a \quad (5)$$

where ESV_{avr} is the average ecosystem service value (US\$ $ha^{-1}year^{-1}$), ESV_t is the total ecosystem service value (US\$ $ha^{-1}year^{-1}$) for a certain study year and U_a is the total geographical area of the urban area (ha).

Table 5.2.3. Biome equivalent and corresponding ecosystem service value (ESV) (in US\$ $ha^{-1}year^{-1}$) estimation. Data source: modified from Mamat et al., 2018.

Ecosystem service category	Ecosystem service function (ESV_f)	Ecosystem service value (ESV) for each LULC type (US\$ $ha^{-1}year^{-1}$) according to the 2018 valuation					
		Urban settlement	Agricultural lands	Vegetation	Lakes	Inland wetlands	Open spaces
Regulating services	Gas regulation	0	74.7	299.4	0.0	268.9	4.2
	Climate regulation	0	133.0	282.1	68.7	2554.7	9.0
	Waste treatment	0	245.0	119.2	3047.7	2716.0	18.0
Supporting services	Soil formation	0	218.1	278.6	1.5	255.5	11.8
	Biodiversity protection	0	106.1	312.6	2719.0	373.5	27.7
Provisional services	Water supply	0	89.6	283.5	372.0	2315.6	4.8
	Food production	0	149.4	22.9	14.9	44.8	1.4
	Raw materials	0	14.9	206.5	1.5	10.5	2.8
Cultural services	Recreation and culture	12.7	1.5	144.2	648.4	829.2	16.6
Total		12.7	1032.3	1949.0	6873.8	9368.7	96.3

iv. Analysis of the Sensitivity Index (SI)

The biomes used in this study as proxies for individual land use and land cover (LULC) types do not perfectly match the biomes proposed by Costanza et al. (1997; 2014); in consequence, an uncertainty exists in computing the value coefficient. Therefore, it is necessary to conduct the sensitivity analysis to determine the changes (%) of the ecosystem service value upon the changes (%) of value coefficient. Using the concept of elasticity applied in economics, the coefficient of sensitivity (CS) was calculated as follows (Kreuter et al., 2001):

$$CS = ((ESV_j - ESV_i)/ESV_i)/((VC_{jk} - VC_{ik})/VC_{ik}) \quad (6)$$

where, CS is the coefficient of sensitivity, ESV is the estimated ecosystem service value, GVC is the global value coefficient after Costanza et al. (1997), i and j denote the initial and adjusted values, respectively, and k represents the land use category. In case CS > 1, the estimated ecosystem value is considered to be elastic (relatively high sensitivity) in response to the GVC and more attention needs to be paid to computing accurately the value coefficient. In case CS < 1, the estimated ecosystem service value is inelastic (relatively low sensitivity) with respect to the GVC and the resultant ecosystem service value is reliable (Mamat et al., 2018).

v. Water Quality Index

To calculate surface water quality index (WQI), seasonal data for ten years (2010–2019) were collected from thirteen stations of the West Bengal Pollution Control Board (WBPCB), Kolkata, India, including the River Hugli, Tolly's Nullah (canal), four ponds and Rabindra Sarobar (lake) (Figure 5.2.2). To calculate the WQI, the Canadian Council of Ministers of the Environment (CCME) model (Almeida et al., 2007; CCME, 2001) was used. The CCME WQI model consists of three measures of variance from selected water quality objectives: scope, frequency and amplitude (CCME, 2001). The resulting CCME WQI values range between 0 and 100, representing the overall water quality. The CCME WQI values are then converted into rankings by applying the index categorization scheme (Table 5.2.4). The water quality variables with corresponding objectives (as per the existing Indian regulatory authorities) tested for the CCME WQI calculation are listed in Table 5.2.5.

Table 5.2.4. The Canadian Council of Ministers of the Environment (CCME) water quality index (WQI) categorization scheme. Data source: CCME, 2001.

Rank	**WQI value**	**Description**
Excellent	95–100	Water quality is protected with a virtual absence of threat or impairment; conditions remarkably close to natural or pristine levels; these index values can only be obtained if all measurements are within objectives virtually all the time.
Good	80–94	Water quality is protected with only a minor degree of threat or impairment; conditions rarely depart from natural or desirable levels.
Fair	65–79	Water quality is usually protected but occasionally threatened or impaired; conditions sometimes depart from natural or desirable levels.
Marginal	45–64	Water quality is frequently threatened or impaired; conditions often depart from natural or desirable levels.
Poor	0–44	Water quality is almost always threatened or impaired; conditions usually depart from natural or desirable levels.

Groundwater quality index was calculated using water quality data of 270 groundwater monitoring stations (Figure 5.2.2) obtained from McAuthur et al. (2018). Fifteen chemical parameters (Table 5.2.5) were applied to calculate the water quality index as per the CCME WQI model.

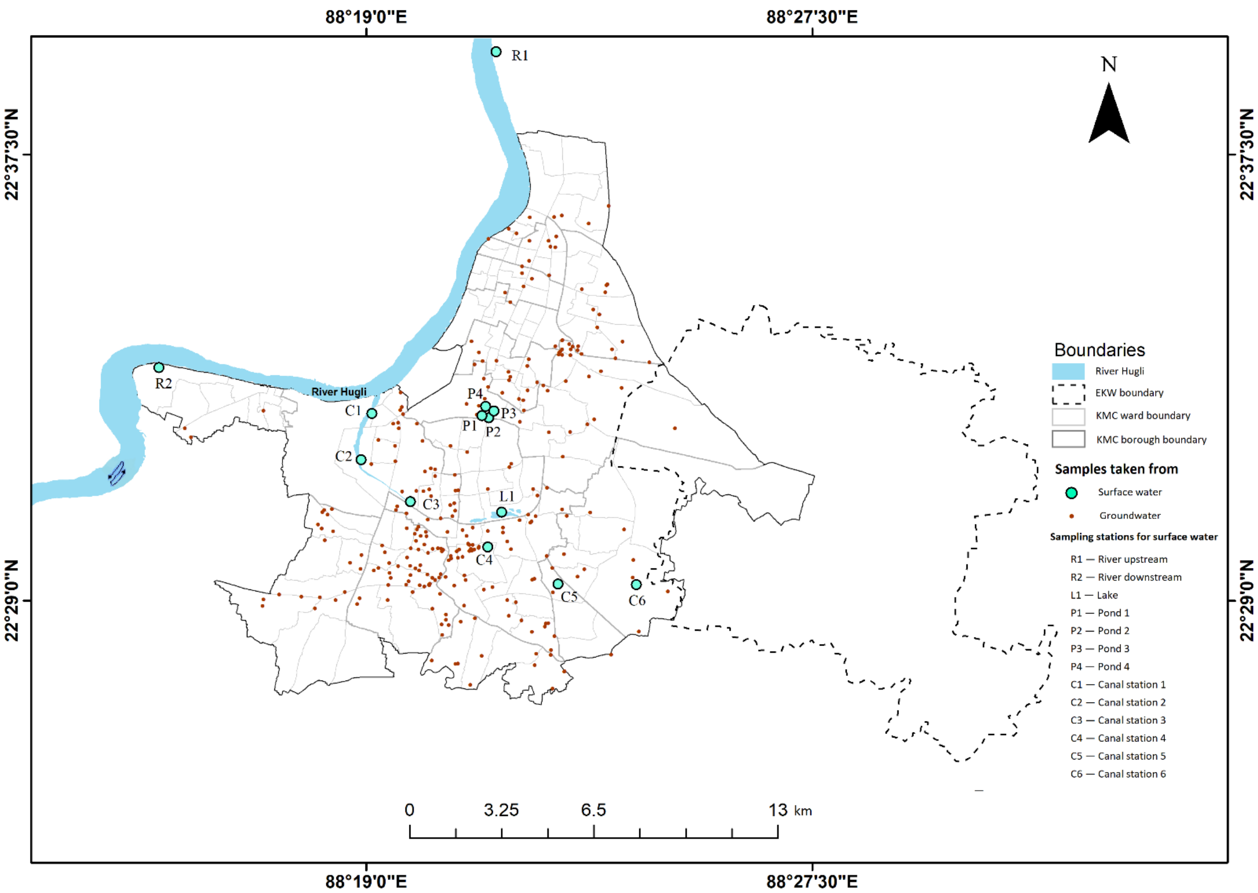

Figure 5.2.2. The water sample collection sites (surface water and groundwater) in the Kolkata Municipal Corporation (KMC) and East Kolkata Wetlands (EKW) areas. Data source: McArthur et al. (2018) and WBPCB (2017).

Table 5.2.5. Parameters of water quality used and the standard for drinking water and bathing/recreational use of water. Data source: BIS, 2012; Miraj and Bhattacharya, 2017.

Parameters	Unit	Drinking water		Bathing/recreational use of water	
		Standard	Recommending agency	Standard	Recommending agency
BOD⋆	mg/L^{-1}	2	CPCB (1992)	3	CPCB (1992)
Cadmium†	mg/L^{-1}	0.003	BIS (2012)	-	-
Calcium⋆†	mg/L^{-1}	75	BIS (2012)	-	-
Chloride⋆†	mg/L^{-1}	250	BIS (2012)	600	CPCB (1992)
Chromium†	mg/L^{-1}	0.05	BIS (2012)	-	-
Copper†	mg/L^{-1}	1.5	BIS (2012)		
Dissolved O2(DO)⋆	mg/L^{-1}	6	CPCB (1992)	5	CPCB (1992)
Fluoride†	mg/L^{-1}	1	BIS (2012)	1.5	CPCB (1992)
Iron†	mg/L^{-1}	1	BIS (2012)	-	-
Lead†	mg/L^{-1}	0.01	BIS (2012)	-	-
Magnesium⋆†	mg/L	30	BIS (2012)	-	-
Manganese†	mg/L^{-1}	0.3	BIS (2012)	-	-
Nickel†	mg/L^{-1}	0.02	BIS (2012)	-	-
Nitrate†	mg/L^{-1}	45	BIS (2012)	-	-
Nitrate-N⋆	mg/L^{-1}	20	BIS (2012)	-	-
pH⋆	-	6.5–8.5	BIS (2012)	6.5–8.5	CPCB (1992)
Potassium†	mg/L^{-1}	10	BIS (2012)	-	-
Sodium†	mg/L^{-1}	180	BIS (2012)	-	-
Sulphate⋆†	mg/L^{-1}	200	BIS (2012)	-	-
Total coliforms⋆	Most Probable Number () / 100 mL^{-1}	50	CPCB (1992)	500	CPCB (1992)
Total dissolved solids (TDS)⋆	mg/L^{-1}	500	BIS (2012)	-	-
Total hardness as $CaCO_3$⋆	mg/L^{-1}	300	BIS (2012)	-	-
Total hardness as $CaCO_3$⋆	Nephelometric Turbidity Units (NTU)	5	BIS (2012)	-	-

⋆ Parameters used for the surface water index; † parameters used for the groundwater index. Abbreviations used: BOD: biochemical oxygen demand; CPCB: Central Pollution Control Board, India; BIS: Bureau of Indian Standards; ICMR: Indian Council of Medical Research.

vi. Urban Environmental Water Security Index

The concept of water security advocates for providing safe drinking water while maintaining sustainable environment integrating efforts to meet the 2030 Agenda Sustainable Development Goals (Grey and Sadoff, 2007; Mayers, 2009; Mukherjee et al., 2018). Quantitative metrics of water security of a megacity are needed for more comprehensive understanding of the dynamic environmental characteristics of its neighborhoods, which otherwise remain obscured (Mukherjee et al., 2018). In this research paper, we are proposing an index linking land use and land cover changes, values of ecosystem services and quality of the supplied water together for clear understanding of the collective results of all the variables considered for the index. The final scores of this index can be used as an indicative tool with greater clarity and usability for further research and planning purposes.

The Urban Environmental Water Security Index (UEWSI) was calculated on the basis of intensity indices (Tate et al., 2005; Su et al., 2011; Suja et al., 2013; Zhou et al., 2014) which explain the degree of change in average ecosystem service value (ESV) in each borough (an administrative block comprising several lowest administrative units called wards) of the Kolkata Municipal Corporation and East Kolkata Wetlands for the given period of time.
The temporal and spatial variation of the UEWSI was prepared using the following equations:
Pre-monsoon ecosystem service valuation index:

$$ESVI_{prm} = \sum \frac{(\Delta ES_{prmx} \times 100)}{AT} \times \Delta t \quad (6)$$

Post-monsoon ecosystem service valuation index:

$$ESVI_{pom} = \sum \frac{(\Delta ES_{pomx} \times 100)}{AT} \times \Delta t \quad (7)$$

Pre-monsoon LULC intensity index:

$$\sum PRMII = \sum \frac{(\sum \Delta C1 \times 100)}{AT} \times \Delta t \quad (8)$$

Post-monsoon LULC intensity index:

$$\sum PPOMII = \sum \frac{(\sum \Delta C2 \times 100)}{AT} \times \Delta t \quad (9)$$

Urban environmental water security index:

$$UEWSI = \sum_{-1}^{1}((ESVI_{prm} + ESVI_{pom} + PRMII + PPOMII) + SuplWQI) \quad (10)$$

where, $\Delta ESprm_x$ and $\Delta ESpom_x$ denote the change of the borough wise average ESV in US$ between 2009–2019 during pre-monsoon or post-monsoon seasons; x is an individual borough of the KMC; ΔC1 and ΔC2 are the change in area (ha) for all LULC classes over the total study period during pre- and post-monsoon seasons, respectively; AT is the total area (ha) of the borough; and Δt is the time (year) span of the total study period.
Weightage for supplied water quality index ($SuplWQI_x$) is a value assigned to the tested supplied water (or main source of drinking water) category in the Canadian Council of Ministers of the Environment (CCME) water quality index (WQI) scheme (Table 5.2.4) for

each borough (example: 1 for poor, 2 for marginal, 3 for fair, 4 for good and 5 for excellent) where the supplied water is considered the main source of water for drinking purposes. Normalization of UEWSI values (−1 to 1) allowed assessing inter-borough variability in environmental water security displayed in a map using ArcGIS 10.6 (ESRI, Redland, CA, USA).

5.2.3. Results

i. Land use and land cover (LULC) changes

The spatial distribution of land use and land cover (LULC) in the Kolkata Municipal Corporation (KMC) and East Kolkata Wetlands is outlined seasonally for the years 2009, 2014 and 2019 (Figure 5.2.3). Urban settlement dominates the urban area of the Kolkata Municipal Corporation, while in the East Kolkata Wetlands, agricultural land is the dominant LULC class. The occurrence of areas under vegetation varies both seasonally and spatially. It is evident that in boroughs VII and XII, vegetation cover is higher than in the other boroughs of the KMC. In boroughs I–VI, urban settlement dominates the LULC classes during the total study period. The distribution of inland wetlands was all over the study period higher in areas of the East Kolkata Wetlands than in the KMC area. Only in boroughs IX and XII, significant area coverage by inland wetlands can be observed. The areas covered by inland wetlands also varied seasonally in distribution, i.e., during post-monsoon periods, the area covered by inland wetlands was generally higher than during the pre-monsoon periods. This seasonal variation of the distribution of inland wetland areas between pre- and post-monsoon periods is clearly evident for borough IV for the years 2009 and 2014. In contrast, in 2019, the area covered by inland wetlands diminished in the pre-monsoon season and completely disappeared during the post-monsoon season. These strong seasonal variations in the distribution of inland wetlands affected the distribution of the other LULC classes, particularly the areas under open spaces which varied inversely to the inland wetlands between 0.4% in the pre-monsoon period of 2009 to 0.15% in the post-monsoon period of 2019 (Table 5.2.6). Within the entire study area, open spaces are rare and could be observed in small portions for boroughs V, VI and VII; however, in the post-monsoon 2014 image for borough V, open spaces are lacking. The area of lakes did not change during the entire study period as these areas within boroughs III and VIII are areas designated by the municipal authorities.

The spatiotemporal variations of each LULC class were examined in terms of total study area (which includes both the KMC and EKW areas) and percentage for each study period (Table 5.2.6). The results indicate that the spatial proportion of each LULC class varied between the seasons and throughout the whole observation period (2009–2019). In 2009, the urban settlement class was the dominant LULC class in the KMC area, covering more than 44% of both the KMC and EKW areas altogether, followed by vegetation-covered areas, agricultural lands and inland wetlands. Lakes and open spaces covered only small shares of the total study area. In 2014, urban settlement remained the dominant LULC class followed by vegetation-covered areas; however, the spatial distribution of agricultural lands and inland wetlands increased substantially during the post-monsoon season at the expense of areas under vegetation (33.95% during the pre-monsoon period of 2014 and 20.47% during the post-monsoon period of the same year). Furthermore, in 2019, the areas under urban settlement were the dominating LULC class in the study area, again, followed by vegetation-covered areas. The shares of areas used as agricultural lands or covered by inland wetlands remained almost the same as in 2014. In 2019, the amount of area under open spaces significantly decreased compared to 2009 and 2014; in contrast, between 2009 and 2019, the area covered by lakes slightly increased in the post-monsoon period compared to that of the pre-monsoon period.

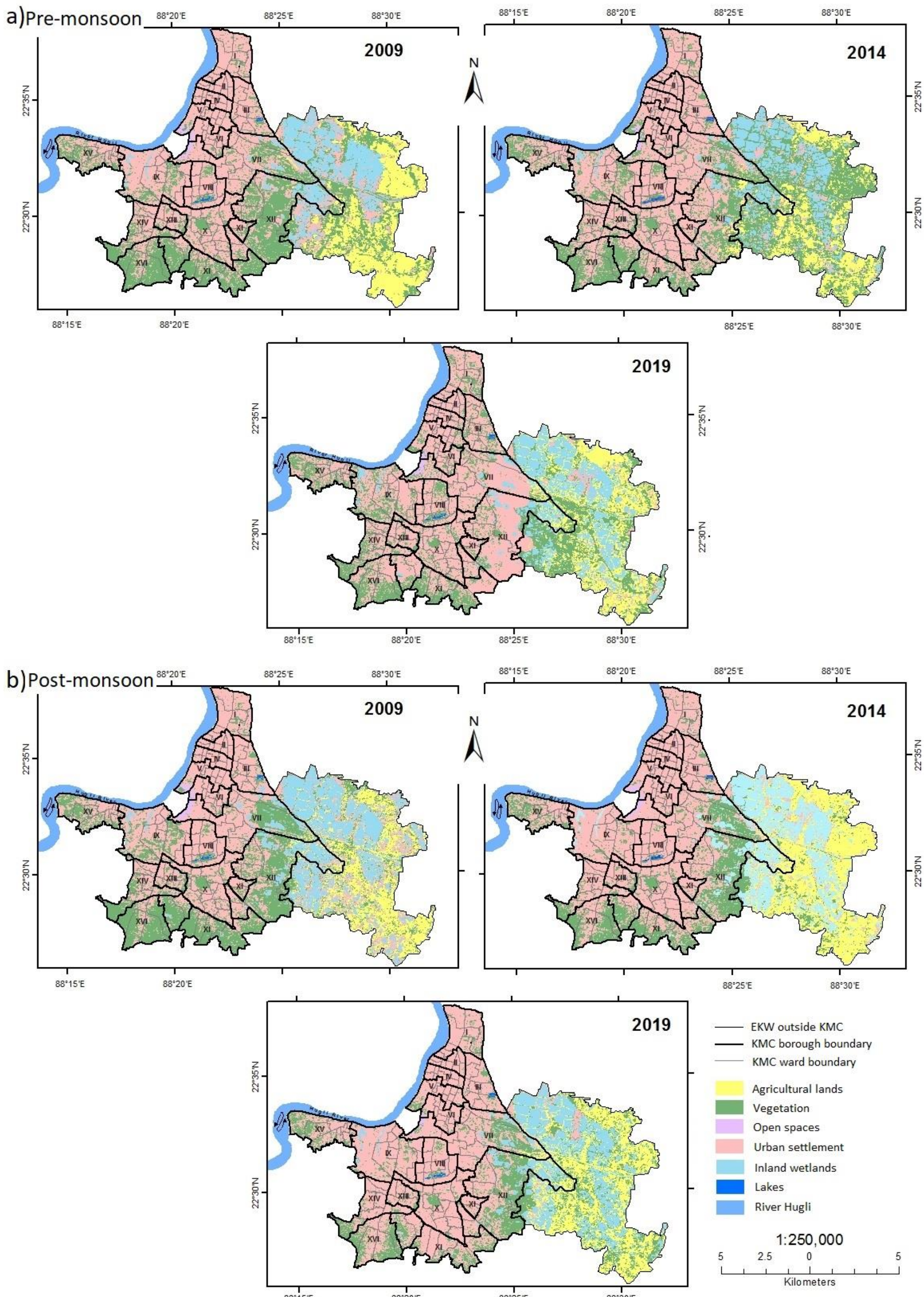

Figure 5.2.3. Distribution of land use and land cover (LULC) classes in 2009, 2014 and 2019 featuring the wards and boroughs of the Kolkata Municipal Corporation (KMC) and East Kolkata Wetlands (EKW) areas differentiated by the (**a**) pre-monsoon and (**b**) post-monsoon seasons. Black outlines within the KMC are borough boundaries, the light grey outlines within each borough are ward boundaries, Roman numerals mark borough numbers. Data source: Satellite image interpretation from Landsat series, United States Geological Survey (USGS).

Table 5.2.6. Distribution of land use and land cover (LULC) by class area extent (km^2) and percentage (%) of the study area during pre-monsoon and post-monsoon seasons of 2009, 2014 and 2019. Data source: Satellite image interpretation from Landsat series (USGS).

LULC classes	Urban settlement	Inland wetlands	Lakes	Vegetation	Open spaces	Agricultural lands
2009, pre-monsoon	139.04	31.14	0.39	98.85	1.26	41.09
%	44.59	9.99	0.13	31.71	0.40	13.18
2009, post-monsoon	139.23	49.69	0.36	86.75	1.54	34.21
%	44.66	15.94	0.11	27.82	0.49	10.97
2014, pre-monsoon	142.73	31.06	0.35	105.85	0.75	31.04
%	45.78	9.96	0.11	33.95	0.24	9.96
2014, post-monsoon	144.50	48.82	0.42	63.83	1.16	53.05
%	46.35	15.66	0.13	20.47	0.37	17.02
2019, pre-monsoon	146.93	40.75	0.38	84.03	0.92	38.76
%	47.13	13.07	0.12	26.95	0.29	12.43
2019, post-monsoon	148.04	45.89	0.41	69.31	0.46	47.67
%	47.48	14.72	0.13	22.23	0.15	15.29

The LULC changes were differentiated into three major observation periods: 2009–2014 (first period), 2014–2019 (second period) and 2009–2019 (total period) with separate examination of seasons (pre- and post-monsoon seasons) (Figure 5.2.4). Change detection analysis showed that during the first observation period, the area of urban settlement increased by 2.62% and 3.85% in the pre-monsoon and post-monsoon seasons, respectively. In the second observation period, the area of urban settlement again increased by 2.95% in the pre-monsoon season and by 2.44% in the post-monsoon season. During the total observation period, the area under urban settlement increased by 5.65% in the pre-monsoon period and by 6.38% in the post-monsoon period. In the case of agricultural lands, during the post-monsoon seasons of 2009–2014, a relative increase of 55.06% was observed, as well as a relative increase of 39.33% was observed for the total observation period 2009–2019. Areas of open spaces overall declined in distribution during both types of seasons of the total observation period (2009–2019). Nevertheless, in the pre-monsoon seasons between 2014 and 2019, the areas under open spaces grew by 22.48%, which is, however, only 0.17 km^2 in total. The areas under inland wetlands increased by more than 30% during the pre-monsoon seasons of the second and total periods. In contrast, during the post-monsoon seasons of all periods, a continuous decrease in inland wetlands was witnessed. Analyzing the distribution of lakes (the water-filled parts) in the pre-monsoon seasons, between 2009 and 2014, a decrease of 11.93% occurred, whereas between

2014 and 2019, it did grow by 10.67%. During the total observation period of 2009–2019, the lake area grew by 14.38% in the post-monsoon seasons, while in the pre-monsoon seasons, a decrease of 2.53% could be observed.

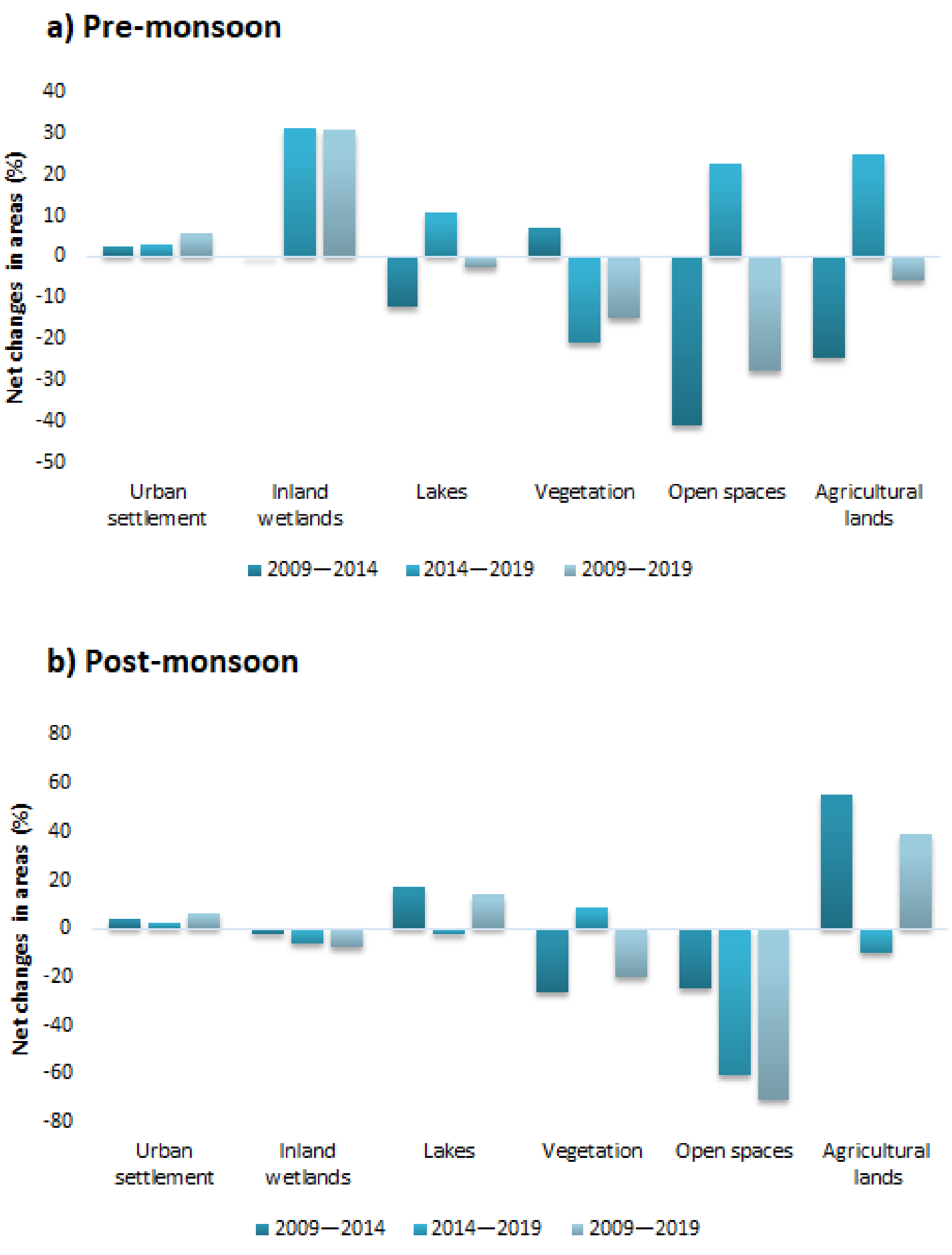

Figure 5.2.4. Relative net changes (%) of different land use and land cover (LULC) classes in the areas of the Kolkata Municipal Corporation (KMC) and East Kolkata Wetlands (EKW) during (**a**) pre-monsoon and (**b**) post-monsoon seasons of the observation periods 2009–2014, 2014–2019 and 2009–2019. Data source: Satellite image interpretation from Landsat series (USGS).

ii. Estimation of the ecosystem services value

a. Categories of ecosystem services

The individual ecosystem service values (ESV) of four categories of ecosystem services (ES)—regulating, supporting, provisioning and cultural—in each borough of the Kolkata Municipal Corporation and East Kolkata Wetlands are compiled in the Appendices 5.2A - 5.2D. The ESV for regulating services has the highest contribution, whereas cultural ecosystem services have the lowest contribution (Figure 5.2.5). The ESV for regulating services for the pre-monsoon period increased from US$26.4 million in 2009 to US$31.4 million in 2019, but in the post-monsoon period, these ESVs decreased from US$33.7 million in 2009 to US$31.4 million in 2019. Cultural ecosystem services contributed a little more than US$1 million corresponding to only 2% of the net contribution to the values for ecosystem services during the post-monsoon season in 2019. The net contributions to ESVs of all four categories of ecosystem services are highest in the East Kolkata Wetlands, where they amount to more than 27% of the net ESV during the entire observation period of 2009–2019 (see the Appendices 5.2A - 5.2D). Within the Kolkata Municipal Corporation (KMC), borough XII provides the highest contribution (16.08%) to its ESV compared to the rest of the boroughs; this applies to all the four categories of ecosystem services, i.e., regulating, supporting, provisioning and cultural services, during the entire 2009–2019 period.

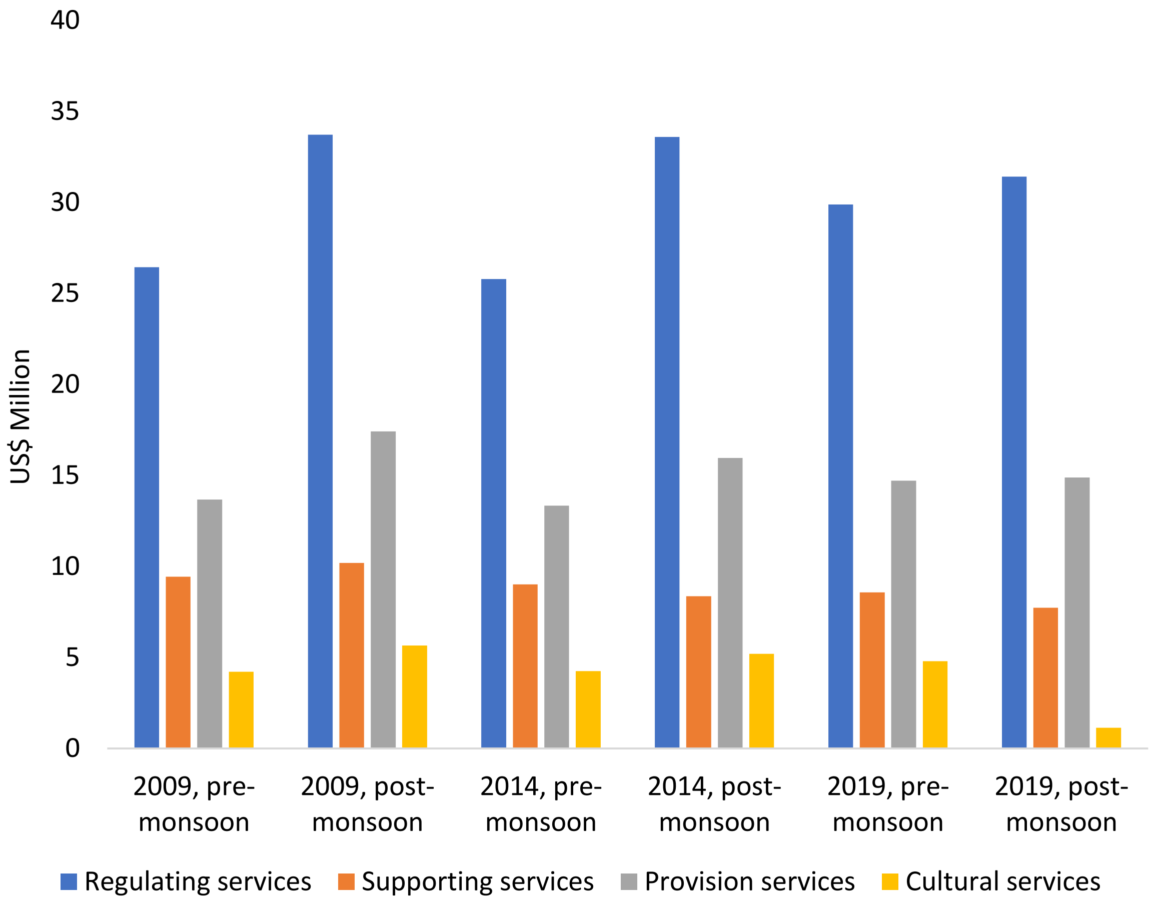

Figure 5.2.5. Individual ecosystem service values (in US$ million) in 2009, 2014 and 2019 differentiated by pre-monsoon and post-monsoon periods in the Kolkata Municipal Corporation (KMC) boroughs and East Kolkata Wetlands areas (outside the Kolkata Municipal Corporation area). Data source: Satellite image interpretation from Landsat series (USGS) and Mamat et al. (2018).

b. Land use and land cover (LULC) class

The effects of changing land use and land cover (LULC) (Table 5.2.6) on the ecosystem services and their contribution to the total ecosystem service values (ESV) (Table 5.2.7) within the areas of the Kolkata Municipal Corporation and East Kolkata Wetlands were calculated using the ecosystem service value coefficients (Table 5.2.3). The data show that the ESV is mainly controlled by the distribution of inland wetlands followed by the areas covered by vegetation (excluding agricultural lands). Inland wetlands contributed more than 50% of the total ESV throughout the entire study period, whereas contribution of the areas covered by vegetation (excluding agricultural lands) varied between 19 and 40% for the whole observation period (2009–2019). Comparison of LULC distribution between base year 2009 and 2019 (Table 5.2.7) shows that contribution of inland wetland areas on the ESV increased during both pre-monsoon and post-monsoon periods. The contribution to the ESV of the areas covered by vegetation (not cultivated) during the pre-monsoon periods increased during the pre-monsoon periods between 2009 and 2014 and then decreased between 2014 and 2019. In contrast, in the post-monsoon periods, the contribution of the areas covered by vegetation to the ESV decreased between 2009 and 2014, but thereafter it increased (Table 5.2.7). The contribution of agricultural lands to the ESV was less than 9% throughout the whole observation period, whereas the contribution of urban settlement areas, lakes and open spaces considered together accounted for less than 1% (Table 5.2.7).

Table 5.2.7. Ecosystem service values in US$ and % of land use land cover (LULC) classes in the study area during 2009, 2014 and 2019 differentiated by pre-monsoon and post-monsoon periods. Data source: Satellite image interpretation from Landsat series (USGS) and Mamat et al. (2018).

	Urban settlement	**Inland wetlands**	**Lakes**	**Vegetation**	**Open spaces**	**Agricultural lands**	**Total**
2009, pre-monsoon	176,576.02	29,174,588.99	271,060.05	19,266,539.74	12,155.51	4,242,172.85	53,143,093.16
%	0.33	54.9	0.51	36.25	0.02	7.99	100.00
2009, post-monsoon	176,823.60	46,550,145.39	246,386.55	16,907,575.00	14,846.85	3,531,861.46	67,427,638.85
%	0.26	69.04	0.37	25.08	0.02	5.23	100.00
2014, pre-monsoon	181,267.10	29,102,059.33	238,718.83	20,630,740.34	7,198.03	3,204,258.48	53,364,242.11
%	0.35	54.53	0.45	38.66	0.01	6	100.00
2014, post-monsoon	183,515.00	45,737,993.40	288,699.60	12,440,467.00	11,170.80	5,476,351.50	64,138,197.30
%	0.29	71.31	0.45	19.4	0.02	8.53	100.00
2019, pre-monsoon	186,601.10	38,178,958.05	264,194.50	16,378,291.11	8,815.85	4,001,219.06	59,018,079.67
%	0.32	64.69	0.45	27.75	0.01	6.78	100.00
2019, post-monsoon	188,010.80	42,992,964.30	281,825.80	13,508,519.00	4,429.80	4,920,974.10	61,896,723.80
%	0.3	69.46	0.46	21.82	0.01	7.95	100.00

c. Seasons

The season-wise changes in ecosystem service values (ESV) between 2009 and 2019 differentiated by each land use and land cover (LULC) class are compiled in Table 8 (in US$) and displayed in Figure 5.2.6 (in %). Inland wetlands showed significant growth in the ESV for all three time periods during the pre-monsoon seasons, while they shrank during the post-monsoon periods. The areas covered by vegetation (without cultivation) show a decline in contributing to the ESV between 2009 and 2019 for both the pre-monsoon and the post-monsoon periods. The maximum yearly increase in the ESV was observed in the case of the areas under agricultural lands (11.1%) during the post-monsoon seasons between 2009 and 2014. The maximum yearly decrease in the ESV was evident for the areas under open spaces which was −14.03% during the post-monsoon seasons during 2009–2019 (Figure 5.2.6).

Figure 5.2.7 displays season-wise changes in the ESV (in %) from individual ES. Among all individual ES, the maximum yearly decrease in the ESV was observed for the cultural ES (−15.62%) during the post-monsoon seasons between 2014 and 2019, while the maximum increase in the yearly ESV was observed in the case of regulating ES (3.18%) during the post-monsoon seasons between 2014 and 2019 (Figure 5.2.7). During the post-monsoon seasons of the total observation period, the decline in yearly relative changes in the ESV for all the individual ES was observed. Among them, cultural ES shrank the most (−7.99%), whereas regulating ES decreased only by 0.69%. In the pre-monsoon periods of the total observation period, only supporting ES had a negative yearly change (−0.092%) in the ESV.

Table 5.2.8. Season-wise changes in ecosystem service values (in US$) during pre-monsoon and post-monsoon seasons of 2009–2014, 2014–2019 and 2009–2019 for the Kolkata Municipal Corporation and East Kolkata Wetlands differentiated for different land use and land cover classes. Data source: Satellite image interpretation from Landsat series (USGS) and Mamat et al. (2018).

	Pre-monsoon			**Post-monsoon**		
LULC classes	**2009–2014**	**2014–2019**	**2009–2019**	**2009–2014**	**2014–2019**	**2009–2019**
Urban settlement	46.91	53.34	100.25	66.91	44.96	111.87
Inland wetlands	−725.30	90,768.99	90,043.69	−8,215.21	−27,356.60	−35,571.81
Lakes	−323.41	254.76	−68.66	423.13	−68.74	354.39
Vegetation	13,642.01	−42,524.49	−28,882.49	−44,564.40	10,680.52	−33,883.88
Open spaces	−49.57	16.18	−33.40	−36.76	−67.41	−104.17
Agricultural lands	−10,379.14	7,969.61	−2,409.54	19,444.90	−5,553.77	13,891.13
Total	**2,211.49**	**56,538.38**	**58,749.87**	**−32,881.42**	**−22,321.05**	**−55,202.47**

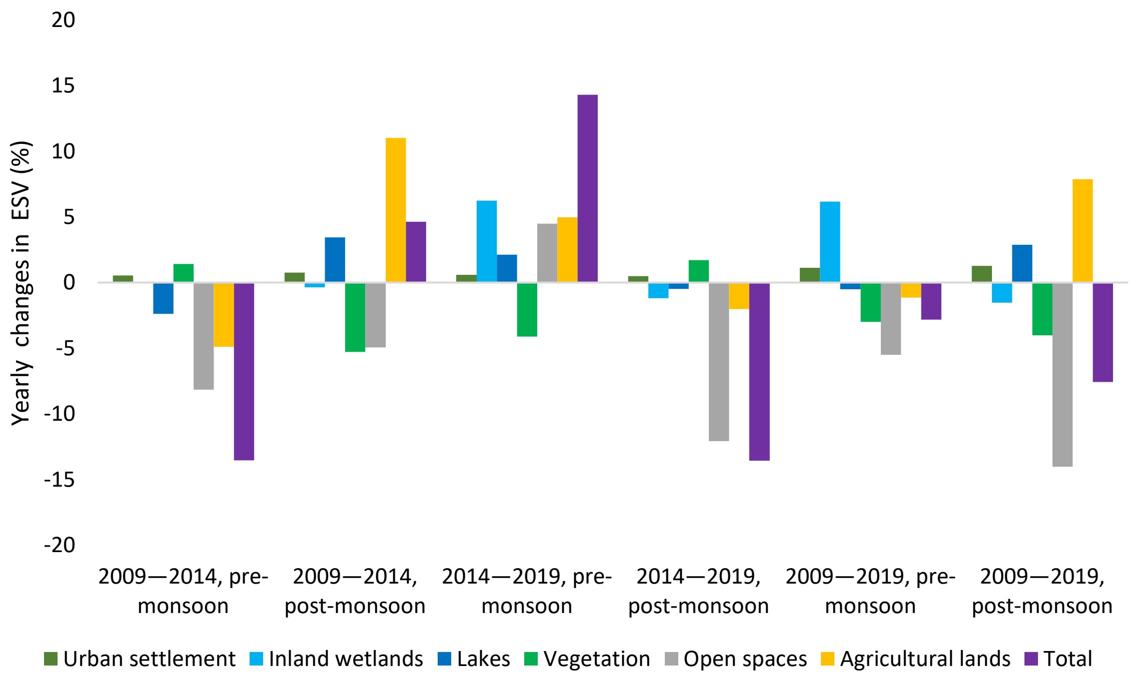

Figure 5.2.6. Season-wise changes in ecosystem service values (in %) obtained from different land use and land cover (LULC) classes in the Kolkata Municipal Corporation and East Kolkata Wetland (EKW) areas during pre-monsoon and post-monsoon seasons of 2009–2014, 2014–2019 and 2009–2019. Data source: Satellite image interpretation from Landsat series (USGS) and Mamat et al. (2018).

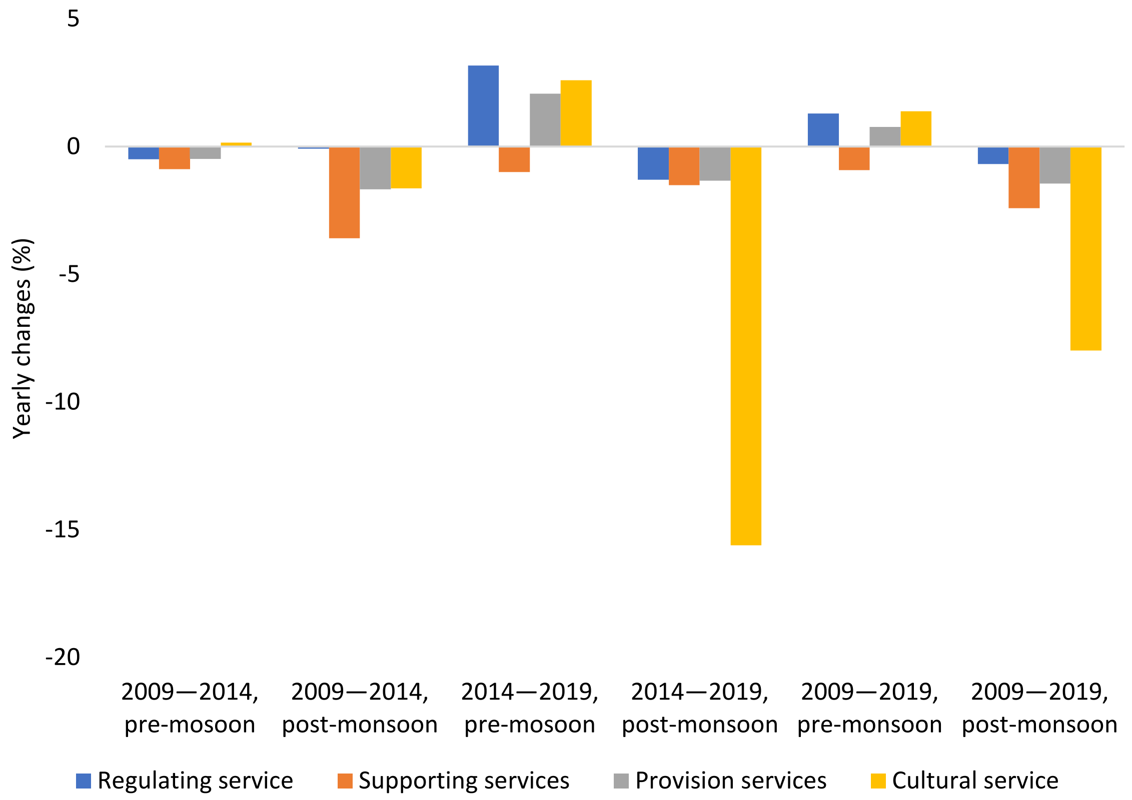

Figure 5.2.7. Relative yearly changes in individual ecosystem service values (in %) during pre- and post-monsoon seasons in 2009–2014, 2014–2019 and 2009–2019 in the Kolkata Municipal Corporation (KMC) and East Kolkata Wetlands (EKW) areas. Data source: Satellite image interpretation from Landsat series (USGS) and Mamat et al. (2018).

d. Total ESV calculation

According to the estimation, the total ecosystem service value (ESV) in the areas of the Kolkata Municipal Corporation and East Kolkata Wetlands was about US$53.14 million during the 2009 pre-monsoon season. The ESV remained almost similar in the pre-monsoon period of 2014 (US$53.36 million) and increased slightly in 2019 (US$59 million) (Figure 5.2.8). In contrast, during the post-monsoon seasons of the total observation period (2009–2019), a decrease in the total ESV could be observed.

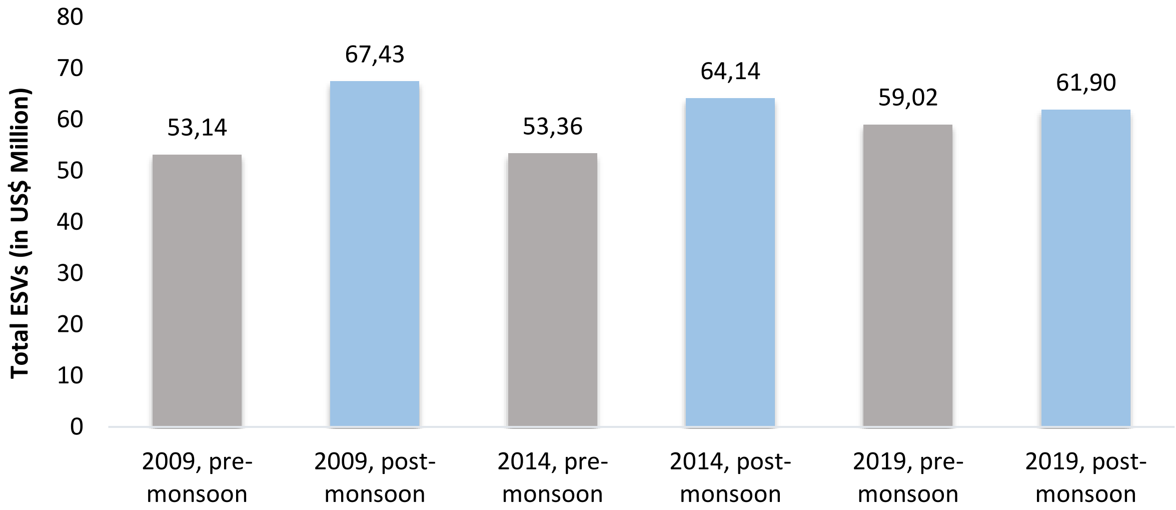

Figure 5.2.8. Values of total ecosystem services (ESV in US$ million) in the total study area including the Kolkata Municipal Corporation (KMC) and East Kolkata Wetlands (EKW) areas during the pre-monsoon and post-monsoon periods of 2009, 2014 and 2019. Data source: Satellite image interpretation from Landsat series (USGS) and Mamat et al. (2018).

The borough-wise average ecosystem service values (ESV) between 2009 and 2019 of the Kolkata Municipal Corporation and East Kolkata Wetlands are shown in Figure 5.2.9. The major contributions to the ESV come from the East Kolkata Wetland area (EKW). Within the KMC, boroughs VII and XII (Figure 5.2.2) contributed the most to the ESV, whereas boroughs II and IV (Figure 5.2.2) contributed the least. In general, the southern parts (boroughs VII–XVI) of the Kolkata Municipal Corporation area contributed more to the ESV compared to the northern parts (boroughs I–VI) of the city. The East Kolkata Wetlands contributed almost a quarter of the total ESV with an increase during the total observation period.

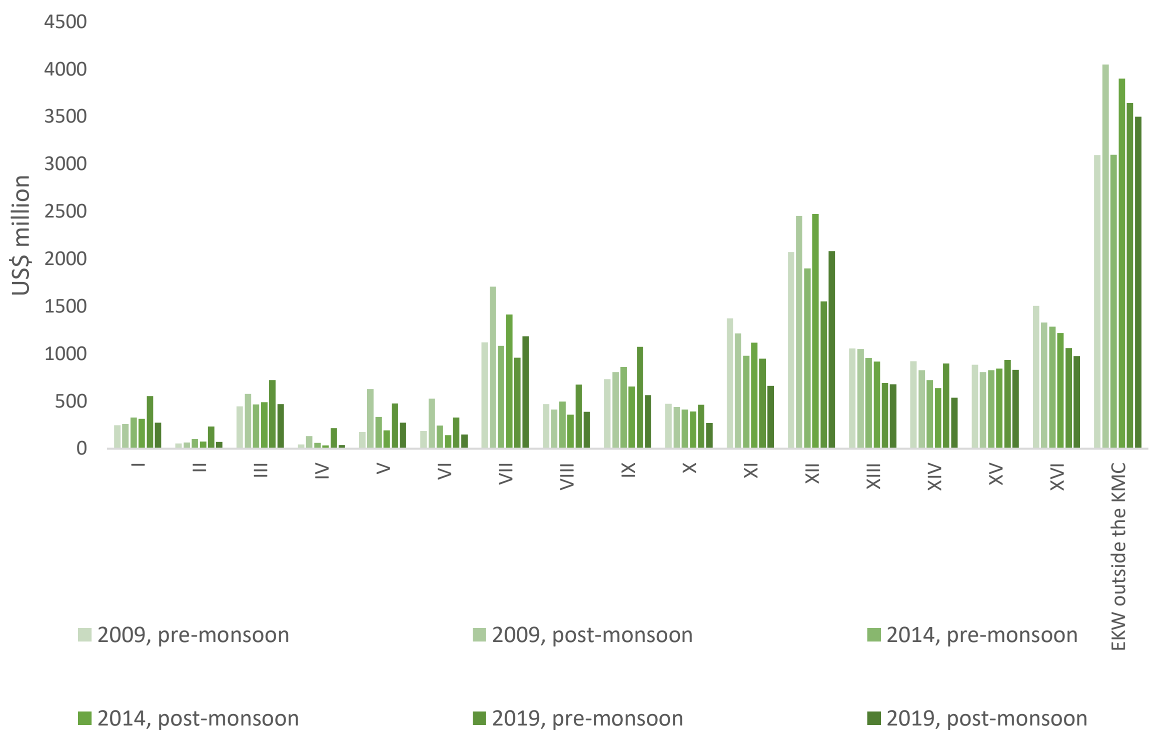

Figure 5.2.9. Borough wise average ecosystem service values (ESV) in US$ million. Roman numerals mark borough numbers. Data source: Satellite image interpretation from Landsat series (USGS) and Mamat et al. (2018).

e. Analysis of the Sensitivity Index (SI)

The sensitivity of ecosystem service values (ESV) to changes in value coefficients (with 50% adjustment) is < 1 and often close to 0. Therefore, the ESVs are inelastic and the estimated ESVs calculated for the 10 years of the study period 2009–2019 for the Kolkata Municipal Corporation and East Kolkata Wetlands are reliable.

iii. Water Quality Index

The overall WQI scores for surface water contemplated season-wise and year-wise were within the “poor” category when the Canadian Council of Ministers of the Environment (CCME) water quality index (WQI) classification scheme was applied (Figure 5.2.10). The water quality scores of groundwater in the Kolkata Municipal Corporation boroughs were assessed as “good”, and in boroughs VIII, XII and XIV even as “excellent” (Table 5.2.4; Figure 5.2.11). Between 2015 and 2017, slight seasonal effects in groundwater quality could be observed: the samples collected during post-monsoon periods showed higher water quality index (WQI) scores than the samples collected in either monsoon or pre-monsoon periods.

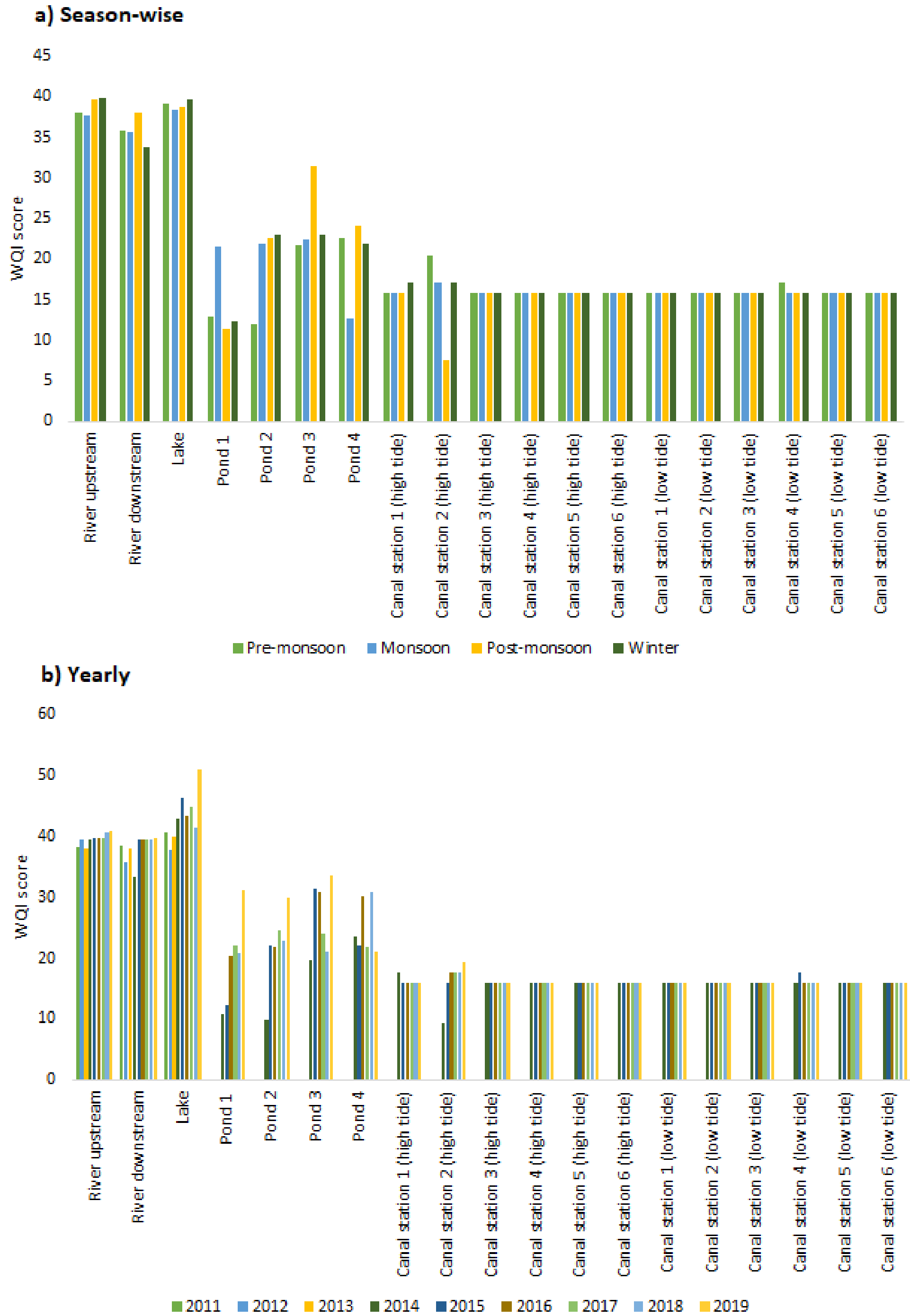

Figure 5.2.10. Surface water quality index (WQI) scores between 2011–2019 (**a**) season-wise and (**b**) yearly for selected stations of the Values of total ecosystem services (ESV in US$ million) in the total study area including the Kolkata Municipal Corporation (KMC) and East Kolkata Wetlands (EKW) areas during the pre-monsoon and post-monsoon periods of 2009, 2014 and 2019. The locations of surface water sample stations are given in Figure 5.2.2. Data source: West Bengal Pollution Control Board, Kolkata, India.

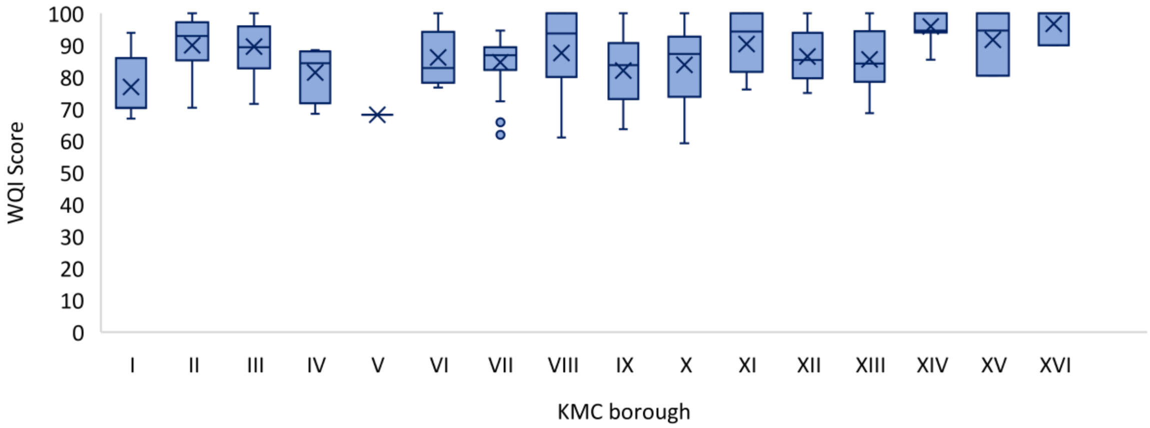

Figure 5.2.11. Distribution of water quality index scores of the groundwater sampled between 2015 and 2017 within the Kolkata Municipal Corporation (KMC) boroughs. Roman numerals mark the different boroughs. Data source: McArthur et al., 2018.

iv. Comprehensive Urban Environmental Water Security Index (UEWSI)

The calculation of the comprehensive Urban Environmental Water Security Index (UEWSI) indicated that the East Kolkata Wetlands showed the highest UEWSI value (Figures 5.2.12 and 5.2.13). Within the Kolkata Municipal Corporation, boroughs VII and XII, which are also part of the greater East Kolkata Wetland area, showed distinctly higher UEWSI values than the other boroughs. Beyond that, the boroughs located in the southern part of the city showed higher UEWSI values than those in the northern part, where some boroughs even showed negative UEWSI values.

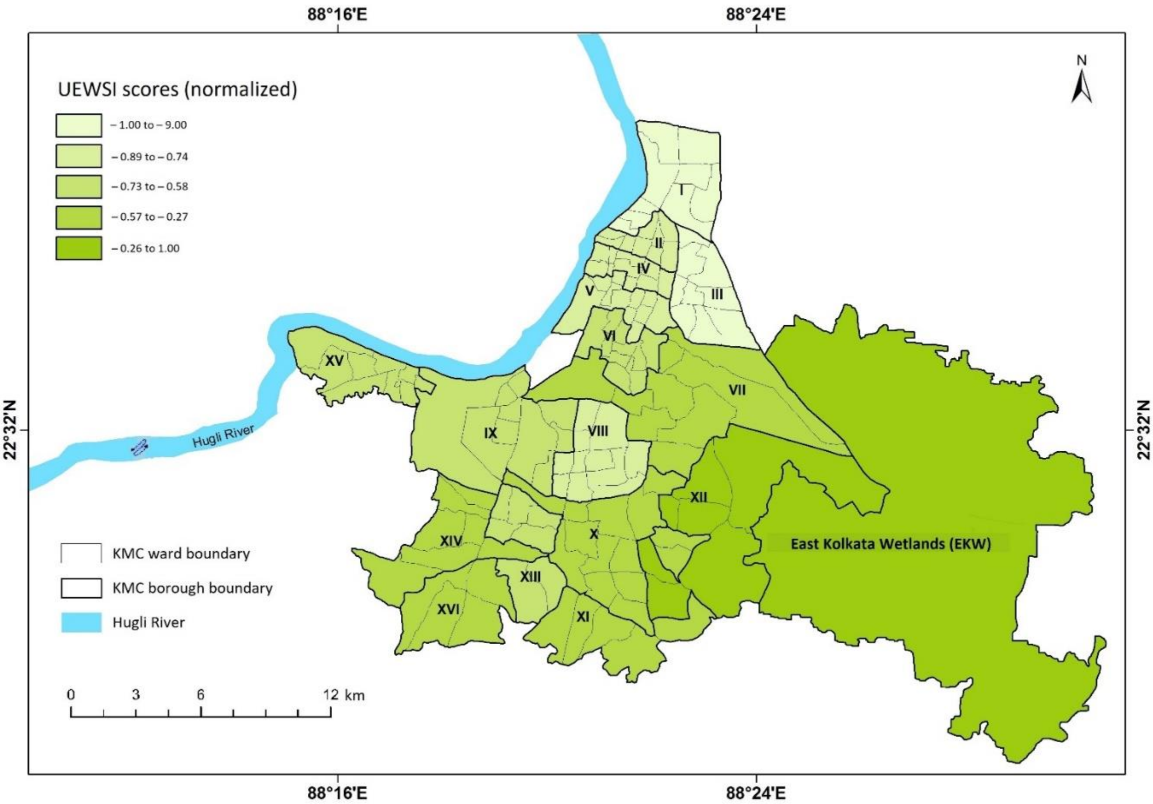

Figure 5.2.12. Distribution of Urban Environmental Water Security Index (UEWSI) scores in the Kolkata Municipal Corporation (KMC) and East Kolkata Wetlands (EKW) areas (calculation based on satellite observation of land use and land cover changes between 2009 and 2019). Roman numerals mark the borough numbers. Data source: Satellite image interpretation from Landsat series (USGS).

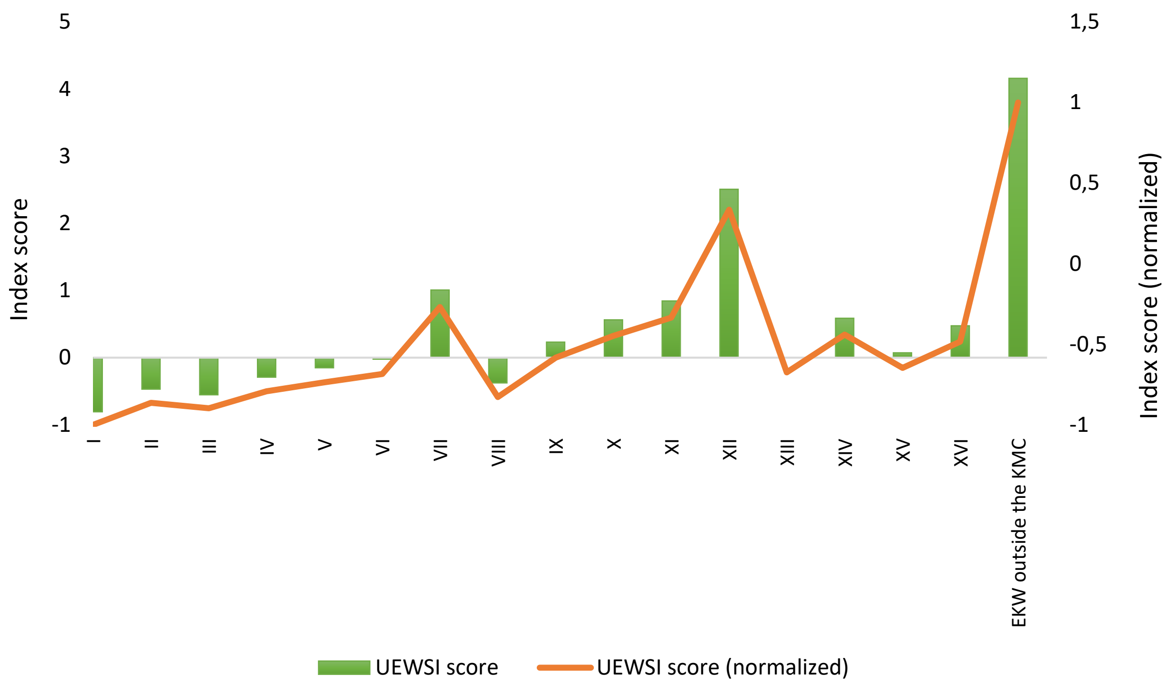

Figure 5.2.13. Distribution of Urban Environmental Water Security Index (UEWSI) scores and normalized Urban Environmental Water Security Index (UEWSI) scores (calculation based on observations within 2009–2019) within the Kolkata Municipal Corporation (KMC) boroughs and East Kolkata Wetland (EKW) areas. Roman numerals mark the borough numbers. Data source: Satellite image interpretation from Landsat series (USGS).

5.2.4. Discussion

i. Effects of changes in ecosystem services on urban water security over the last decade

Ecosystems are impacted when they are utilized to meet human needs (e.g., water supply, food production) (UNEP, 2009). The concern is whether an ecosystem is able to provide such services in a sustainable manner as countries and communities continue to grow, adding to an increase in human impact (UNEP, 2009). Ecosystem services (ES) reflect the benefits that humans obtain from ecosystems. These services are both direct and indirect in nature, some easily recognizable and others subtler. Human well-being fundamentally depends upon these ecosystem services. Changes in ecosystem services can affect the humanity with negative impacts on resource security, health and well-being and the maintenance of social and cultural relations (Mandal et al., 2019).

a. Effect of changes in values of individual ecosystem services on urban water security

Regulating ES: In the Kolkata Municipal Corporation and East Kolkata Wetlands, regulating ecosystem services (ES) which control the effects of natural events such as floods are the most prominent (Figure 5.2.5). Regulating ES are responsible for stability and resilience of the flow of other ES (Carpenter et al., 1998). Decrease in regulating ES which was observed in the Kolkata Municipal Corporation area during the post-monsoon seasons of the total observation period (2009–2019) (Figure 5.2.7) can be linked with the loss of vegetation and inland wetlands in the city area (Figure 5.2.6 and Table 5.2.8) (Suja et al., 2013; Zhou et al., 2014; Mandal et al., 2019). The reduction in values of regulating ES leads to the increase in volumes of surface water runoff and thus increases the vulnerability to water flooding (UNEP, 2009; Mandal et al., 2019).

Provisioning ES: Provisioning ES generally coincide with regulating ecosystem services' function areas (Hack, 2013). Therefore, benefits from a better provisioning ES are defined on-site by the producing ecosystem, such as waterbodies for fish production (Hack, 2013). According to Ravetz et al. (2015), season of the year and temperature influence provisioning ES, as low water level can increase pollutant concentrations in waterbodies. Beyond that, increased temperatures as occurring in the pre-monsoon season boost agricultural production; however, irrigation is required. In the study area, provisioning ES follow the regulating ES. The fluctuations in provisioning ES during the post-monsoon period and sudden increase in the pre-monsoon period of 2019 in the East Kolkata Wetlands (Figure 5.2.5 and Figure 5.2.7) can be linked to economic activities dependent on the varying monsoonal rainfall (Mandal et al., 2019; Ravetz et al., 2015; Chauhan, 2019).

Supporting ES: Values of supporting ES declined in the Kolkata Municipal Corporation and East Kolkata Wetland areas during the last decade (2009–2019) (Figure 5.2.7). This resulted in a decrease of total ES due to the impact of human activities and infrastructure. Human activities include increased urban impervious surface due to construction of buildings which results in hydrologic alteration manifested by (i) increased surface runoff causing flood risk, (ii) reduced evapotranspiration and (iii) decreased shallow and deep groundwater infiltration (Sukhdev et al., 2010). Other impacts include input of pollutants such as sediments, heavy metals, etc. (Sukhdev et al., 2010; Tobias, 2013). This observation also confirms the continuous fragmentation of natural landscapes through urbanization processes due to, for example, transportation and infrastructure projects in the wetland areas, land grabbing due to construction of urban buildings, leisure activity areas such as parks and indoor swimming pools or agriculture (Jaeger et al., 2007; Di Giulio et al., 2009). Supporting ES, acting as intermediate services (Hack, 2013), can be regarded as the underlying ecological structures, processes and functions essential (Ravetz et al., 2015) for producing all other ES (Hack, 2013; Sukhdev et al., 2010; GWP, 2016). As a consequence, the decline of supporting ES has a direct negative impact on biodiversity (Ravetz et al., 2015).

Cultural ES: Further, decreased values of cultural ES in the study area document a reduction in the supply of cultural ES, such as recreation and augmented social cohesion (Kremer et al., 2016). Further, as cultural ES are directly experienced and appreciated by people through ecosystems, thus, unlike other services, cultural ES cannot be replaced if degraded (La Rosa et al., 2016) . This problem is especially crucial within the Kolkata Municipal Corporation and East Kolkata Wetlands because of high population density and constant pressure on the trade-offs between natural ecosystems and people (Kremer et al., 2016).

b. Effect of land use and land cover (LULC) changes on ecosystem services

Ecosystem dynamics are influenced by land use and land cover (LULC), especially in the ecological functions that reflect into values of ecosystem services (ESV) (Figure 5.2.6, Tables 5.2.7 and 5.2.8) (Kindu et al., 2016; Tolessa et al., 2017). Urbanization has been globally the main cause of LULC change, often coinciding with irreparable consequences to the urban ecosystem services (ES) (Ferreira et al., 2019).

Urban settlement: The results of LULC changes (Figure 5.2.3) show that the areal change of urban settlement expansion is not dominant in the Kolkata Municipal Corporation and East Kolkata Wetland areas. Our results show slight seasonal variations in the area under urban settlement. This may be attributed to the mixed pixel problem which is a constraint on estimation of seasonal changes in urban settlement due to the complexity associated with Landsat image interpretation for a megacity like Kolkata (Sun et al., 2020). Expansion of settlement areas affected other LULC classes, especially the vegetation-covered areas and open spaces. In consequence, the pressure on the water security of Kolkata City is predominantly driven by vertical urbanization (Kulkarni, 2016). However, vertical city growth is difficult to detect applying two-dimensional remote sensing approaches as used in this study.

Vegetation: Areas under vegetation (excluding agricultural lands) decreased significantly during the total observation period between 2009 and 2019 contributing considerably to the total ESV. Urban vegetation (excluding the agricultural lands) constitutes the urban green spaces and regulates microclimate (Akbari, 2002), which provides monetary benefits by lowering consumption of the energy sourced mainly from the fossil fuels for air conditioning (Elmqvist et al., 2015; Nicholson-Lord, 2003; Gill et al., 2007). Further, urban green spaces play an important role in regulating rainwater interception by trees, lowering pressure on the drainage system and flood risks (Pataki et al., 2011) and reducing pollution to improve air quality (Escobedo et al., 2011; Escobedo and Nowak, 2009) indirectly improving public health (Mitchell and Popham, 2008; Maas et al., 2006). Therefore, a substantial decrease in urban vegetation negatively directly impacts these monetary benefits as well as non-monetary benefits, such as greater social cohesion and trust, human well-being, sharpened sense of place and sense of identity (Fuller et al., 2007; Brander and Koetse, 2011; Ninan, 2009).

Agricultural lands: Agricultural lands also provide benefits such as regulation of soil and water quality, carbon sequestration, support for biodiversity and non-monetary benefits such as cultural services along with food production as the most important monetary service (Power, 2010). The Kolkata Municipal Corporation area does not have enough space for agricultural lands. Therefore, all the benefits for agricultural lands to Kolkata City come substantially from the East Kolkata Wetland area. The decrease in the area under agricultural lands, therefore, has a direct negative effect on Kolkata City from the perspective of the ESV, as well as of job and food security (Ghosh, 1999; Power, 2010; Chaudhuri et al., 2012). At the same time, a substantial increase in agricultural lands (as we observed during pre-monsoon seasons of the 2014–2019 period) at the expense of inland wetlands can be blamed for raising water insecurity of Kolkata City (Kundu et al., 2008; Chaudhuri et al., 2012; Mukherjee et al., 2018).

Lakes: Within the Kolkata Municipal Corporation and East Kolkata Wetland areas, designated areas for lakes between 2009 and 2019 did not change, but a significant seasonal variation was noticed for water-filled parts of these lakes during the observed period. Moreover, the decreased amount of vegetation in boroughs III and VIII could be linked with the deteriorating water quality of the lake in borough VIII (Figure 5.2.1) (Government of West Bengal, 2006 and 2007; BIS, 2012).

Open spaces: The most unfavorably affected land cover class in the Kolkata Municipal Corporation and East Kolkata Wetland areas is the open spaces which constitute a key element in the provisioning ecosystem services of urban environments from the esthetic and cultural benefits perspective (cultural ecosystem services). Open spaces as regulating ecosystem services also have a strong effect on the urban heat balance (Inostroza, 2014).

Inland wetlands: Inland wetlands support the basal objectives of water security by ensuring both water availability and quality of water (Russi et al., 2013). In consequence, they maintain a key role for increasing water security (Ramsar Convention Secretariat, 2014; Nagabhatla et al., 2017). Inland wetlands provide a range of different ecosystem services (80). They provide regulating ecosystem services by controlling floods, cleaning the city's sewage, protecting and mitigating impacts from storm events (Ramsar Convention Secretariat, 2014). Located in one of the most cyclone-prone zones in the world, the East Kolkata Wetlands are extremely important for the existence of Kolkata City (Kundu et al., 2008; Kundu and Chakraborty, 2008; Sahu and Sikdar, 2008). These wetlands also help in sediment, nutrient retention and export (Sikdar et al., 2002; Sahu and Sikdar, 2008; Sahu and Sikdar, 2009a). Undoubtedly, such wetlands act as reservoirs of biodiversity through providing supporting ecosystem services (Tolessa et al., 2017). Inland wetlands play a role in supplying provisional ecosystem services by purifying wastewater and producing goods through agricultural activities (Sikdar et al., 2002; Russi et al., 2013; Ramsar Convention Secretariat, 2014). We must not forget the cultural values these wetlands offer through recreational, touristic and social cohesion activities providing cultural ecosystem services (Kremer et al., 2016; La Rosa et al., 2016; Tolessa et al., 2017). Moreover, inland wetlands are invaluable to support climate change mitigation and adaptation providing a natural infrastructure that meets the policy objectives for a water-secured city (Russi et al., 2013; Ramsar Convention Secretariat, 2014; Mamat et al., 2018). The major benefits of ecosystem services for Kolkata City are obtained from the East Kolkata Wetlands and borough XII of the KMC which is adjacent to the East Kolkata Wetlands. Therefore, to maintain regional water security, inland wetlands within the KMC area and the East Kolkata Wetlands are the key elements for Kolkata City (WWF, 2014). At the same time, a continuous decrease in the inland wetlands of the East Kolkata Wetlands may lead to the loss of status of a Ramsar site in the near future (Chaudhuri et al., 2012).

ii. *Availability and quality of surface and groundwater in relation to land use and land cover changes*

The results of water quality analysis of surface water imply that the quality is almost undesirable for the intended use. The major drinking water supply in the Kolkata Municipal Corporation area depends on the treated surface water of the River Hugli. A big portion, particularly in the added areas in the southern parts of the Kolkata Municipal Corporation area, are deprived of this water supply. Drinking water supply in these deprived areas depends on groundwater (Mukherjee et al., 2020). Therefore, availability, physical accessibility and quality of groundwater are also important issues for the Kolkata Municipal Corporation area's water security (Mukherjee et al., 2018; Mukherjee et al., 2020). Groundwater extraction by tube wells immediately beneath the settled area is still a common practice, especially in slum households and condominiums around the periphery of the city (Mukherjee et al., 2018). According to the Kolkata Municipal Corporation 2015 report (Basu, 2016), Kolkata City (the entire Kolkata Municipal Corporation area) officially counted about 12,000 hand-pumped tube wells, predominantly found in slums (Basu, 2016; Singh, 2019). The groundwater in the Kolkata Municipal Corporation area faces high levels of manganese ($Mn > 0.3$ mg/L^{-1}) and iron content (Fe; up to 23 mg/L^{-1}) which can induce serious ailments (McArthur et al., 2018; Singh, 2019). In general, increased solute concentrations in the groundwater are related to industrial activities, sewage effluent and unregulated groundwater extraction (BCGWA, 2007; McArthur et al., 2018; Wagh et al., 2019; Banerjee and Sikdar, 2020). Further analysis for arsenic (As) in the groundwater samples from across the Kolkata Municipal Corporation area failed to meet the permissible limit set by the Bureau of Indian Standards (BIS, 2012) due to As concentrations > 10 μg/L^{-1} in few samples (McArthur et al., 2018). The As present in the groundwater of Kolkata is anthropogenic in origin, unlike in other areas of the Bengal Basin where it is geogenic in origin (McArthur et al., 2018).

Unregulated groundwater withdrawal has resulted in the development of local groundwater mounds and troughs in and around the East Kolkata Wetlands where the regional topography is otherwise flat. The water quality of that area is dependent on these groundwater mounds and troughs that affect the groundwater flow pattern and distribution (McArthur et al., 2018). About 800 million liters of wastewater purged daily from Kolkata are naturally treated through these wetlands (Sahu and Sikdar, 2008). Leaching of pollutants from this wastewater of the city containing a mixture of domestic and industrial effluent loaded with high amounts of heavy metals is accelerated due to growing overwithdrawal of groundwater for domestic, irrigation, industrial and commercial needs. This exposes the aquifer below the East Kolkata Wetlands to contamination and affects water quality of the wetland aquifer (Sahu and Sikdar, 2008; Sahu and Sikdar, 2009b) from where groundwater is extracted in large volumes for agricultural use (Chakravarty, 2007).

The parameter outputs of the water quality index scores of the surface waters show that in all surface water samples, the total coliform count is high. Dissolved oxygen (DO) and pH values did not pass the quality standards set by CPCB-1992 (Table 5.2.5) (41). In case of inland wetlands, along with pH, DO and total coliform count, biochemical oxygen demand (BOD) values are above the threshold value for the bathing water set by CPCB-1992 (Table 5.2.5) (BIS, 2012). In consequence, surface water samples analyzed also did not meet the BIS-2012 drinking water quality standard. The input of fecal matter and nutrients from point and extensive sources into aquatic ecosystems affects the surface water's pH values, DO concentrations and oxygen consumption values as well as bacteria concentrations (Ternus et al., 2011). This also suggests that, like in most urban areas, the major problem is the discharge of point sources to surface waters (Daniel et al., 2002; Ternus et al., 2011; Sridhar and Kumar , 2013; McGrane, 2016). However, being in the area of influence of tides, DO concentrations as well as concentrations of alkali and alkaline earth metals increases in the canal water during high tides driven by the influence of seawater (McArthur et al., 2018). Clear differentiation of the origin of the major cations and anions either from sewage water or seawater is not possible (Daniel et al., 2002; McArthur et al., 2018).

Rapid urbanization has degraded the conditions of the canal system of Kolkata of which Adi Ganga or the Tolly's Nullah is a prime example (Basu, 2012; Das et al., 2015; Sarkar, 2017). Apart from the regular tidal influence which is also disrupted by newly constructed elevated Metro railway lines, the water in the canal does not have any flow and it has black color and stinking odor (WBPCB, 2017). The sewage effluents to this canal system contain predominantly domestic wastes from the surrounding area, animal remains from slaughterhouses and crematory wastewater (Sarkar et al., 2007). It has been estimated that humans and animal excreta cause a large portion of the fouling of the canal water flowing along the slum areas (Sarkar et al., 2007). Lack of sewage systems and overflow of sewage caused by heavy rainfall events introduce a large amount of sewage into the canal system. Isobe et al. (2004) (Isobe et al., 2004) document high values of linear alkaline benzenes (LAB3) with concentrations of 4.45 mg g^{-1} dry wt. in bed load sediments of the Adi Ganga Canal (Figure 5.2.2). The drainage system in the Adi Ganga Canal waterways has been choked due to high siltation and dumping of garbage including non-degradable wastes (Sarkar et al., 2004). McArthur et al. (2018) showed that groundwater of 33% of the public wells (median depth = 91 m) and 14% of municipal wells (median depth = 121 m) is contaminated by chloride (Cl) from the sewage effluent. The anthropogenic Cl has been drawn down to below 110 m depth by pumping (McArthur et al., 2018).

iii. Urban Environmental Water Security Index (UEWSI) and its spatial variations

The Urban Environmental Water Security Index (UEWSI) scores (Figure 5.2.13) reveal the issues with urban water security in the core areas of the Kolkata Municipal Corporation (KMC) area, especially in the most populous northern areas (Mukherjee et al., 2018). These northern boroughs (I–VI) of the Kolkata Municipal Corporation have a higher number of slums than the rest of the city areas as well. Slum areas are more vulnerable to water insecurity than non-slum areas as they lack the basic provision of water and sanitary infrastructure (Mukherjee et al., 2020). In contrast, at present, the southern boroughs (VII–XVI) are more stable in water security, but following the increase in urbanization in the area, these boroughs may lose their water security in the near future if proper management is not introduced on time. The urbanization is highly visible along the bank of the River Hugli; these urbanization processes have a dynamic influence on the spatial pattern in LULC (Shaw and Das, 2017) changes which predominantly result in a reduction of ecosystem service values. Mondal et al. (2017) suggested that the presence of the East Kolkata Wetlands in the east of the megacity limited the urbanization in the eastern part of the Kolkata Municipal Corporation. The entire East Kolkata Wetlands is considered to have peri-urban nature which continues beyond the eastern boundary of the EKW as evident from satellite imagery (Figure 5.2.1). The overlapped areas of the East Kolkata Wetlands within the Kolkata Municipal Corporation jurisdiction, particularly boroughs VII and XII, are newly added areas having peri-urban characteristics under sporadic urbanization (Mukherjee et al., 2018). Consequently, boroughs along the eastern border of the Kolkata Municipal Corporation area (boroughs VII and XII) show higher UEWSI scores than the other boroughs of the Kolkata Municipal Corporation area. These higher UEWSI index scores of boroughs VII and XII result from their proximity to the East Kolkata Wetlands.

The spatial distribution of UEWSI scores (Figure 5.2.12) documents the strong influence of the East Kolkata Wetlands located in the periphery of the Kolkata Municipal Corporation area, both in terms of providing livelihoods and products and in making use of a natural source of water (Mondal et al., 2017; Pal et al., 2018). The wetlands serve as a carbon sink with their greenery and water bodies and, in addition, they support purification of the Kolkata's sewage water (Pal et al., 2018). In the East Kolkata Wetlands, Everard et al. (2019) identified a wider diversity of services across all categories of ecosystem services. Among them, water purification and flood regulation significantly serve to secure Kolkata's water security directly. At the same time, provisional ecosystem services in terms of agricultural production (mainly food and flower production) benefit city dwellers in terms of the betterment of the quality of their city lives (Everard et al., 2019) by providing locally generated products (Bolund and Hunhammar, 1999). Mondal et al. (2017) showed that 14 km^2 of the wetland area of the East Kolkata Wetlands were transformed into urban settlement between 2000 and 2011; due to the vast completion of this process in the first decade of the 21st century, this transformation is not recorded in the study at hand. Beyond that, wetland loss was observed in the study area during 2009–2019, mainly because of continuous urban expansion in the Kolkata Metropolitan area potentially compromising the overall sustainability of Kolkata City itself (Parihar et al., 2013). Mondal et al. (2017) projected that only 39% of wetlands within the existing East Kolkata Wetlands will remain in place by 2025 if the current trend of urbanization continues. Complementary, the results of our study show a decline of ecosystem services in the Kolkata Municipal Corporation's urban areas over the entire observation period of 2009–2019.

5.2.5. Limitations

This study attempts to link the advantages of urban and peri-urban ecosystems to water security of a megacity, applying the method of valuation of ecosystem services. There is a variety of detailed direct and indirect methods for estimating values of ecosystem services which may produce higher accuracy and precision with a demand of precise and adequate empirical data (Costanza et al., 1997; Mamat et al., 2018; Costanza et al., 2014). Keeping this fact of lacking adequate data, our study can be considered as a crude initial estimation based on a simple benefit transfer method proposed by Mamat et al. (2018). According to them, "one of the disadvantages of this ESV estimation is its vagueness, especially because the uncertainty of the value coefficient and the spatial, biophysical, and socio-economic heterogeneity were not considered'' (Mamat et al., 2018). Secondly, we did not find any ESVs that are unique to the EKW. Perhaps, in the next phase, while considering the local valuation methods, this can be estimated with precision and adequate accuracy. This is certainly a limitation of the study, but not from the perspective of objectives set for the research. Here, we wanted to show the distribution of changes of the ecosystem service values (ESV) quantitatively, using a standard global value coefficient. Detailed survey, generation of participatory data and valuation techniques considering the heterogeneity and complexity of nature/human systems can reduce the uncertainty and generalization in the future research.

5.2.6. Conclusions

The transformation of land use and land cover (LULC) of the Kolkata Municipal Corporation and East Kolkata Wetland (EKW) areas has confronted water insecurity. It is examined in this study during pre-monsoon and port-monsoon seasons of 2009, 2014 and 2019 and we have derived major conclusions. For the calculation of the UEWS index and to discuss the dynamics of spatiotemporal changes in LULC, ES values and water quality, a thorough temporal analysis is needed. Therefore, an additional year in between 2009 and 2019 was necessary to explore the continuity of these changes even at the slightest portion. In the UEWS index, we incorporated the intensity indices, which require yearly changes in areas of LULC classes for both pre-and-post-monsoon seasons. We emphasized this precision in order to create and analyze the distribution of UEWS index values across the city. Even small changes in LULC classes have a substantial effect on the resultant ES values, for example, in open spaces or lake areas. The study aimed to explore the dynamic relationship between the changing pattern of LULC, ES values and water quality from a holistic water security point of view. Therefore, the global value coefficient for ES proposed by Costanza et al. and modified by Mamat et al. (2018) was taken into consideration after careful review of the literature for the calculation of ES. It also paved a path for future research to calculate local ES values and analyze ES for water security studies. This is a novel approach to amalgamate quantitative variables and processes (LULC changes, ES valuations, water quality index) together to get a resultant effect as urban environmental water security which can be quantified and analyzed further.

This study shows that it is impossible to disregard the role of peri-urban wetlands and the benefits or services from their ecosystem for securing a city's water and environmental security. In fact, for megacities like Kolkata, the need is stronger. The process of rapid urbanization has blurred the distinction between the "urban" and the "peri-urban" zones which used to play a role of an intermediary between urban and rural areas. There is a need to understand and document social, economic and institutional characteristics of peri-urban regions in a better way. An understanding of these unique characteristics is essential to develop new and innovative ways of addressing peri-urban challenges, cutting across the frontiers of rural and urban governance. The unplanned and unregulated development process in the Kolkata Municipal Corporation area has proved to be quite unsustainable and has turned out to be a serious threat to the city and its environment. The growth has affected basic amenities, especially water supply, for the increasing population in the newly developing areas. Peri-urban wetland areas of Kolkata City are under stress because of expanding urban settlement which hampers the natural water cycle and its regulatory functions. This compromises the natural protection of controlling floods, recharging the shallow aquifer and natural waste management of the city itself. The entire transformation may introduce new pollutants such as wastewater, arsenic or pesticides ultimately affecting the entire water security of the urban area.

River Hugli is the main source of drinking water for Kolkata, and it is the main distributary of the River Ganga since ages. Historically, this river has been the lifeline of this megacity in the eastern hemisphere. We did not consider the stretch of the river while calculating the ecosystem service valuation as there was no recent change in the course of the River Hugli. Rather, we considered its water quality issues in the analysis which is crucial for discussing Kolkata's water security. The Ganga–Hugli river system contributes significantly towards the transport of pollutants of the coastal areas of the Bay of Bengal. The deterioration of water quality is closely related to inefficient water management, non-functioning of wastewater treatment facilities and lack of environmental planning and coordination. Coliform counts in the river water sampled result from microbial contamination by municipal waste sources. Results of the water quality study show that most physiochemical features may be appropriate for domestic water supply after traditional water treatment. However, bacteriological quality observations revealed a high degree of contamination from domestic and animal wastes.

We require more research on critical water-related ecosystem services to encourage additional policy momentum, business commitment and investment in the conservation, restoration and wise use of wetlands. They must show how recognizing, demonstrating and capturing the local values of ecosystem services related to water and wetlands can lead to better informed, more efficient and fairer decision-making for sustainable urban planning. It is evident from the literature that the poorer sections of the society suffer the most when biodiversity is lost, as their survival depends on the multitude of nature. When wetlands are destroyed, the nature's water cycle and its ability to provide water for households and farms are disrupted, and the suffering of the poor exacerbates inadvertently. Thus, restoration and protection of the water environment is vital to address today's most pressing challenges of water and food security, climate change and poverty in urban spaces.

Struggle against climate change will set off substantial opportunities for the economy, specifically in the Global South. We should adopt circular production systems in a water-efficient way. As the global population grows, so does the demand for water, settlement and urban infrastructure development. These, in turn, deplete natural resources and damage the environment in many places. Solutions include protecting carbon sinks such as green cover and wetlands, adopting climate-smart agricultural techniques, rainwater harvesting and artificial recharge and increasing the safe reuse of wastewater in urban areas. Water is our most precious resource—we must use it more conscientiously. The significant trade-off between the mankind's water needs and water security will protect everyone from being left behind. In this context, it is also important to determine how much water the ecosystem needs to ensure its own water security within an urban space. Urban water security research needs to go deeper to learn how complex ecosystems behave at vastly different scales and under the stresses of changing patterns of climate and water availability along with the increasing water demand. This approach is the first of its kind applied to both the KMC and EKW areas. From this study, we found that the regulating ecosystem services have the highest contribution to the monetary values. Therefore, the regulating ES must be given preference for protecting Kolkata City's water security. This should be given priority while framing the policy and planning framework for the sustainable management of both the city and its peri-urban areas.

5.3. Case study 3

An integrated quantitative assessment of urban water security of Kolkata, India: An inclusive approach[5]

Abstract

Water security will remain a hugely important issue over the next decade and is a matter that will be exacerbated by climate change and related hazards, food insecurity and social instability. Despite attempts made by many researchers and water professionals to study different dimensions of water security and urban dynamics, there is still an absence of comprehensive water security measurement index. This study aims to untangle the interrelationship between biophysical and socio-economic dimensions that shape the water security in Kolkata, a megacity in India. It provides an interdisciplinary understanding of urban water security by extracting and integrating relevant empirical knowledge on urban intersection and water issues in the city from physical, environmental, and social sciences approach. We also use intersectional perspectives in relationship with urban water security at a micro (respondent) level and associated challenges. Based on surveys and secondary datasets, the study carries out quantitative analysis and presents findings. This study further recommends future research guidelines that include the need to comprehend the possible alternatives to the existing water policies towards a sustainable water secure future 'leaving no one behind'.

Keywords: Water security, water scarcity, water access, governance, intersectionality

5.3.1. Introduction

Water security is defined as 'the availability of an acceptable quantity and quality of water for health, livelihoods, ecosystems, and production, coupled with an acceptable level of water-related risks to people, environments, and economies' (Grey and Sadoff, 2007, p. 548), which embodies a complex, multi-dimensional and interdependent set of issues (Wheater, 2015). Water Security, therefore, represents multiple challenges associated with 21st century water management (Cook and Bakker, 2012). The concept of water security conforms to the concept of Sustainable Development that meets the needs of the present without conceding the ability

[5] Mukherjee, S, Sundberg, T, Sikdar, P.K. and Schütt, B., 2021. An integrated quantitative assessment of urban water security of Kolkata, India: An inclusive approach (Draft of a journal article; status: Internal review)

of future generations to meet their own needs (UN, 2015). As Sustainable Development, Water Security has three primary dimensions: environmental, economic, and social (Giddings et al., 2002). To achieve this “sustainability and security” with water, all these dimensions should be addressed. While water scarcity has historically been more severe in rural areas, emerging research has shown a worsening availability and quality in urban areas (Mukherjee et al., 2020; Mukherjee et al., 2021a; Cook and Bakker, 2012; Mohan et al., 2011; Maiti and Agrawal, 2011). From the rapidly changing urban perspective, the dimension of water security includes a focus on the need for organizational and institutional flexibility to address increasing uncertainty and change, a need for social capital and adaptive governance, and the need for engagement with stakeholders in knowledge exchange (Wheater, 2015). Thus, the interface between the scholars, practitioners and stakeholder communities has been increasingly important for the measurement and management of Urban Water Security (UWS) (Wheater and Gober, 2014).

UWS here relates to both the physical-environmental, and societal barriers to access, availability, and quality of water for drinking, food production, hygiene, and sanitation (Obani and Gupta, 2016). Water security is a human rights issue recognized by UN’s sustainable development goal 6 (SDG) (Mukherjee et al., 2020). The Human Right to Water and Sanitation (HRWS) was recognized as a human right by the United Nations General Assembly on 28 July 2010 (UN, 2010). Social inequities in cities play an important role in water and sanitation-related risks – with informal settlements and socially deprived areas generally having lower levels of water security than other parts of the city (WHO, 2020). Marginalized groups, which include women, children, refugees, indigenous people, disabled people, and many others, are often overlooked, and sometimes face discrimination, as they try to access and manage the safe water they need (Mukherjee et al., 2020). For example, gender roles and relations can be important explanatory factors for water access, needs, and use are shaped by gender roles and relations in every society (Wallace and Coles, 2005; Ray, 2007). Water security risks are higher among women and transgender people (Denton, 2002; MacGregor, 2009; Demetriades and Esplen, 2010). Water insecurity includes vulnerability due to natural disasters like floods and droughts. In addition, it influences and is influenced by socio-economic pressures – which leads to increased water insecurity for marginalized groups, including women, girls and trans individuals (Saravanan, 2010). For transgender people, despite of accordion of the Supreme Court of India in 2014, the community is still waiting for gender-neutral public toilets (Gopalakrishnan, 2016). Pangare (2016) argues that water security for the poor cannot be achieved without considering socio-economic factors as a determining issue (Pangare, 2010; WWAP, 2019).

Previous studies in different disciplines have highlighted that vulnerabilities and experiences of water security vary according to a range of bio-physical and socio-economic factors (Mukherjee et al., 2021a). Water Security in relation to population size and growth has been the focus of many studies from the 1990s (Cook and Bakker, 2012; Vörösmarty et al., 2000). Recent studies have demonstrated the development of numerous definitions and assessment frameworks for water security over the past decade (Denton, 2002; Lundqvist et al., 2003; MacGregor, 2009; Demetriades and Esplen, 2010; Pangare, 2010; Vorosmarty et al., 2010; Sullivan, 2011; Truelove, 2011; Aihara et al., 2015; Muller, 2016; Romero-Lankao and Gnatz, 2016; Thompson, 2016; Harris et al., 2017; Hellberg, 2017; Allan et al., 2018; Castán Broto, and Neves Alves, 2018; van Ginkel et al., 2018; Aboelnga et al., 2019; Shrestha et al., 2019; Aboelnga et al., 2020; Sultana, 2020). It is proven that UWS is driven by a complex set of biophysical and social factors – which needs to be dealt with together, rather than independently. However, there is still no agreed-upon understanding of how to hypothesize and quantify an assessment framework to measure the current state and the dynamics of water security particularly at the urban level (Mukherjee et al., 2021a).

The existing measurement frameworks of UWS have been conceptualized in various ways; some focus on risks, while others have adopted broader aspect with a focus on the management of water as a resource for fulfilling human needs only [Clement, 2013; Giordano, 2017; Garrick and Hall, 2014). Several studies have stressed the lack of quantitative and comprehensive assessments of UWS and applications that can be used at the micro level (Grey and Sadoff, 2007; Cook and Bakker, 2012; Srinivasan et al., 2017; Mukherjee et al., 2021). Moreover, some studies show that given the difficulties and shortcomings associated with accurately measuring the proportion of the population without access, it is probable that the proportion thought to have access is grossly overestimated (Adams, 2017; Nganyanyuka et al., 2014; Satterthwaite, 2016). These indicate the considerable disparity in dynamics of UWS to address urban water challenges effectively and provide decision-makers with robust policy instruments and measures to achieve UWS from the bottom-up approach (Allan et al., 2018; Rouse, 2013). It is therefore important to cultivate the concept behind the assessment frameworks to better understand disparities in everyday water-access and practices across different scales especially for all in an urban setup.

The approaches of quantitative assessment and the corresponding dimensions and issues of urban water mentioned in the previous studies are summarized in appendix 5.3A. This list shows that any attempt to assess UWS needs to consider the intersecting characteristics of bio-physical environment, society, and communities together along social, economic, ethnic, religious, caste, gender sexuality characteristics – to ensure inclusion across divisions and levels of insecurity (Sullivan, 2011; Truelove, 2011; Thompson, 2016; Harris et al., 2017; Hellberg, 2017; Castán Broto, and Neves Alves, 2018; Sultana, 2020). This study, therefore, aims to assess UWS from a quantitative bottom-up approach which will include the factors behind these multiple intersections in an Indian megacity comprehensively (Mukherjee et al., 2021a). Therefore, the objective of this study is to develop a novel quantitative assessment framework of water insecurity in urban areas to address the complex intersectionality present between bio-physical and social dimensions (for details see Mukherjee *et al.*, 2021a) and their interrelationships.

5.3.2. Study area

Kolkata city (22°28′00″–22°37′30″ N and 88°17′30″–88°25′00″ E) is the capital of the state of West Bengal (Figures 1 and 2). The city area which under Kolkata Municipal Corporation (KMC) covers about 205 km^2 area with a population of 4,496,694; of which male and female are 2,356,766 and 2,139,928 respectively, as per the Census-2011 (KMC, 2012). The entire KMC area is now divided into 16 boroughs or administrative blocks having 21 assemblies and 3 parliamentary constituencies and 144 wards. The density of population is 24,760 km^{-1}. Ratio of population is 956 females for every thousand males, where the literacy rate is 81.31%. Every day, about 6 million people (floating population) come to Kolkata for work, business, and other purposes (Mukherjee et al., 2021a). Within KMC area, there are little more than 1 million households (KMC, 2012). The Census-2011 of India shows that one third of the total population of KMC live in semi-permanent houses within 5600 (c. 1.141 million residents) deprived areas called slums (officially known as 'Basti') comprising a total area of 25.95 km^2 (Mukherjee et al., 2020). Most of these houses do not have direct piped water supply or toilets (Mukherjee et al., 2020). The number of public toilets in whole KMC area is 375 of which, only 14 are transgender inclusive. The statistics of boroughs of KMC are given in appendices 5.3B and 5.3C.

The city is situated on the east bank of River Hugli in the famous deltaic Bengal Basin, the largest one in the world developed by the action of Ganga-Brahmaputra river system and nearly 120 Km away from the Bay of Bengal. Kolkata forms a part of the lower deltaic plains of the Ganga-Bhagirathi river system. It is a typical deltaic flat land with surface elevation ranging between 3.5 and 6 m above mean seal level (Mukherjee et al., 2018). Several low-lying depressions in the form of marshes, shallow lakes occur within the city and most of these represent river scars of the paleo-river channels of Bhagirathi. The master slope of the land is towards south. Geomorphologically the area can be divided into fluvial plain, tidal flat, natural levee and aggravated channels (Das and Chattopadhyay, 2009). Deltaic plain, inter-distributary marsh, paleo-channels and younger levee adjacent to River Hugli and older levee on both sides of the old Adi Ganga are the important geo-morphological units present in the area. The area is covered with younger alluvial soil mainly of silty and clayey loams (KMC, 2012; Das and Chattopadhyay, 2009). It has also been one of the most water-rich cities of India, because of the presence of the River Hugli (Ganga) flowing beside its western end. It is also blessed with a huge groundwater reserve and wide wetlands areas in its eastern side which naturally treats its wastewater and turns that as raw water for other economic activities in the primary sectors, e.g., fishery and agriculture. However, all these advantages are now running into a deep trouble in terms of water (in)security in Kolkata (Mukherjee et al., 2018).

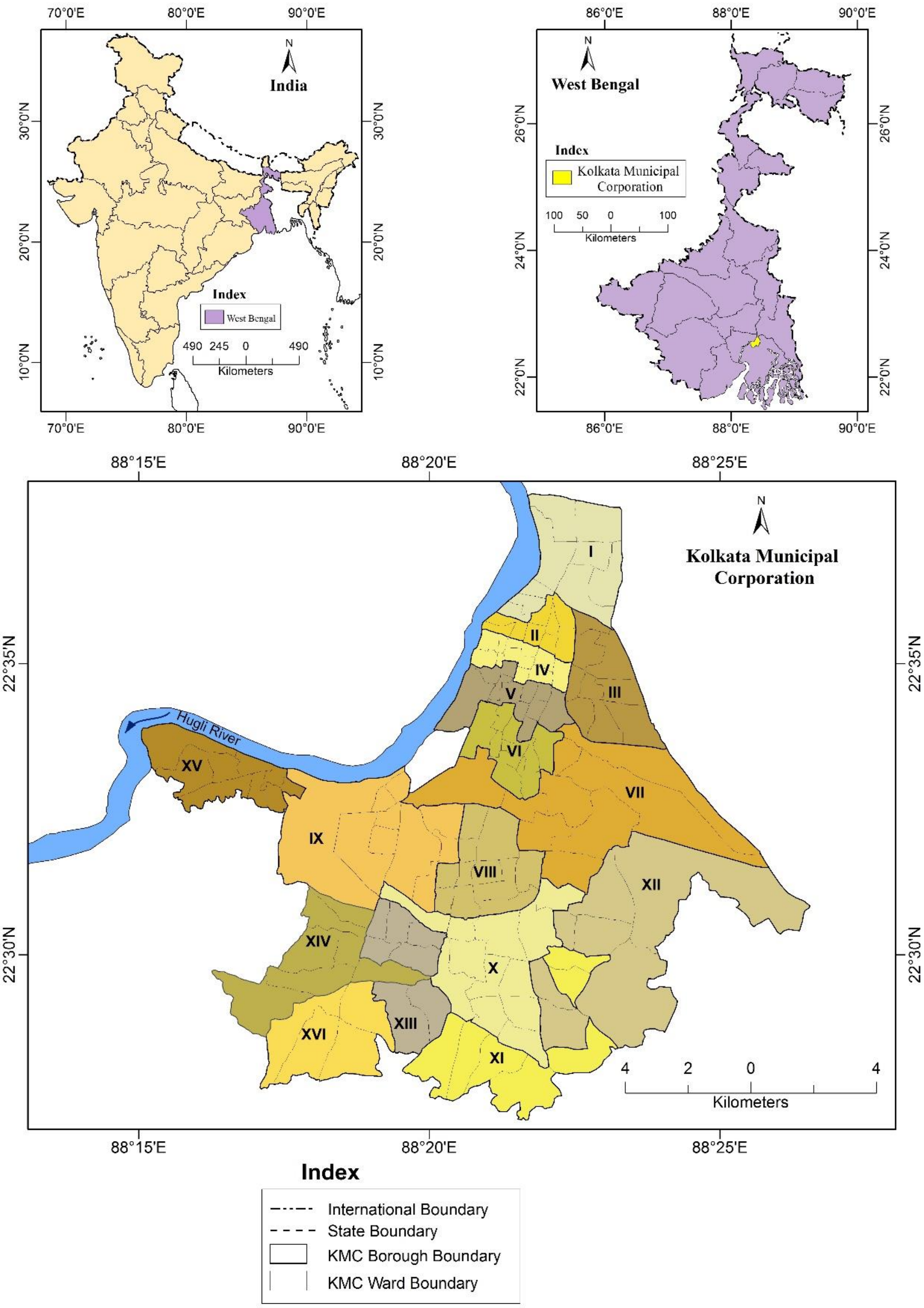

Figure 5.3.1. Location of Kolkata Municipal Corporation (KMC) boroughs (featuring the wards associated in a borough) within West Bengal, India. Roman numbers mark the borough numbers. Data source: Mukherjee et al., 2018.

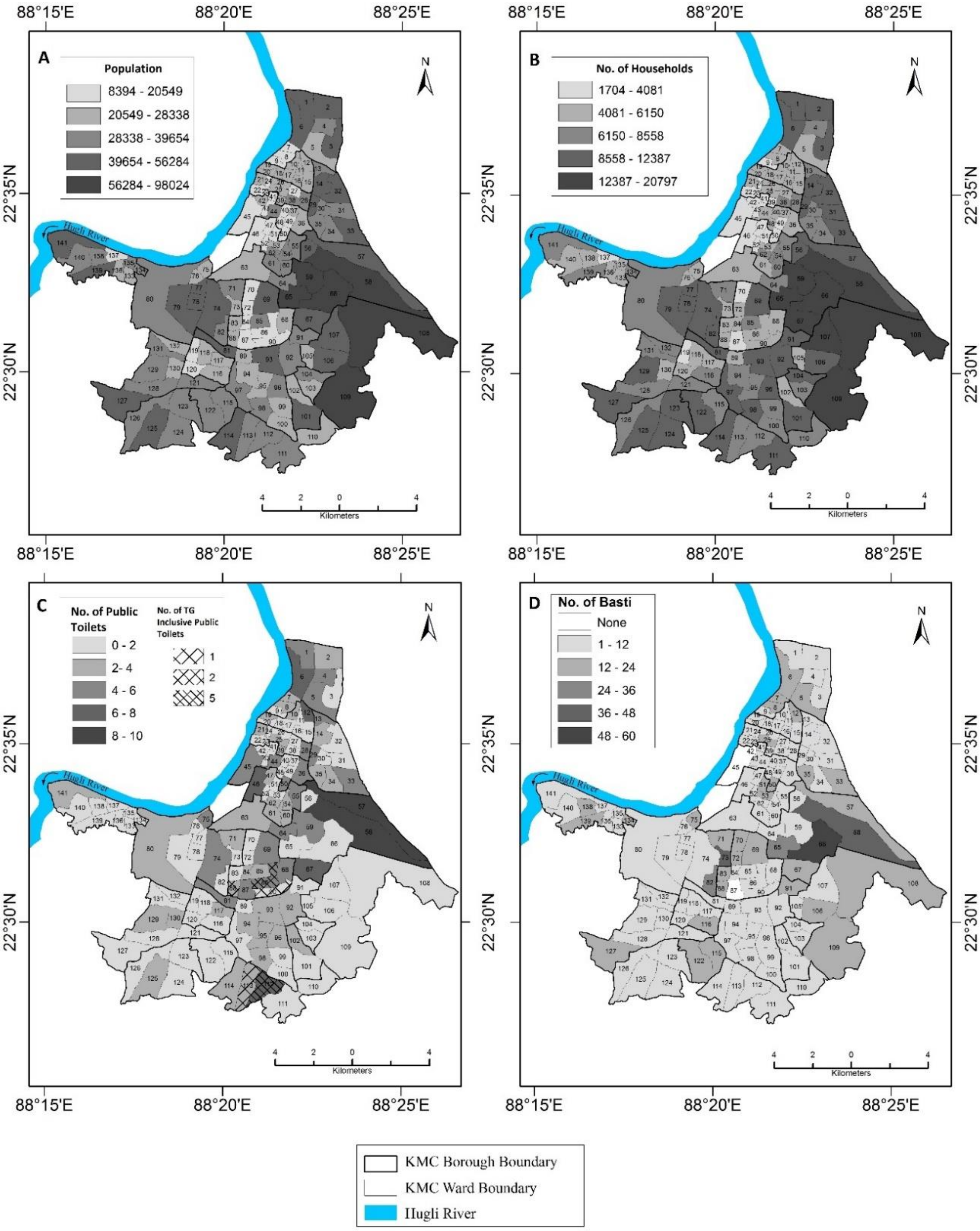

Figure 5.3.2. Demographic features of the Kolkata Municipal Corporation (KMC) area (ward wise): A) Population, B) Number of households, C) Number of public toilets along with number of Transgender (TG) inclusive public toilets, and D) Number of basti. Data source: Census of India, 2011; Department of Slum Development and Department of Water Engineering, Kolkata Municipal Corporation, India.

5.3.3. Methods

i. Data

a. Primary data: Household survey

The primary data is based on a household survey using Stratified Random Sampling method. Data were collected from 45 households from each of the Boroughs of Kolkata Municipal Corporation (KMC) area. Altogether 720 households were surveyed within November-December 2018.

Based on the definition of 'Water Security' by Grey and Sadoff (2007), this study constructs an Urban Water Security assessment framework to score 4 major components of water security: water availability, water accessibility, water quality and water risks and hazards. The details of each variable are given in the appendix 5.3D.

The Survey questionnaire (Appendix 5.3D) forming the basis of the household survey consists of 48 questions divided into 5 segments. The first 4 segments are differentiating issues of (32 questions) 4 components of water security (*Water Availability*: 11 questions, *Water Accessibility*: 8 questions, *Water Quality*: 2 questions and *Water Risks and Hazards*: 11 questions). The last segment includes demographic data (16 questions) assemblage to reflect the social aspects of water security in the city's neighbourhood which includes information on socioeconomics such as income, literacy, gender, religion, and ethnicity (based on language spoken) statistics. The four components of water security are:

- ***Water Availability*** which encompasses the physical availability of water and presence of toilet in the house, other options to fetch water from, the number of users and the way of waste management.

- ***Water Accessibility*** which includes the intersectional characteristics of water security in the house focusing on the gender dimension of the users. This component also questions on the WaSH provision.

- ***Water Quality*** comprises the reason for using different sources of water for drinking and other household tasks.

- ***Water Risks and Hazards*** cover the risks related to physical/meteorological hazards such as flood and human-health hazards, i.e., water-borne diseases.

These 4 components cover all relevant aspects of the integrated urban water security index as well as, together with socio-demographic indicators form the assessment framework. We combined environmental (bio-physical) and socioeconomic indicators (Hoekstra 1998; OECD 2016; Van Leeuwen and Chandy, 2013) for each of the water security components, which grouped first into the water security component-scores (at the respondent level) and then aggregated into ward level scores and finally averaged into brough level scores to create the Urban Water Security Index at the borough level.

Due to the ethnic and linguistic diversity of Kolkata, interviewers with a range of language spoken, socio-economic and ethnic background were recruited, allowing us access and higher levels of rapport with respondents who we otherwise would not have been able to interview due to distrust with members of higher caste/different ethnicity etc. Any time a suitable sample is used, it may confound the analysis because subjects were chosen based on availability rather than being representative of the full population. The interviewers undertook training to ensure they learnt about the crucial (both bio-physical and social) dimensions of water security. Further, to ensure they were fully trained both on interviewing skills; they were trained how to avoid bias as well as ethical issues that may arise during an interview. Survey training activities were also particularly important to maintain survey quality and gender sensitization because our survey included the entire gender spectrum to be notified on record. Interviews were conducted based on the availability of respondents, which might affect how representative the sample is. The average survey response rate across the city was about 80% which varied across the study area.

b. *Secondary data*

Alongside, the survey data, secondary data were collected from the Department of Water Investigation and Department of Urban Development of Government of West Bengal.

Additionally, the data from the Kolkata Municipal Corporation (KMC) (Department of Slum Development, Department of Water Engineering), West Bengal Pollution Control Board (WBPCB) and Kolkata Municipal Development Authority (KMDA) were also collected. These data contained information on the components of water security within Kolkata Municipal Corporation (KMC) area.

ii. Data processing

a. Initial data processing

We assigned variables' scores on a 0 to10-point scale (as Security status where 0-2 denotes 'Very Insecure', 2-4 denotes 'Insecure', 4-6 denotes 'Around acceptable threshold' and 8-10 denotes 'Very Secure' state of UWS). The nomenclature of these score ranges is deemed from the 'Urban water security dashboard' proposed by Ginkel et al. (2018) where they used a 1-5 level scale. The scores were based on the direct numerical information (such as presence/absence of the facility), respondent's perception, data collected from the Kolkata Municipal Corporation and other Governmental institutions and related literature. Aggregation from each level to the next was done by calculating the arithmetic mean. Finally, the borough level scores of the 4 components of water security were further combined into one water security index (borough level), which determined the final ranking of the KMC boroughs.

b. Principal Component Analysis (PCA)

Principal Component Analysis (PCA) allows us to identify principal components and correlations within the data, and thereby is a way of identifying patterns and components that enhances our understanding of water security (Raschka, 2015). In this case, it helps us identify the crucial components of water security and create an index to measure it (Aihara et al., 2015; Shrestha et al., 2018).

Principal components are the eigen vectors of a variance–covariance matrix (Raschka, 2015). The methodology involves three steps: (i) standardization of the raw data in terms of a zero mean and a unit variance and computation of the variance–covariance matrix; (ii) computation of a set of mutually orthogonal principal component axes (the elements in each axis referred to as ''loading'') which are actually the eigen vectors of a variance–covariance matrix, the corresponding eigenvalues denote the proportion of variability accounted for by the respective

PC axis, which decrease from the first principal component to the last and (iii) computation of a set of PC scores for each of the varimax-rotated factor PC axis, corresponding to individual samples (Raschka, 2015). Each of the PC axis or factors (with high loadings on one or more variables) may be representing an independent source of variation in the data (Vyas and Kumaranayake, 2006). The first principal component is selected as the linear index of all the variables that captures the largest amount of information common to all the variables which may then be used as the index (Filmer and Pritchett, 2001). This approach allows the determination of the most appropriate weightings for each variable to derive an index which captures maximum variation (Filmer and Pritchett, 2001; Vyas and Kumaranayake, 2006; Raschka, 2015; Shrestha et al., 2018).

iii. Calculation of Urban Water Security Index

Urban Water Security Index (UWSI) scores have, therefore, been calculated integrating scores of variables of *Water Availability, Water Accessibility, Water Quality* and *Water Risk and Hazards* variables from the survey data collected across the city. Here the objective is to analysis the interrelationship between UWSI scores and socio-demographic parameters (such as gender, religion, monthly income, caste, ethnicity, occupation, education, and household type) within boroughs across the city.

The Urban Water Security Index (UWSI) at the borough level was calculated as:

$$UWSI = (Avl*w1) + (Acs*w2) + (Wqt*w3) + (Wrh*w4) \quad \ldots Eq1$$

where,
Avl = Score for *Water Availability* variables
Acs = Score for *Water Accessibility* variables
Wqt = Score for *Water Quality* variables
Wrh = Score for *Water Risk and Hazards* variables, and,
w1, w2, w3, w4 are the weights assigned (determined by the ''loadings'' of PCA 1) for each variable.

Finally, the UWSI scores were used to categorize each borough on the 0–1-point scale (Category of security status) classifying the status of urban water security, as follows:

8-10: Very Secure

6-8: Secure

4-6: Around acceptable threshold

2-4: Insecure

0-2: Very Insecure

iv. Interrelationships between UWSI and socio-demographic variables

Indicator scores were aggregated to an UWSI to the borough level. We then studied the coherence between UWSIx's scores and the sociodemographic characteristics of the Kolkata Municipal Corporation area, through statistical analyses (Pearson's correlation and crosstabs-contingency tables) using SPSS.

5.3.4. Results

i. Results of Principal Component Analysis

The respondent levels aggregated values of 4 water security components were considered for Principal Component Analysis (PCA) that split the indicators into 4 principal components (PCs). Each of the PCs explained data variation between 13.02 and 36.23% and accounted for 100% of the total variance (Table 5.3.1). In the analysis of the variables described above, the resulting first principal component explained 36.23% of the variability in the data, while PC2 explained 27.58% of the variance. Rest of the PCs (PC3 and PC4) accounted for >10-20% of the variation. Communalities statistics revealed that, >70% of the variance can be explained by the factor in *Water Availability* and *Water Accessibility*, >60% of the variance for *Water Quality* variables and >45% of the variance in *Water Risk and Hazards* variable (Table 5.3.2).

Table 5.3.1. Total variance explained.

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	1.45	36.23	36.23	1.45	36.23	36.23	1.43	35.72	35.72
2	1.10	27.58	63.82	1.10	27.58	63.82	1.12	28.10	63.82
3	0.93	23.16	86.98						
4	0.52	13.02	100.00						

Extraction Method: Principal Component Analysis.

Table 5.3.2. Communalities.

	Initial	**Extraction**
Water Availability	1.000	.742
Water Accessibility	1.000	.738
Water Quality	1.000	.614
Water Risk and Hazards	1.000	.458

Extraction Method: Principal Component Analysis.

Table 5.3.3. Factors' loadings (Rotated Component Matrix) of the first and second principal components.

	Principal Component	
	1	2
Water Availability	0.837	0.204
Water Risk and Hazards	0.667	-0.113
Water Accessibility	0.332	0.792
Water Quality	-0.416	0.664

Extraction Method: Principal Component Analysis.

Rotation Method: Varimax with Kaiser Normalization[a]

a. Rotation converged in 3 iterations.

The UWSI aggregates the components of water security into a single index which better represent the set of information collected through survey, and we argue, better captures the multidimensional issues forming part of water security. The factors loadings or Rotated Component Matrix (Table 5.3.3) associated with the variables indicate which are the most important in terms of distinguishing between different levels of well-being and so which variables the index is most sensitive to (Filmer and Pritchett, 2001; Vyas and Kumaranayake, 2006; Raschka, 2015; Shrestha et al., 2018). *Water Availability* (0.837) and *Water Risk and Hazards* (0.667) with the highest factor loadings are the most highly correlated with the first principal component, or the best single-dimensional descriptor of the dataset. As the data have been scaled and centred, the resulting principal component and index of values based on this component are all relative values enabling comparisons, however their absolute values do not mean anything (Tables 5.3.1 - 5.3.3), whereas the variables which were less important in the index, but still contributed to the distinction, included *Water Accessibility* (0.332) and *Water Quality* (-0.416). These factor loadings are the weights assigned to each variable in Equation 1 to calculate UWSI values.

ii. Spatial distribution of UWSI values

After calculating UWSI values using the weights from the first principal component, the results were tallied with individual water security component scores to compare with UWSI.

Distribution of scores of UWSI values in comparison to scores of the components of water security within Kolkata Municipal Corporation (KMC) area at the respondent level (Figure 5.3.3) shows the scores of UWSI (mean/median = 7.33; Interquartile Range (IQR) = 8.56-6.20) are normally distributed with no skew and falling within the range of ''Security'' status of water security within Kolkata Municipal Corporation area. UWSI also has the highest median. However, skewed (non-symmetric) distribution is seen in case of the components of UWS. For *Water Availability*, data is right-skewed (mean = 4.60; median = 4.43; IQR = 5.33 – 4.08), whereas Water Quality data has the highest variability in scores among all the water security components and is potentially left-skewed. *Water Accessibility* (mean = 4.88; median = 4.91; IQR = 5.34 – 4.50) has the least variability and falling almost within the range of ''Around acceptable threshold''. *Water Risk and Hazards* (mean = 6.99; median = 7.11; IQR = 6.55 – 7.70) ranges within the ''Secured'' status of water security and having almost identical mean and median.

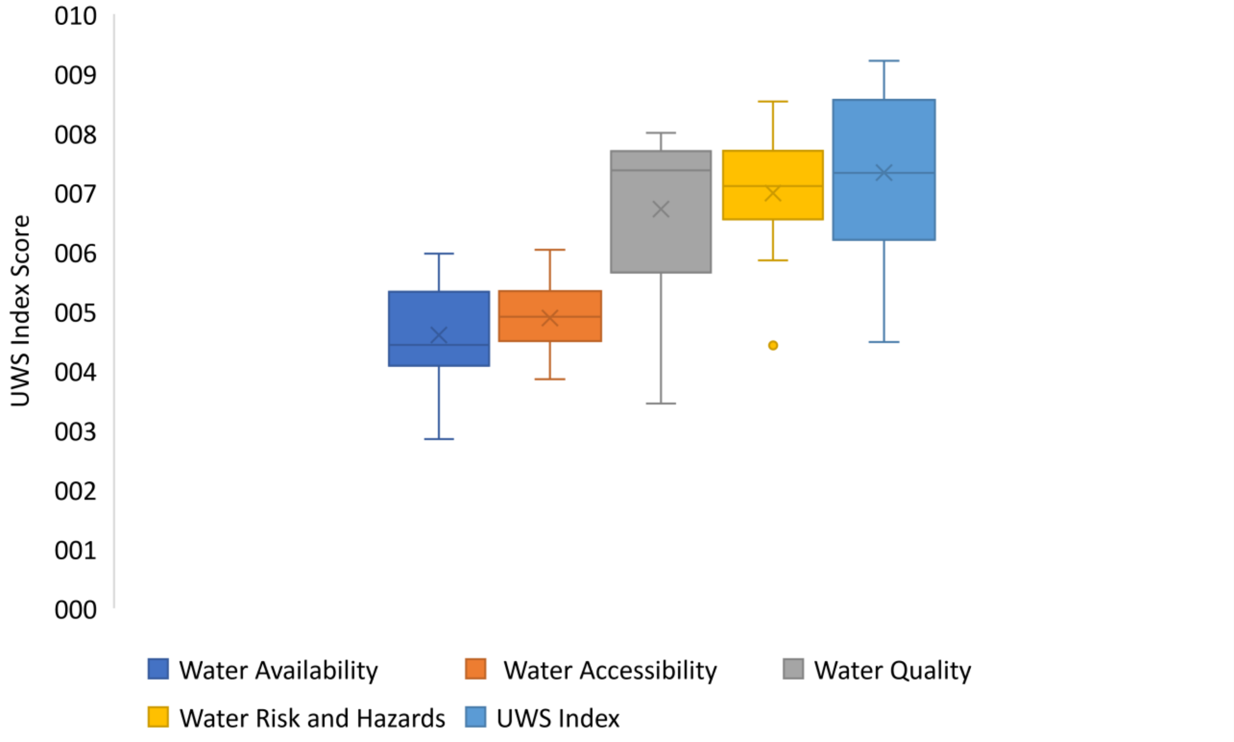

Figure 5.3.3. Distribution of scores of Urban Water Security (UWS) Index and components of urban water security (*Water Availability, Water Accessibility, Water Quality* and *Water Risks and Hazards*) within Kolkata Municipal Corporation (KMC) area at the respondent level. Data source: Survey data (2018-19).

The distribution of UWSI scores and components of Urban Water Security (*Water Availability, Water Accessibility, Water Quality* and *Water Risks and Hazards*) (Figure 5.3.4) shows that the scores for both *Water Availability* and *Water Risks and Hazards* played a major role in the status of the UWS of the boroughs. Particularly, higher values of *Water Risks and Hazards* component dominate the final index scores for all the boroughs. Therefore, depending on the scores of *Water Risks and Hazards* component, boroughs VIII and XV have the higher UWS index scores (9.21 and 9.05 respectively). For borough VIII, both *Water Risks and Hazards* and UWS Index score are greater than 8. Nevertheless, for borough XV, UWSI score is higher than 9 despites of other UWS components' 'not 'so high' scores (for example, score for *Water Quality* is 3.44 which means 'Insecure'). Scores of Water *Quality* component have no impact on the total index scores for boroughs IX and X. These boroughs have the lower scores in *Water Quality* (5.11 and 3.66 respectively), but the index category for borough IX and X are still 'Very secured' because of the higher scores in *Water Risks and Hazards*. Likewise, despite of having comparatively higher values for *Water Quality* component (7.89), borough VI is still falling within the ‘Around acceptable threshold’ status of UWS as it has low score in *Water Availability* (3.65). Borough XIII is ranked as the lowest among the list in UWSI score (4.48), having the lowest score in *Water Availability* (2.85).

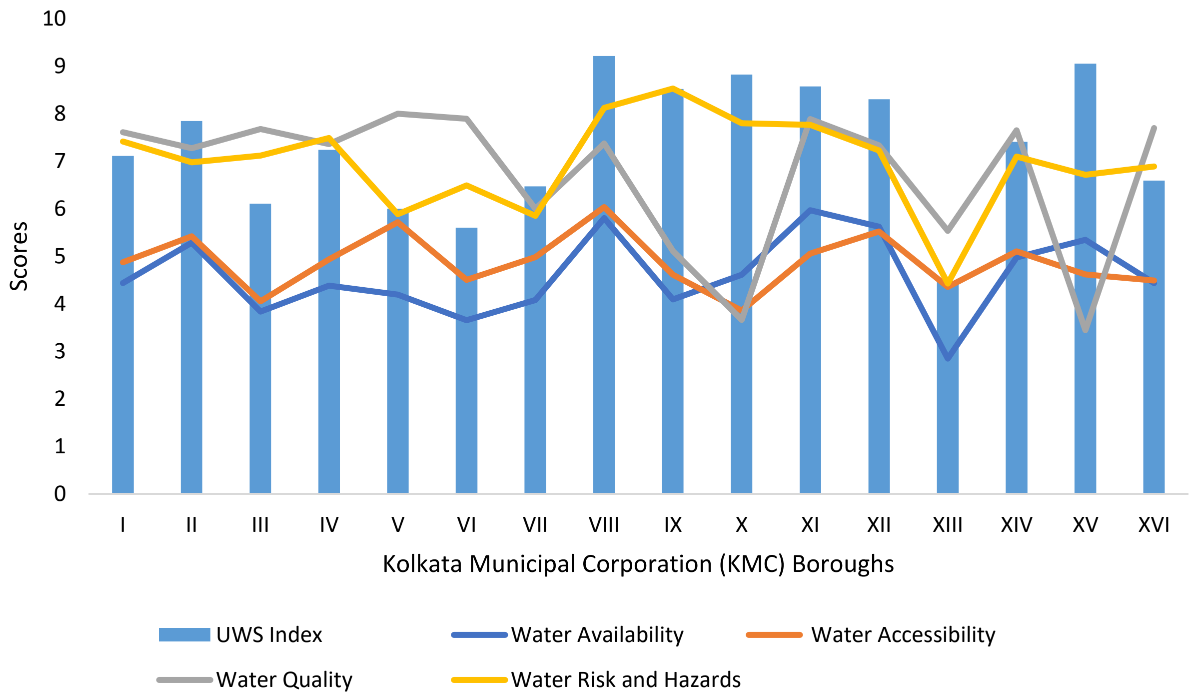

Figure 5.3.4. Borough wise distribution of average scores of Urban Water Security (UWS) Index and components of urban water security (*Water Availability, Water Accessibility, Water Quality and Water Risks and Hazards*) within Kolkata Municipal Corporation (KMC) area. Roman numbers mark the borough numbers. Data source: Survey data (2018-19).

Figure 5.3.5 shows the borough wise distribution of respondents in each category of UWS index status. The highest percentage of respondents projected as ‘’Very Secured’’ are in borough VIII (>86%). Borough I has the maximum respondents within ‘’Secured’’ category. No respondent in borough VI and XIII was projected as ‘’Very Secured’’. At the same time, more than 2% of respondents within borough XIII are falling into ‘’Very Insecure’’ category and this is the only borough which has ‘’Very Insecure’’ status of urban water security. Maximum percentage of respondents (39.16%) within the whole survey dataset are falling within ‘’Very Secured’’ category. Boroughs I, IV, VIII, IX, XI, XII and XV-XVI have no respondent falling within ‘’Very Insecure’’ and ‘’Insecure’’ categories.

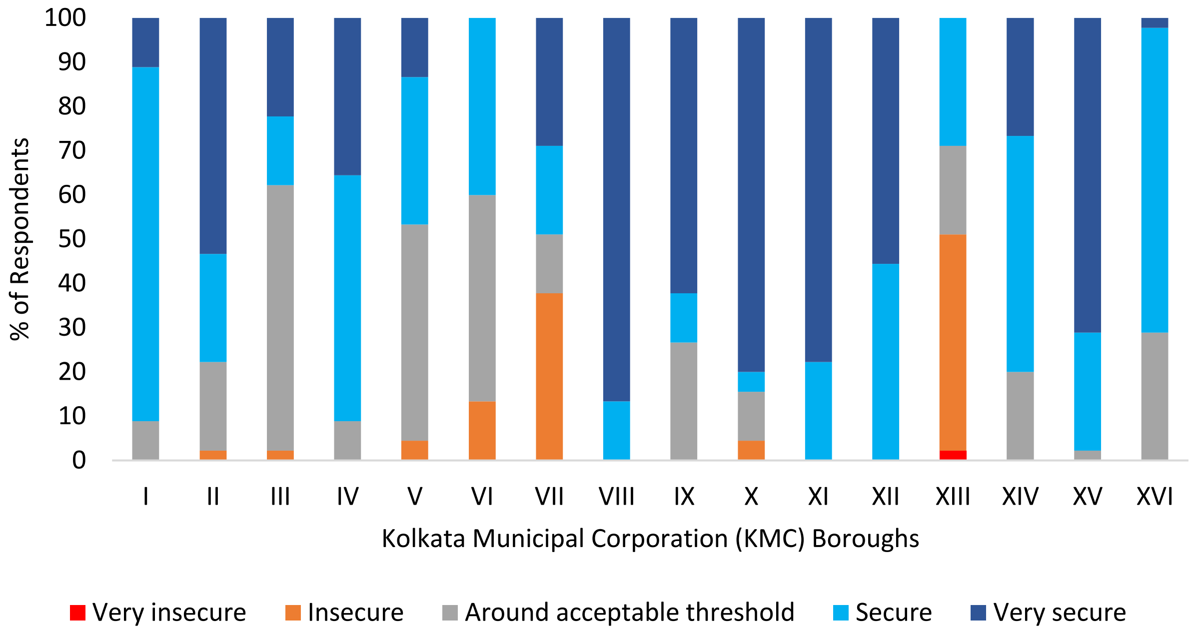

Figure 5.3.5. Distribution of % of Respondents in each category of Urban Water Security (UWS) Index status within each borough of Kolkata Municipal Corporation (KMC) area. Roman numbers mark the borough numbers. Data source: Survey data (2018-19).

Components of UWS (*Water Availability, Water Accessibility, Water Quality* and *Water Risks and Hazards*) are showing varied status of UWS in each borough across the entire KMC area (Figure 5.3.6). For *Water Availability*, no borough is entirely either ‘Very Secure’ or ‘Very Insecure’ status of UWS. Most boroughs are within ‘Secure’ categories, except boroughs IX, XIV and XV where the status is limited to ‘Around acceptable threshold’ where the median value (5), of the score 1-10, is the threshold. Borough XV has the same ‘Around accepted threshold’ status of UWS for *Water Accessibility* scores, where borough I is in the ‘Very Secured’ status. The rest of the boroughs are ‘Secured’ with *Water Accessibility* scores. Variations are also less for *Water Risks and Hazards* component of UWS across KMC. In this case, boroughs XIV and XVI are within ‘Around accepted threshold’ category and broughs I, II, and III are in ‘Very Secure’’ category of UWS status, where rest of the boroughs are having ‘’Secure’’ status for *Water Risks and Hazards* component of UWS. Borough wise scores for *Water Quality* vary more than other components of UWS across the entire KMC. Boroughs IV and XIII are within ‘’Very Secure’’ category, boroughs II, III and VII are within ‘’Around accepted threshold’’ category and the rest are in ‘Secure’ category.

Borough wise UWSI scores reflects the results of each component of UWS across the KMC area (Figure 5.3.7), which in turn show mostly ‘Secure’ status for the broughs I-V and VII in the north-central part of KMC and XIV and XVI in the south, except boroughs VI and XIII where the UWSI status is ‘Around accepted threshold’. However, southern boroughs VIII-XII and XV have ‘’Very Secure’’ status of UWS within KMC area.

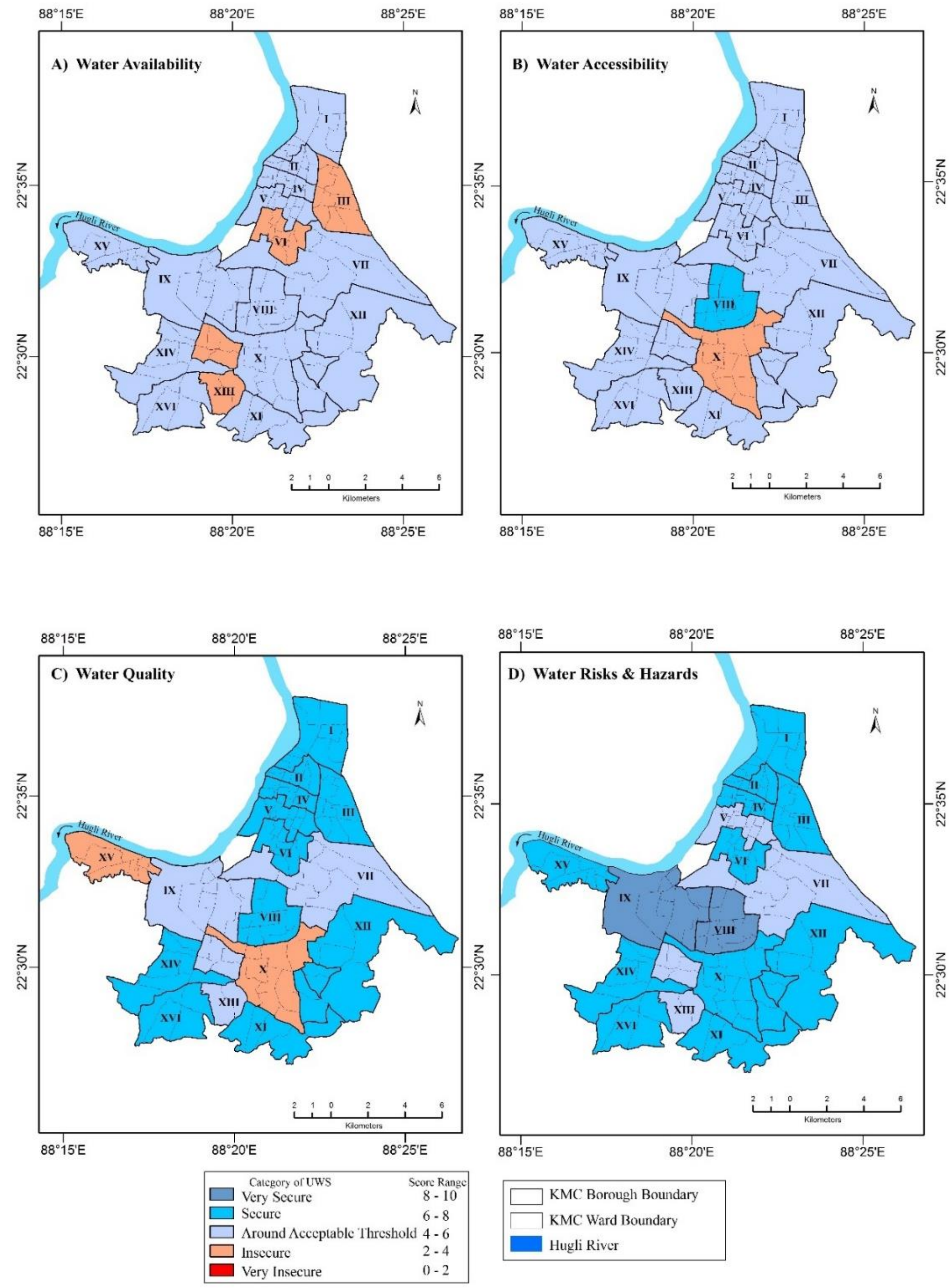

Figure 5.3.6. Urban Water Security (UWS) status associated with each component (*Water Availability, Water Accessibility, Water Quality and Water Risks and Hazards*) of UWS within each borough of Kolkata Municipal Corporation (KMC) area. Roman numbers mark the borough numbers. Data source: Survey data (2018-19).

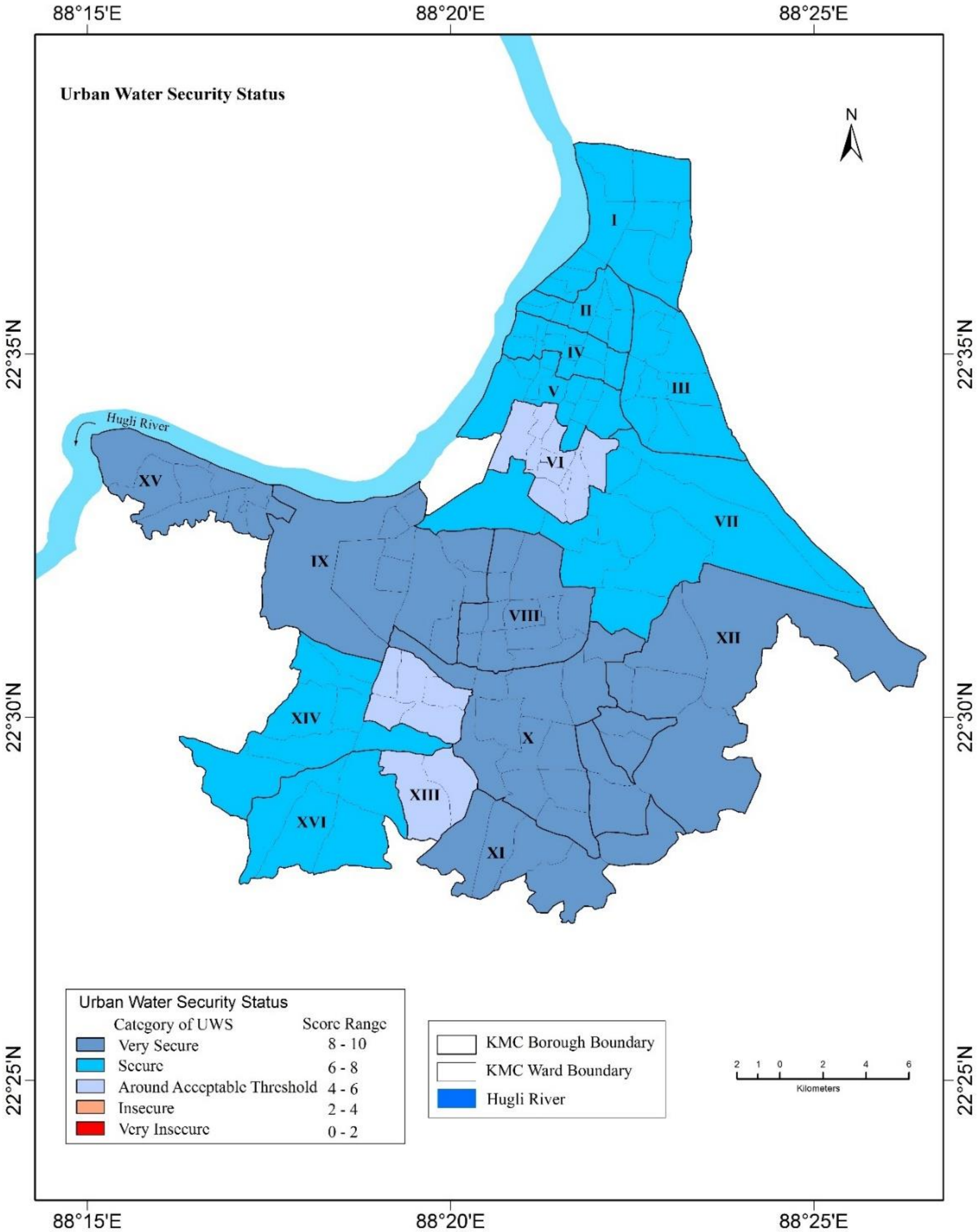

Figure 5.3.7. Borough wise distribution of Urban Water Security (UWS) Index status within Kolkata Municipal Corporation (KMC) area. Roman numbers mark the borough numbers. Data source: Survey data (2018-19).

iii. Interrelationships between Index values and socio-demographic variables

a. Pearson's r

Pearson correlation coefficient was applied to assess to assess the strength and direction of their correlation amongst socio-demographic variables (Independent variables), the urban water security (UWS) components (*Water Availability, Water Accessibility, Water Quality and Water Risks and Hazards*) and the UWS Index (Dependent variables) (Table 5.3.2) within the Kolkata Municipal Corporation (KMC) area.

There is a statistically significant correlation in the data between the UWSI values with all the components of water security variables along with type of households, number of members in the households, *Caste*, and *Employment status* of the respondents ($\alpha < 0.01$). UWSI values also correlates with *Ethnicity* ($\alpha < 0.05$). *Water Availability* component of UWS shows statistically significant correlations with other UWS components and types of household, monthly household income, caste, ethnicity, occupation, gender, and the education levels of the respondent and other family members. Gender of the respondent also correlates with the *Water Quality* and *Water Risks and Hazards* components of UWS ($\alpha < 0.01$). Employment status and religion of the respondent only correlate with Accessibility component of UWS ($\alpha < 0.01$). There are statistically significant relationships between *Accessibilit*y component of UWS and education level of the respondent, *Water Quality* variables and types of household, education levels of both the respondents and their family members ($\alpha < 0.05$). Castes of the respondents statistically corelate with all the components of UWS. Number of members in the household and *Water Risks and Hazards* also have a statistically significant relationship ($\alpha < 0.01$). The survey data do not provide statistically significant relationships between the dependent variable UWSI scores and the independent variables such as monthly household income, religion, occupation, employment status, gender, and the education levels of the respondents.

Table 5.3.4. Pearson correlation coefficient (r) to assess the linear correlation between Urban Water Security Index scores, the components of Urban Water Security (*Water Availability, Water Accessibility, Water Quality and Water Risks and Hazards*) and Socio-demography within Kolkata Municipal Corporation (KMC) area (n= 720). Data source: Survey data (2018-19). * marking 95% confidence level, ** marking 99% confidence level.

	Components of Urban Water Security				UWS Index Scores
	Water Availability	**Water Accessibility**	**Water Quality**	**Water Risks and Hazards**	
Availability	1	.271**	-.128**	.303**	.801**
Accessibility	.271**	1	.290**	-	.722**
Water Quality	-.128**	.290**	1	-	-.515**
Water Risks and Hazards	.303**	-	-	1	.642**
Type of Household	.384**	.261**	-.084*	.169**	-.074**
Number of members in the house	-	-		-.104**	-.110**
Monthly Household Income	.269**	.221**	.105**	.195**	-
Caste	.148**	-.086*	-.074*	.128**	-.098**
Ethnicity	.125**	-	-.130**	-	-.088*
Religion	-	.180**	-	-	-
Employment Status	.205**	.220**	-	-	-.123**
Occupation	.162**	-	-.128**	.134**	-
Employment Status of the	-	.093**	-	-	-
Highest Level of Education in	.346**	.136**	-.090*	.194**	-
Education Level of the	.107**	.074*	.082*	.100**	-
Gender	-.114**	-	-.145**	.124**	-

b. Cross tabulation

The Cross tabulation of survey data reveals the percentages of respondents based on its different socio-demographic characteristics (such as caste, ethnicity etc.) within different categories of UWSI scores (*Very Insecure* to *Very Secure*). The main findings from the Cross-tabulation analysis are as follows:

Household types: Respondents having their own house (55.1% out of 47.4% of the total respondents) are the majority in *Very Secure* UWS index category. In contrast, respondents dwelling in semipermanent houses (100% out of 0.4% of the total respondents) in deprived areas are having *Very Insecure* status of UWS.

Monthly household income: Respondents from the higher income group (monthly income >25,000 INR) are within the *Very Secure* category (47.1% out of 19.1% of the total respondents), followed by the middle income (monthly income 10,000 - 25,000 INR) (33.3% out of 19.1% of the total respondents) and the lower income group (monthly income <10,000 INR) (16.7% out of 19.1% of the total respondents). While respondents from the lower income group (100% out of 19.1% of the total respondents) is the only income group within the *Very Insecure* status of UWS.

Caste: More respondent belonging to general (upper) caste (86.2% out of 19.1% of the total respondents) are categorized as *Very Secure* than the scheduled caste/scheduled tribes/other backward castes (SC/ST/OBC) (13.8% out of 19.1% of the total respondents). Respondents from general caste also have the majority (86.2% out of 45.1% of the total respondents) in *Secure* status of UWS than the SC/ST/OBC (12.9% out of 45.1% of the total respondents) respondents.

Ethnicity based on languages spoken Bengali speaking respondents (81.9% out of 19.1% of the total respondents) are having the *Very Secured* status of UWS than *Other Indian languages speakers* (17.4% out of 19.1% of the total respondents). Nonetheless, 0.3% of total Bengali speakers, which is 80.5% of the total respondents and 0.8% of total *Other Indian language* speakers, which is 18.3% out of the total respondents, are within *Very Insecure* category of UWS.

Religion: Hindu respondents (83.3% out of 19.1% of the total respondents) are more secured with *Very Secure* status of UWS than Muslim respondents (11.6% out of 19.1% of the total respondents). In contrast, *Insecure* status of UWS is higher in Muslim respondents (40% of the total Muslim respondents) than Hindus (10% of the total Hindu respondents).

Occupation: Respondents within the household works (44.9% out of 19.1% of the total respondents) are the most secured with *Very Secure* status of UWS amongst other respondents, while students and those in unorganized business/jobs are the least water secured.

Level of education: Respondents with a college/bachelor's degree are the most secured (34.7% out of 19.1% of the total respondents) with the *Very Secure* status of UWS, while Postgraduate degree holders (2.9% out of 19.1% of the total respondents) are the least secured.

Gender: Within the *Very Secure* index category Cis-men are the majority (37.7% out of 19.1% of the total respondents). Nonetheless, 45% of all gendered respondents are categorized as *Secure*. 9.6% of total Cis-women, 5% of total Intersex, 13.2% of total Cis-men and 13.7% of total Trans (gender) people respondents are within the *Insecure* status of UWS. 0.8% of the total Cis-male respondents and 0.9% of the total trans (gender) people respondents are categorized as *Very Insecure*.

5.3.5. Discussion

This research quantifies the spatial distribution of urban water security (UWS) of Kolkata city through a novel assessment framework that encapsulates both bio-physical and social dimensions. In this discussion section, we discuss the reasons and factors driving the spatial variations of UWS index scores, based on the individual components as well as the overall scores of the quantified UWS index and their interrelationships. This section also discusses the study area specific findings from the UWS index, despite of the current limitations (mentioned in Section 6)) of the quantitative assessment framework, how megacities in emerging economies such as Kolkata suffer from intrinsic water insecurity even when their advantageous location and resource-abundance (Basu, 2015; Mukherjee et al., 2018) in terms of water seem to be 'secure' (van Ginkel et al., 2018). Variations in individual components of Urban Water Security (UWS) are discussed in the following sections: water availability, water accessibility, water quality and water security.

i. *Water Availability*

Water Availability corresponds to sufficient and continuous water supply for personal and domestic uses, including drinking and other domestic purposes (Mukherjee et al., 2020; Gleick, 2004). Although having the highest contribution for Urban Water Security (UWS) index within Kolkata Municipal Corporation (KMC) area. *Water Availability* component of UWS is 'around acceptable threshold'. As this survey scores were primarily based on the respondents' perception, the lower range of *Water Availability* indicates that there is a demand for supply of potable water, particularly in the southern peripheral boroughs such as boroughs XIII-XIV (Figure 5.3.1 and 5.3.2; Appendix 5.3B and 5.3C).

The water supply system of KMC has been in operation since 1865. The average per capita supply is 134 *liters per capita per day* (lpcd), which is near to desired supply of 150 lpcd (for metropolitan cities). Nevertheless, the supply is very uneven, ranging from 310 lpcd to 40 lpcd with an average supply period of 8 hours a day. The water supply system for KMC area is mainly based on water of River Hugli after treatment, where 92% of the total households within the whole KMC area relate to direct piped supply (WWF, 2011). This estimation does not include the semi-permanent households of the deprived areas of KMC, where around 35% of KMC's population lives without having direct piped supply of potable water. The daily water demand is estimated as 293 million liters per day as per 2012, where the total daily treated water supply capacity of the 4 treatment plants of Kolkata is 271 million liters per day. Nevertheless, age-old water pipelines cause high water loss in distribution (KMC report, 2011; ADB, 2012; Mukherjee et al., 2018. It is also accounted that 35% of the water is wasted everyday due to the leakage in pipes (Basu, 2015; Mukherjee et al., 2018). As a result, there are gaps in demand-supply which we see as one of the drivers for the low scores of *Water Availability* component. Another issue is disparity of distribution of piped supply throughout the entire KMC area. Most of the direct supply of treated water is seized by middle and upper strata of the society which also include bigger commercial establishments. Therefore, disparity can be evident in *Water Availability* of water among different sections of society within KMC.

Areas classified as urban settlement in KMC increased from 49% in 1980 to 79% in 2014 and population increase within this period of time is more than a million (Mukherjee et al., 2018). The resultant increased demand of water put pressure on groundwater resources. Around, 10-15% of KMC's potable water supply is sourced from groundwater which covers up to 30% of the potable water used in households (Chakravarthi, 2011; Chakrabarti, 2013; KMC, 2014). There are around 439 big diameter tubewells fitted with motor-pump and 10,050 small diameters tubewells fitted with handpump within KMC area, which exclude the numbers of 'unaccounted' tubewells installed and used by the large housing complexes (Chatterjee, 2014). Issues associated with unplanned, excessive, and 'unaccountable' groundwater extractions are land subsidence, depletion of groundwater lvel and aquifer contamination (Sahu et al., 2013; McArthur et al., 2018; Hati et al., 2020). Absence of water meters or penalty system also encourage this unaccountable groundwater extraction (Mukherjee, 2018; Hati et al., 2020).

Another important aspect of urban water availability is the declining inland surface waterbodies (urban wetlands such as canals, ponds, or constructed inland fresh waterbodies) and their littoral zones due to urbanization (Vörösmarty, 2000; Feng et al., 2010; Moss, 2014; Veldkamp et al., 2017; Chen et al., 2020). Mukherjee et al., (2018 and 2020) showed the areas under wetlands within Kolkata Municipal Corporation drastically reduced from 23% in 1980 to 4% in 2014 (Mukherjee et al., 2018). Borough wise declining rate was higher in the main city areas whereas the peripheral areas lost comparatively less. Nevertheless, the gross reduction of wetlands in Kolkata and its suburban areas impacted the direct availability (and, accessibility) of freshwater for other household purposes except drinking. These waterbodies were one of the major sources of water for household purposes for the residents of deprived areas (slums) as well as for the lower income groups living in semi-permanent squatters near /on the bank of these waterbodies (Mukherjee et al., 2020). Apart from the human dimension of water supply and groundwater recharge issues (Young, 2015), urban wetlands are also vital for managing the environmental functions, such as controlling flood, pollution and soil erosion and managing microclimate of the surroundings with the relative cooling impact (Forman, 2014; Manteghi et al., 2015; Neelakantan & Ramakrishnan, 2017).

Our survey data show only 67% households (n = 720) within KMC are having toilet. According to KMC's report (2012) for Asian Development Bank (ADB), only 44% of all households within KMC are having toilet facilities. In the derived areas, according to the Census of India (2011), more than 50% of the total households, 14 to 25 people are having access to only one community toilet (Mukherjee et al., 2020). Four percent of the KMC population had no toilet facilities nearby and used gutters, open drains, canals, or vacant lands instead (KMC, 2012). There are 383 public (pay and use) toilets in the KMC area (KMC, 2015) some of which are having poor quality without necessary sanitation facilities making them useless throughout the year (Mukherjee et al., 2020). Fifty percent of the population of KMC has access to sewerage services (Mukherjee and Ghosh, 2015). A total number of 358,750 households (75% of the total households) within KMC are directly connected to the underground sewer network. The collection efficiency of sewage is 71%. The collection efficiency is around 90% in the core city area whereas, the remaining peripheral areas have no formal sewer system yet and collection is zero (KMC, 2015).

ii. Water Accessibility

Water Accessibility points to the need for adequate and safe water, sanitation, and hygiene (WaSH) facilities to be located or constructed in such a way that they are always accessible to everybody. Safe access to clean water, sanitation and hygiene facilities is particularly important for people with constrained physical movement and marginalized groups who may face safety risks (Mukherjee et al., 2020; WHO, 2018; UN, 2004). Gender, ethnicity, religion, and caste matters when it comes to access and availability to toilets and required WaSH facilities, for example, females stay home and face the tremendous issues with access to WaSH. Provisions of WaSH are crucial factors of water security, maintaining basic health standard. *The provision of WASH in health care facilities serves to prevent infections and spread of disease, protect staff and patients, and uphold the dignity of vulnerable populations* (WHO, 2015, p. 4).

Our survey revealed that 22.5% households within KMC did not have any access to WaSH facilities. The National Family Health Survey of India showed that 47.2% slum households had access to WaSH facilities in 2005-2006 (IIPS, 2007; Sau, 2017). However, our study revealed the importance of deprivation as a factor explaining water security. As, after almost 15 years, in 2018, 42.5% household in deprived areas (known as slums) had access to WaSH facilities and 32.2% respondents did not have any WaSH facilities within their accessibility, which can tend to open defecation. This percentage is much higher than the national average, where, according to Census 2011 data, open defecation among the slum dwellers in India was 18% (Sau, 2017; Satapathy, 2014). This finding also shows the need for better and more accurate data.

Fundamentally, water is a social good (Day, 1996; Rogers et al., 1998). Therefore, ensuring universal access to water is the most essential element for achieving urban water security

(WWAP, 2019). Our results suggest that the most water-secure groups in Kolkata are either Cis-gendered or general (upper) caste or more educated or people living in their own houses. Inequalities along the multiple intersecting dimensions of various social categories such as gender, caste, ethnicity and religion are strong in Indian societies, which are now deepened with the emerging prosperity of the country widening the gaps between majority and minorities (Anne et al., 2013). Power politics, livelihood gaps, inherent stigmatisation are increasing the gaps in necessities, preferences, and capacities in every segment of city-life (Anne et al., 2013; Shahid and Pelling, 2020). As a result, the intersecting categories and inter-categorical differences in access to water and sanitation provisions are complex and spatially heterogenous. (Fletcher, 2018). These inequalities also include the extremes such as physical-sexual assaults and denial of access to water specially for marginalised groups such as transgender communities (Alston and Whittenbury, 2013; Boyce, 2018). Disregarding the essentiality of inclusive (and intersectional) analytical framework may ignore or generalise the existing inequalities in the urban water system (Yuval-Davis 2006; Valentine 2007; May 2015; Fletcher, 2018). Gender issue has already been highlighted in the Dublin Principles (1992) on bridging the gender gap in water resource management and other literatures (GWP, 2019). However, the notion of inclusive approach is still lacking its significance in the research and practices raising the concern of basic right to water (Mukherjee et al., 2020), and we have also seen very few studies on gender along a continuum where water security for those outside of the gender binary are taken into account.

iii. Water Quality

Water quality must be safe for human consumption (i.e., drinking, and other household purposes including cooking) as well as for personal and domestic hygiene. This means the water must be free from germs, chemical substances, and radiological hazards that constitute a threat to a person’s health both short term and over a lifetime of consumption (Mukherjee et al., 2020; Gleick, 2004). According to our results, Water Quality component of UWS of KMC area are significantly related to risks and hazards associated with urban water as well as type of households. The main sources of contamination in the supplied water services with KMC are leakage in the supply-pipes (Ghosh, 2002) and seepage from the landfills (Mandal, 2007), stormwater discharges containing industrial wastes and uncovered sewage in both surface water and groundwater (WWF, 2011; Ganguly, 2012; Singh et al., 2015). The analyses of the survey data reveal that in KMC, the supply of good quality drinking water is not sufficient and inadequate quality drove most of the total respondents of boroughs II, III and III away from using the supplied water to find out other sources of water for drinking and other household purposes. These areas of KMC consist of the older parts of the Kolkata city, where the existence of leakage and outlived metal pipes are possible sources of contaminants in water (Chacraverti et al., 2011; Basu, 2015; Mukherjee & Ghosh, 2015).

Within the KMC, groundwater is susceptible to pollution due to the leakage from the open dumping of domestic and industrial wastes. Therefore, the direct usage of groundwater through both deeper and shallower tubewells and bore wells can have direct and indirect issues of water quality, including dysfunctional colors, odors, and other visible quality issues. Chacravarty et al. (2011), traced the source of contaminants such as mercury (Hg), lead (Pb), cadmium (Cd) and chromium (Cr) in samples taken from tube wells, river Hugli and piped water within KMC area. The presence of lead (Pb) in river water and drinking water were very much noticeable in almost all the samples in both summer and winter seasons while the presence of chromium has been noticed in river water during monsoon seasons. Presence of mercury during monsoon season has also been detected in samples within KMC (Chacravarty et al., 2011). Decrease in wetlands and increase in urbanized impervious surface within KMC area are another cause of discharge of wastes into the surface and groundwater systems and increase the pollution (both organic and inorganic contaminants) levels of receiving water (Ganguly, 2012). McArthur et al. (2018) traced in few groundwater samples arsenic concentrations between 10 and 79 μg/L to a factory site producing Paris Green, an arsenical pesticide manufactured between 1965 and 1985, sporadic lead > 10 μg/L from well-fittings, many samples contaminated by Cl from wastewater (sewage and septage) and natural Mn >0.3 mg/L.

iv. Water Risks and Hazards

Water risks and hazards related issues include mainly floods, water scarcity, water-borne diseases due to the presence of organic and inorganic substances in the water and land subsidence. The changes in land use and land cover (LULC) within KMC area since 1980 (Mukherjee et al., 2018) resulted in the drainage of wetlands and its replacement by either compact surfaces or barren land for urban development. The shrinkage of surface waterbodies, clearing of the trees in the city increased surface runoff (Kiran and Ramachandra. 1999) and consequently, groundwater level lowered (Ali et al., 2008; Hagler, 2007; Mendoza et al., 2011). According to our results, two boroughs, XIII and XIV, which are situated at the periphery of the KMC boundary and within the reach of Adi Ganga canal remained within ''Around accepted threshold'' status of UWS. Poor and inadequate living conditions and municipal services increase morbidity and mortality rates as well as sanitation issues (Douglas, 1983). These problems are especially critical in socially excluded areas and for squatters in fringe areas (Kundu, 2003). Peri-urban fringe areas (e.g., newly added wards, such as 101, 141-46) are lacking access to piped water supply from the municipality. The residents must either use the groundwater through hand-pumped tube wells or get access from KMC supports such as water delivery by water trucks few times a week. The increasing numbers of slum dwellers have been the key concerns for urban planning in respect to accessibility of safe drinking water and availability of adequate sanitation facilities (Sau, 2017).

During severe flooding, such as in September 1999, the slum areas suffered from a paucity of power supply, acute shortages of safe drinking water, outbreaks of water borne diseases such as gastro-enteritis, typhoid, entamoebiasis, hepatitis etc. and a long period of water logging. Palit et al. (2012) conducted a study on the potential of different water sources, both for drinking and domestic purposes, for diarrheal disease transmission in Kolkata's urban slums (Mukherjee et al., 2018; Palit et al., 2012). The results show a significantly higher prevalence of fecal coliforms (58%) in stored water for washing than the stored water for drinking (28%) and tap/tube well water (8%) collected (Palit et al., 2012). Samples containing stored water for washing also had the highest non-permissible range of physico-chemical parameters. Household water containers storing water for washing were rich in fecal coliforms and residual chlorine contents. Palit et al. (2012) found less than the satisfactory level of residual chlorine (57%), TDS (37%) and pH (20%) present in almost two thirds of the samples of water stored for washing (Palit et al., 2012).

Another hazard witnessed in Kolkata is land subsidence in Bowbaar area of borough VI on 2^{nd} September 2019 due to leakage of aquitard-aquifer pore water in an under-construction tunnel of East-West Metro Railway Project. The tunnel boring machine hit the local aquifer at 14 m depth. As a result, the shallow aquifer was dewatered very rapidly and consequently the hydrostatic pressure decreased and lithostatic pressure increased in both the aquitard and aquifer leading to land subsidence and development of cracks in tens of buildings; few of which collapsed immediately, and some stood in such a precarious position to be eventually razed.

Mass evacuation was also undertaken from the area (Banerjee and Sikdar 2020). Pumping of groundwater had to stopped in nearby areas leading to water insecurity.

v. Urban Water Security Index

The result of Urban Water Security (UWS) Index revealed the intrinsic spatial disparity of water security within the city as a combined result of physical setup of the cityscape including subsurface structures and over-ground infrastructure as well as social inequality and exclusions (Sultana, 2020). According to the right skewed distribution of the variables across the city, there are higher levels of water insecurity on average in Kolkata (Figure 5.3.3). The most water insecure boroughs are those which are either regarded colloquially (because, unlike many cities, Kolkata does not have any official central business district) as the ''central business district'' (borough VI) where the main railway station, *Sealdah* and the biggest market, Burrabazar, are located, and the area which is going through a continuous infrastructural alteration due to urbanisation (borough XIII and XVI) including bridges and other developmental activities are taking place (KMC Report, 2012; Roy and Dhali, 2016; KMC report, 2018; TOI, 2019). The subsurface structure of the city having active clay layer, age of the existing sewage system, non-biodegradable solid waste generation, lack of adequate pumping stations to remove water from the water logged areas, land subsidence, sporadic development of high-rise buildings, increasing traffic on the roads (particularly in the central city areas) and increasing density of population in these areas are to be blamed for the water insecurity (Roy and Dhali, 2016; KMC report, 2018; Mukherjee et al., 2018). Borough XVI has another issue with water and its infrastructure as this borough includes the newly added areas which still lack required infrastructure like direct piped water services to the households (KMC Report, 2012; Mukherjee et al., 2018; Mukherjee et al., 2020).

Multiple intersecting dimensions between water insecurity and societal disadvantages related to gender, deprivation related to economic and social classes, caste, ethnicity, and religion (Simpson 2009; Thompson, 2016) are clear from our results. These intersectional disparities are *particularly critical for women and girls and for making progress towards* both SDG 5 (gender equality and empower all women and girls) and SDG 6 (clean water and sanitation for all) ensuring inclusive water security for everyone in a city (Truelove, 2011; Sultana, 2020; Dickin et al., 2021, p. 1). The participation of Cis-female in the labour force is still considerably low across developing countries and emerging economics comparison to Cis-male (Bhagat et al., 2008; Kundu and Mohanan, 2009; Agbodji et al., 2015; Biswas, 2018). Despite of the fact, the (Cis)male-female gender gap has been slowly decreased, the Cis-female workers have much lower participation rates than their Cis-male counterparts and hence comprise a marginalized section (ILO, 2016; Biswas, 2018; Deshpande, 2020). As per census-2011 of India, the workforce participation rate for Cis-females is 25.51% against 53.26% for Cis-males In India and 18.08% Cis-female workforce participation against the 57.07% Cis-males in West Bengal (Govt-WB, 2015; Biswas, 2018; Deshpande, 2020). Our survey results show that 31% Cis-male respondents and 27.6% Cis-female are employed. These portray the involvement of Cis-men in workplaces within Kolkata is higher than their female counter part, but this higher involvement makes Cis-men more vulnerable to water insecurity at their workplaces. In Kolkata (and India in general), the WaSH facilities both at workplaces and institutions, for all gendered, are either inadequate or are in poor condition (UN report, 2019; Paul et al., 2020). In schools (of India), for example, 50% children do not have access to a toilet at school, within them 22% are Cis-men (Deivam, 2016; Tiberghien, 2016). This scenario is same in other public places, including the marketplaces and railways stations where thousands of people commute through every day (Paul et al., 2020). Therefore, Cis-men face more consequences of lack of WaSH infrastructures in their workplaces and on the way to the work.

This issue is even worse for trans (gender) people. They are not properly registered officially - often live-in high levels of deprivation and poverty and are not able to access work (Dhall and Boyce, 2015; Boyce et al., 2018). This means they on the one hand share characteristics and WaSH struggles of those living in poverty but have the double burden of the hostility towards their very way of living and identity (Dhall and Boyce, 2015; Boyce et al., 2018). Thus, they often face physical humiliation during fetching water or using the common public latrines (Boyce et al., 2018, Mukherjee et al., 2020). Therefore, the results from our survey showing the number of transgender inclusive public toilets (14; Fig 2C) are crucial, as they are among the first attempts at demonstrating the exclusion factor for achieving water security in Kolkata city.

The result depicts that the portion of the respondents who are regarded as working in ‘’household’’ are the most water-secure and most of them are women (this category of women includes both Cis-women and trans (gender) people although no national level statistics show the trans-women’s data as of now. Therefore, the term women in the following sentences are meant for only Cis-women). Chances are high that a major portion of women having higher education are not engaged in active workforce. This non-engagement of women in active workforce doesn't only reduces their role as decision-maker about WASH expenditures at home, but also for their workplaces lessening women's empowerment and gender equality at work (Dickin et al., 2021, p.1). This assumption is supported by a study which states that the Gross Enrolment Ratio in higher education for male population is 18.3% and for women it is 19.1% s for the year 2018-2019 (Mitra and Ghara, 2019). In contrast, Chatterjee et al. (2018) showed that the Indian women's work force participation is low. Recent studies have observed that women's education has largely J-shaped or U-shaped relationship with their work-force participation, particularly in India (Reddy 1979; Sathar and Desai 2000; Das and Desai 2003; Kingdon and Unni 2001; Das 2006; Klasen and Pieters 2015). Past studies asserted that both cultural factors (for example, norms restricting the mobility of women) and structural factors (for example, lack of appropriate job opportunities for educated women) play important roles in determining the U-shaped relationship between women's education and work-force participation in India (Das and Desai 2003; Das 2006, Chatterjee et al., 2018).

The 2011 census reports that 87.3% of office clerks and 93.1% of sales jobs are taken by Cis men (Chatterjee et al., 2018). Rather than demonstrating the lack of adequate jobs for moderately educated groups in the country, these statistics especially imply the exclusion of women from these jobs which explains the low rates of work-force participation for these women. Nevertheless, skilled work in education sector (and health sector) is not entirely gender segregated except in part, where some types of work, such as nursing, fit better with gender stereotypes of women's nurturing roles (Chatterjee et al., 2018). Then, much of these works necessitate education beyond secondary level. Therefore, the 'weaker sex' segregation in these jobs ends in a greater demand for educated female workforce and the rise in work-force participation can then be observed among female having Bachelors' degree and above. According to the Census 2011, in India, more than three-quarters of teachers have education above secondary level, and over one-third of them, 36.8%, are women (Chatterjee et al., 2018). Therefore, WaSH provisions in educational institution (Paul et al., 2020) would also matter for the low water security of the respondents with Postgraduate degrees and above, considering the similar situation for the Cis-male teachers.

Lack of and inadequacy of WaSH provision in the socially deprived areas in Kolkata is also influencing some boroughs' overall UWS index scores (Mukherjee et al., 2020), such as borough XIII. Moreover, the statistically significant correlations between water accessibility variable and monthly income, caste, religion, education, and employment status of the respondent show that water insecurity and social exclusion go hand in hand. We can see this in the socially deprived areas of borough XIII, where the majority are of Muslim religion having lower level of education and monthly household income, and we have a low UWS score. Within the city's deprived areas, 81% of the dwellers have direct piped water supply in their houses for drinking purpose; among them only 8% use the same supplied water for other household works such as toilet flushing, washing clothes etc (Mukherjee et al., 2020). However, 43% of the dwellers from these deprived areas depend on water from standposts outside their houses for household tasks other than drinking (Mukherjee et al., 2020). Gender inequalities play an important role here. Cultural values regarding religion shape the water insecurity for different genders due to the influence they have on division of household tasks as well as on and restriction of certain social interactions. For example, Muslim women are more water insecure in the deprived areas as they are not allowed to go outside to take bath (Schenk, 2010) which made it difficult to maintain hygiene for them particularly in the summer days. This significant public exposure may not be a problem for Hindu women from the lower income groups living in those deprived areas in the city, which make them choose occupations like domestic servants or vegetable vendors (Roy et al., 1992; Schenk, 2010). These cultural factors are also behind the under-representation of Muslims women in higher education and employment which shape their water security in Kolkata (Roy et al., 1992; Schenk, 2010; Rahaman and Barman, 2015; Mollah, 2018; Mukherjee et al., 2020).

Political factors also influence the water security of Kolkata city. According to Asian Development Bank's reports (Ram,2019; Strazzabosco, 2020), KMC currently accounts for 50 per cent of non-revenue water, which is a threat to any city's water security (Lai et al., 2020). It is planned to reduce this to 25 percent this year (Strazzabosco, 2020). There is also talk of 'volumetric' and 'non-volumetric' water tariffs, which have direct impact on UWS regarding policy decisions *ensuring financial sustainability of service provision and access to all, including vulnerable and poor social groups* (Leflaive and Hjort, 2020, p.3). Therefore, after processing the untreated water, the required cost of drinking water supply to the house goes higher. This higher cost imposes burden on the state government, as the entire cost is dependent on municipal funds and financial support from the state government itself. There is a clear lack of political will to impose a tax on water in terms of the amount supplied at the household level and in introducing volumetric tariffs at home (Strazzabosco, 2020). This *lack of political will* may create a shortage of drinking water soon. This water-tax issue also triggers another crucial element of water security, i.e., affordability of water (Xia et al., 2007; Cook and Bakker 2012). Water affordability reveals disparities and inequalities within the society (Meehan et al., 2020). In Kolkata, there is no water-tax (Mukherjee et al., 2018) and hence the poor subsidizes the rich in terms of water cost. Due to the inadequacy of direct supply of water to the household, citizens spend money (sometimes one third of their salary) for buying water. It is evident that the poorer people living in semi-permanent households in socially deprived areas in the city, pay more than who live in the high-rises (Basu, 2015; Mukherjee et al., 2020).

5.3.6. Limitation of the study

The existing literature on UWS assessments is not holistic or inclusive and rarely considers both bio-physical and societal factors in consider quantitatively. Therefore, we cannot apply any already established weighting methods to all the indicators of UWS. Lack of representation of the ground reality and underestimating the micro level issues may produce a fragmented scene of the UWS. The limited number of respondents to the survey questionnaires, their individual background, beliefs, ideology, and personal judgment about water security produce uncertainty and subjectivity in the indicator scores. We do, however, have a large enough random sample to provide strong and robust findings. Moreover, scoring through qualitative interpretations of the existing literature could weaken the precision of the findings. To overcome this issue, we weighed the data according to the Census-2011 to accurately reflect the population studied (particularly for gender and religion categories). However, the data were aggregated spatially into borough level, which lost the heterogeneity at the ward level scale. This way, we may have lost valuable information about the inequality present in the water security spectrum across the city.

5.3.7. Conclusions

The inclusive framework for urban water security assessment presented in this article highlights the challenges of UWS in Kolkata which goes beyond traditional indicators such as quantity of supplied water, access to water and sanitation or water quality. It captures the issues of water (in)security holistically along the four major dimensions of UWS—availability, accessibility, quality water-related risk and hazards. It does so draw on scientific and social scientific indicators to answer the key questions of UWS: *how and where a city is water insecure*. To answer this the empirical approach of the study used spatial analysis of all the components of UWS with a megacity perspective from a location within an emerging economy. The findings suggest that water insecurity of a city is not only due to the malfunction or inadequacy of city's water system but also stems from the intersecting disadvantages of disparity, inequality and exclusion found in a society. Along with conventional quantifiable components of bio-physico-chemical dimensions, social factors were included as a key dimension of UWS to capture and improve our understanding of UWS, and as a result provide better recommendations for effective policy measures.

Despite being water blessed by having River Hugli in the west, East Kolkata Wetlands in the east and vast groundwater reserve, Kolkata faces a range of UWS challenges. Changes in freshwater resources and urban land use, increasing water demand owing to population growth, poor sanitation and lack of enough water treatment facilities coupled with mismanagement aggravated the water insecurities in Kolkata. In emerging and developing countries like India, these challenges affect urban dwellers, who experience difficulties in meeting daily water needs. The gap between the availability, supply and demand for fresh water will widen even further in mega cities in emerging countries, where this unequal state of urban water security affects mostly the people residing in the societal margins. This means we need to direct our attention to the consequences for public health, livelihoods, and wellbeing of these populations, with a particular focus on gender disparities. Municipal governments, as a result, need to constantly reconcile available water supply with growing demand in an equitable manner.

Overall, this study provides a unique quantitative assessment framework to quantify UWS at the borough level and to define the presence of multiple intersecting dimensions between bio-physical environment and society. This study identifies water-insecure areas within an Indian megacity which are under deprivation in both spatially and socially beyond the possibilities of limited resources prudently. This novel quantitative approach would help policy makers and water stakeholders to fix their objectives to manage their available water and social resources judiciously toward achieving UWS managing the trade-offs and equity challenges. The variation within the city builds on and adds to our argument in the previous studies and underlines the need to look at within city variation in our future work where we would focus on more individual level from the data collection, validation approaches to index creation to prevail over this critical issue of urban water security.

6. Synthesis

6.1. Integrated Urban Water Security Index

This synthesis chapter reflects on the idea of integrated and inclusive framework to assess urban water security (UWS). The objective here is to make sense of the chapters in this doctoral thesis and literature elsewhere by proposing an integrated index to identify and assess the issues of urban water security in Kolkata.

Water security is a growing concern in urban areas in emerging economies (Obani and Gupta, 2016) as populations in these countries lack access to clean water and sanitation. This research is unique due to the inclusion of bio-physical and socio-cultural factors to gain invaluable knowledge of the issues related to water security and gender. This inter-disciplinary vantage point is crucial to enhance knowledge and create new solutions. Underlying the approach is the conviction that ensuring clean water and sanitation for all, including environment, is fundamental to sustainable growth and development (Barbier and Burgess, 2017). The aim of this doctoral research is to create knowledge and ideas that can propose innovative assessment of urban water security in an integrated and inclusive manner. Overall, the objective was to address the issues regarding water security in Kolkata, India as an example of mega cities of the Global South through an inclusive quantitative Socio-Eco-Hydrological framework of UWS. Referring to various desiderata, this doctoral study attempts to answer the following research questions arising from the dynamics of the processes of change impacting UWS of the study area of Kolkata Municipal Corporation area, in India:

1. What are the key factors affecting urban water security of Kolkata?

2. What are the impacts resulting from the rapidly changing socio-eco-environmental processes within the study area affecting water, sanitation, and hygiene (WaSH)?

3. What is the extent of the ability of the polycentric urban region to attend the varying sustainable and equitable water security at the micro level?

4. How do the social, cultural, economic, political, and institutional factors influence individuals' and specific groups' (groups in vulnerable positions from an intersectional point of view) water security in a megacity?

To answer these questions, this doctoral study presents a comprehensive urban water security (UWS) framework that integrates sustainability issues, inclusive and exclusive social, cultural, economic, and political and institutional factors such as responses, combining indices already demonstrated in the previous chapter (Chapter 5). The integrated framework results in the spatial representation of the Integrated Urban Water Security Index (IUWSI) to create an effective link between bio-physical and social factors.

Integrated Urban Water Security Index (IUWSI) comprises normalized scored of all the indices proposed in the previous chapters, namely WaSH Provisions Index (WPI) (see Chapter 5.1) , Urban Environmental Water Security Index (UESI) (see Chapter 5.2), at the borough level, Urban Water Security Index (UWSI) (see, Chapter 5.3), that means the indicators used for the proposed indices are therefore summated to convert the combined result into a single measurement framework. The IUWSI recognizes the contributing indices are of same weights to reflect same level of intensity in the resultant index.

The Integrated Urban Water Security Index (IUWSI) (normalized) within Kolkata Municipal Corporation (KMC) area, at the borough level, can then be calculated as:

$$IUWSI = (WPI + UEWSI + UWS)\ [0,1]$$

where,

WPI is WaSH Provisions Index

UEWSI is Urban Environmental Water Security Index, and

UWS is Urban Water Security Index.

To validate the IUWSI, the association of normalized scores of its constructing indices at the borough level, were examined to each other and the result of IUWSI, and graphically plotted and mapped.

6.1.1. Synthesis of finding

Since the Integrated Urban Water Security Index (IUWSI) within Kolkata Municipal Corporation (KMC) area has been developed based on the combined (normalised) scores of WaSH Provisions Index (WPI), Urban Environmental Water Security Index (UESI), and Urban Water Security Index (UWSI), the resultant scores represented the similar outcomes. According to IUWSI, borough wise distribution of the scores (figure 6.1.1) suggests that the boroughs X and XII located in the southeast of KMC area are higher in urban water security. The distribution of boroughs with lowest IUWSI scores are concentrated mainly in the southern part of the KMC area (boroughs XIII and XVI) and in the center of the city (borough VI).

Comparing the scores of Integrated Urban Water Security Index (IUWSI) with the scores of other three water security indices in this study (WPI, UESI and UWSI) reveals that within Kolkata Municipal Corporation (KMC) areas, the combined outcome of the scores follows the urban water security index (UWSI) scores more prominently than other indices (figure 6.1.2.). Therefore, the scores from IUWSI showed higher scores for some boroughs, for example, borough XI, where UWSI score was distinctively lower. The similar difference can be seen for boroughs I, II and VIII, where WPI scores were lower, but scores of IUWSI were comparatively higher.

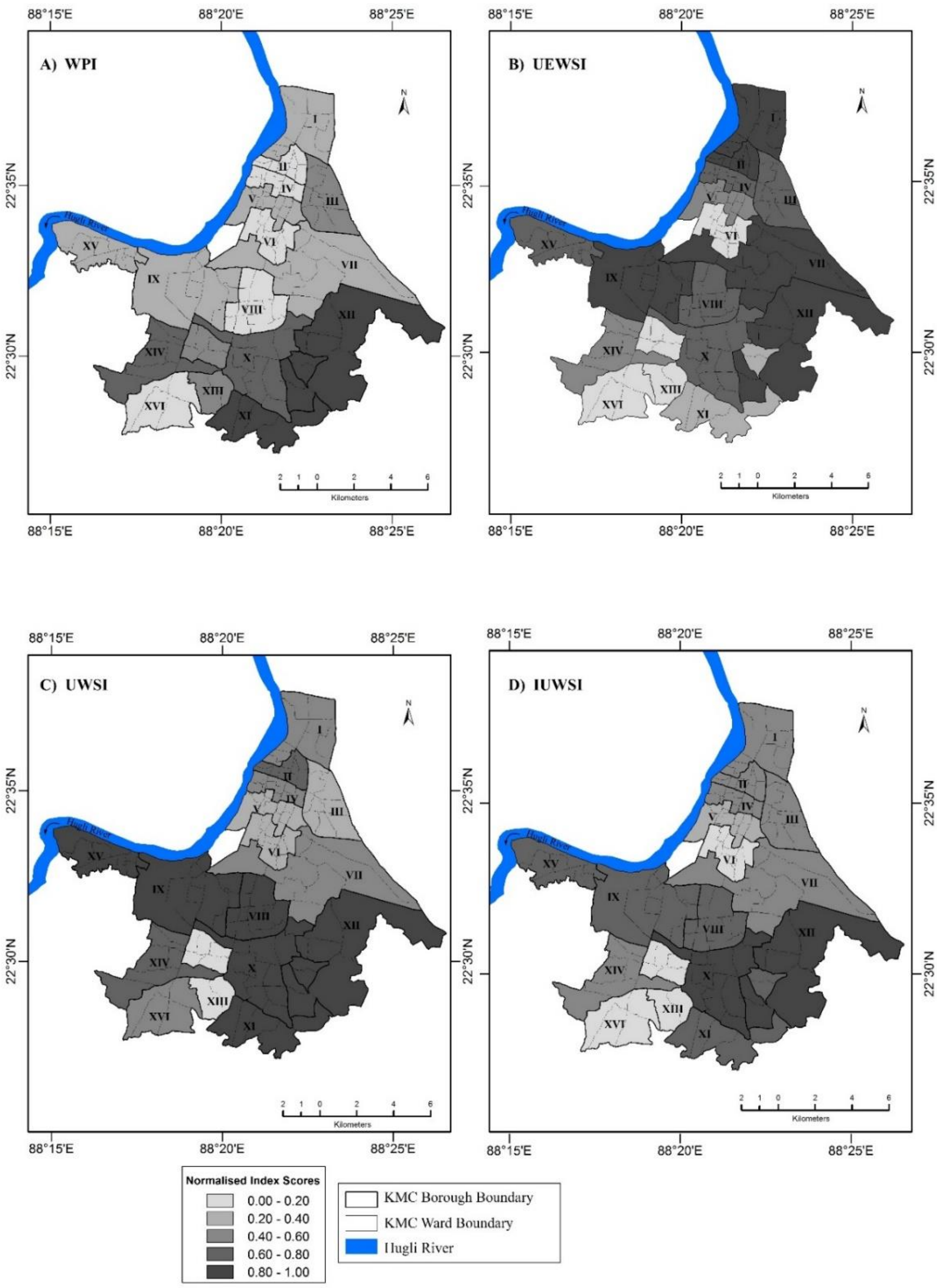

Figure 6.1.1. Borough wise distribution of normalized scores of Urban Water Security Indices i.e., A) WaSH Provisions Index (WPI), B) Urban Environmental Water Security Index (UESI), C) Urban Water Security Index (UWSI) and D) Integrated Urban Water Security Index (IUWSI) within Kolkata Municipal Corporation (KMC) area. Roman numbers mark the borough numbers. Higher scores represent more water security within a borough. Data Source: Indices Scores.

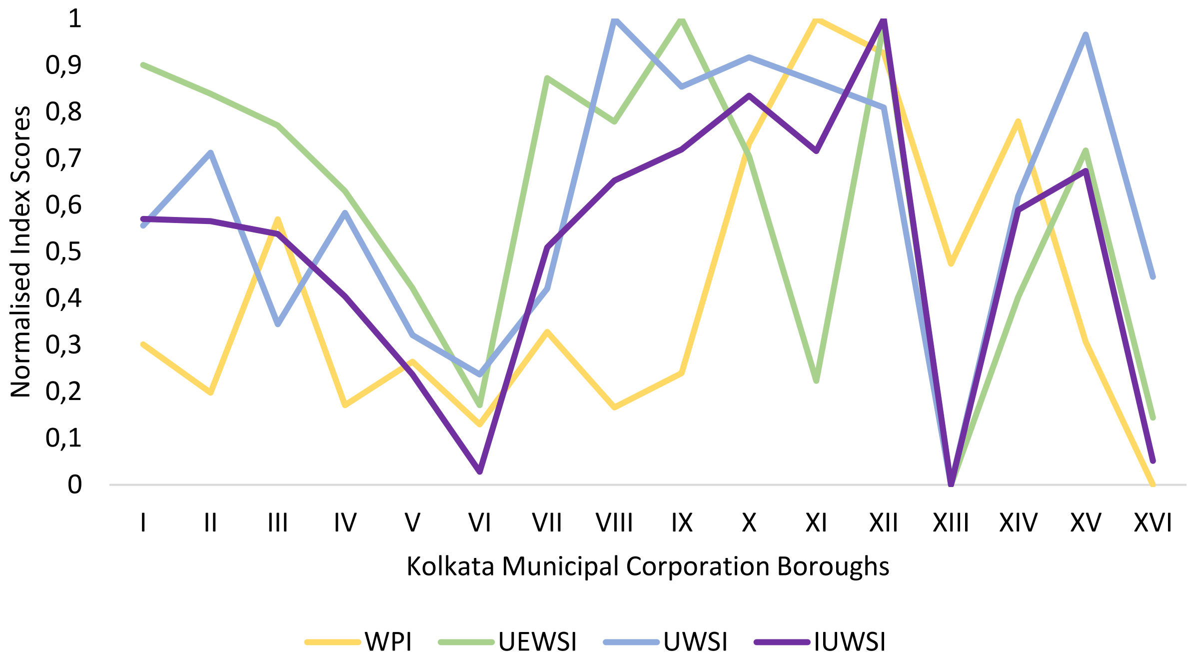

Figure 6.1.2. Borough wise distribution of normalized scores of Urban Water Security Indices i.e., WaSH Provisions Index (WPI), Urban Environmental Water Security Index (UESI), Urban Water Security Index (UWSI) and Integrated Urban Water Security Index (IUWSI) within Kolkata Municipal Corporation (KMC) area. Roman numbers mark the borough numbers. Data source: Survey data (2018-19).

6.1.2. Appraisal of the findings

IUWSI creates an initial evaluation matrix incorporating the key socio-economic factors affecting urban water security of population in Kolkata based on primary data collected in the frame of this study, as well as those of the socially excluded marginalised groups, investigating the trade-offs between urban environmental water security and its peri-urban wetland area. Further, IUWSI indicates the potential to create indices that can reliably measure water security to develop sustainable solutions to fight water insecurity and inequality.

The next sections discuss the key findings of the research while answering the research questions:

1. **What are the key factors affecting urban water security of Kolkata?**

Urban water security lies in the heart of Sustainable Development Goals (SDGs), particularly for but not limited to Goal 6 (Clean Water and Sanitation) intersecting the realm of Goal 5 (Gender Equality) and Goal 11 (Sustainable Cities and Communities). SDG 6 calls particularly for clean water and sanitation for all people, paying special attention to the needs of females and other gendered people, and those in vulnerable situations (Goal 5 & 6.2) by supporting and strengthening the participation of local communities for improving water and sanitation management (Goal 6B). Other SDGs also include different water and sanitation targets, such as:

- end of malaria and other waterborne diseases (Goal 3.3),
- reduction in number of deaths from water and other pollution and contamination related risks (Goals 3.9 and 6.3),
- proper management of water related disasters in an urban area (Goal 11.5),
- chemical wastes to minimize the hazardous impacts on water (Goal 12.4),
- with the focus on protecting the poor and people in vulnerable situations (Goal 11.5), and
- conservation, restoration and sustainable use of terrestrial and inland freshwater ecosystems and their services including wetlands (Goals 6.4 and 15.1).

In lieu of the above-mentioned intertwined SDGs across different dimensions of urban water security, results of the Integrated Urban Water Security Index (IUWSI) also reveals that the combined effect of both bio-physical and social factors affect the water security of a city (figure

6.1.1 and 6.1.2), which vary across the KMC area. Boroughs X and XII have higher scores in both Urban Environmental Water Security Index (UESI) and Urban Water Security Index (UWSI), but according to WaSH Provisions Index (WPI) borough was in the second highest category (score ranges between 0.06 – 0.80) (figure 6.1.10). Similarly, Borough VI scored low in both WPI and UEWSI, which made it to rank the lowest in IUWSI, albeit having not so low scores for UWSI. Similar examples can be drawn from other boroughs too for all the indices including the combined IUWSI.

Thus, water security in a city is driven by a complex and intersecting set of biophysical and social factors – which need to be dealt holistically (Chapter 2). This study found that levels of water security vary within a city and its sub-administrative units (for example, wards, boroughs, districts) as well as within individuals distinctly (Chapter 5). UWS is not only essential in urban planning to manage cities' water infrastructures and strengthen their disaster resilience and adaptive capacities but also to promote inclusive and equitable water governance. Decision making, governance and socio-economic factors, for example gender, caste, religion, along with the bio-physical factors (mainly water availability, water quality and ecosystem), thus, play important roles in achieving UWS. Kolkata, which is under jurisdiction of Kolkata Municipal Corporation (KMC), is a growing megacity in an emerging economy, which is facing immense pressure on water-environmental provision due to the rapid population growth coupled with urbanization and resultant governance and infrastructural issues, used here as a case study.

Based on the results obtained from the satellite data-based land use - land cover classifications, household survey, available literature, and documents from public institutions, this study found that unprecedented population growth since 1980, a changing climate, rapid urbanization, expansion of infrastructure, migration, land conversion and pollution render into changes in the city's water fluxes, water pathways, water stores and water use. Population density and per capita resource-use have been increased dramatically over the past four decades in KMC area. Concurrently, urban ecosystems have undergone substantial modifications that affect the availability, quality, and consumption patterns of the water resources in KMC. Therefore, the following intersecting bio-physical and social factors lay the foundation of the assessment signalling the direction of change required to achieve UWS (Chapter 5):

- **Availability:** availability of both surface and groundwater and where relevant other sources of water (e.g., water reuse, rainwater harvesting etc.), taking account of diversity, quality, and renewability of water.

- **Accessibility:** the extent of access to water for human use, including both domestic and industrial water uses, considering water treatment capacity, coverage, and affordability.

- **Risks and hazards:** the extent of water related risks, including flood risk and health related risks.

- **Ecosystem:** the extent of freshwater ecosystem services in the era of rapidly changing climate and urbanisation.

- **Capacity:** institutional capacity to manage water resources in terms of water supply and water demand, and water-related disasters.

- **Responses:** the effective and participatory nature of the governance and adaptation planning.

Urban Water Security (UWS) addresses various water challenges in a city, including its urban and peri-urban parts, where the issues depend on its physical factors such as water availability in a straightforward manner as well as on its relations to and influences by social, cultural, economic, and political factors. These factors affect security of urban water and related livelihood of the people, environment, and the society combined. For instance, rapid and sporadic urbanisation drives the city's urban water security into a continuous insecure state. In 1980 the urban settlements covered 49% of the total KMC area while in 2014 it almost captured the whole KMC area covering 79% (161.91 km^2) of the total area. Between 1980 and 2014, the space occupied by *wetlands* decreased from 47.15 km^2 (23%) to 8.70 km^2 (4%) (Chapter 3).

Considering this aspect of the multiple functions of water as a resource across the urban landscape, this study found that Hugli river in the west, a huge wetland system in the East and the deltaic plain of Ganga-Brahmaputra could not save Kolkata from becoming a water-insecure city (Chapter 3 and 5). Increased water use associated with domestic and small-scale industries and real estate business is leading to changes in water supply infrastructure, high rates of groundwater use, and new water conveyance networks. Poor and inadequate living conditions and municipal services expose to lethal health and sanitation issues (Douglas, 1983). These problems are especially critical in socially deprived areas, commonly known as slums, *basti* and squatters, in fringe areas (Kundu, 2003; Chapter 5.1). Households in peri-urban fringe areas which includes the newly added wards, such as 101, 141-46, are lacking access to piped water supply from the municipal corporation (Chapter 5.3). The residents must either use the groundwater through hand-pumped tube wells or get access from KMC supports such as water delivery by water trucks few times a week. The increasing number of slum dwellers has been the key concern for urban planning in respect to accessibility of safe drinking water and availability of adequate sanitation facilities (Sau, 2016).

2. **What are the impacts resulting from the rapidly changing socio-eco-environmental processes within the study area affecting water, sanitation, and hygiene (WaSH)?**

Water security essentially ensures availability and accessibility of water for drinking, producing food, washing and maintaining both human and environmental health. The 2011 Census of India reveals that 17.4% of urban households in India live in deprived areas in urban landscapes which are designated as slums in the Census dataset. The increasing number of the people living in these areas poses serious challenges to the provision of basic urban water, sanitation, and hygiene (WaSH) services. This study attempted to assess the present situation of water, sanitation and required hygiene provisions within the areas defined as slums of Kolkata, India. Based on the results obtained from the datasets from the Census of India, 2011, and a simultaneous household survey questionnaire, this study found lack of supplies associated with WaSH provisions in these underprivileged areas of Kolkata. The WaSH provisions in the disadvantaged areas within Kolkata city are facing various issues back to regularity, quality, and quantity of supplied water.

Additionally, there is poor maintenance of existing WaSH services including latrine facilities and the per capita allocation for a sustainable water security among the dwellers of these deprived pockets. Providing required WaSH provision is a human right according to United Nation. Perceived susceptibility of risks from contaminated water and lack of proper sanitation and hygiene needs to be addressed in the light of social exclusion factors. By adding to the existing understanding of the importance of factors such as gender, religions, and knowledge of drinking water in slums the study analyses the links between physical and social issues determining vulnerability and presence of deprivation associated with basic WaSH provisions as human rights of these deprived slum communities.

Results from the analysis of WP Index (Chapter 5.1) shows that 86% respondent from the general caste category have presence of toilet in their houses, but for the SC/ST/OBC it is only 13.6%. The presence of toilet in the house seemed to demonstrate biasness towards Cis-male (25.6%) and female (33.7%) against transsexuals (15.9%) and intersex (13.1%) respondents, Bengali-speaking (82.8%) respondent against other Indian language speakers (17%) and Hindu (86.2%) respondents against Muslims (10.8%) and others (2.6%). 38% of the respondent who are in unorganized business(es) and 69.2% of the respondent who work in the unorganized sectors do not have toilet in the houses.

81% of the total respondent (n = 755), depend on the piped water supply for drinking and among them only 8% use that for household works. 43% of the total respondents are depending on the water from stand-posts. 82.3% respondents are of general (upper) caste that have direct water supply in the house. For the Scheduled Caste or Scheduled Tribes (SC/ST) or Other Backward Castes (OBC), 73% have direct supply in the houses altogether. The majority are the Bengali speakers (83.7%), among them almost 83.4% have direct water supply in their houses. 15.9% of other-Indian language speakers have this direct water supply facilities in their houses. Hindus have the maximum share (86.6% houses have direct water supply facilities). Cis male (34.9%) and females (25.2%) are also having the maximum share of direct piped water facilities in their houses than transsexuals (17%) and intersex (11.05%) respondents. 2.3% respondents who are in unorganized sector of business have direct water supply facility in their houses. For workers in unorganized sectors, only 1.8% has direct water supply facilities within their houses.

3. **What is the extent of the ability of the polycentric urban region to attend the varying sustainable and equitable water security at the micro level?**

Security is the counter function of risk; by and large respected as safeguard or reliability to prevent uncertainty predicted (Xiao and Chen, 2002). Sustainable and equitable water security in an urban landscape can be integrated with environmental water security which offers guarantee against the destruction of ecological integrity and environmental pollution for both nature and the human society, including basic assurance of water and food security, water and air quality and green environment. Evaluating urban environmental water security embodies the ability of human activities by ensuring the security of inland wetlands and related ecosystem services within a polycentric urban region.

Achieving UWS requires sustaining the arrangements between the exploitation of ecological factors which include water-environmental resources and ecosystem services. This achievement not only reduces the pollution and contamination in the environment, level of water stress and provides good ambient water quality but also secures a sustainable future and livelihood. Changes in land-use, land cover and growth of impervious structures can immediately generate severe ecological, and social issues and increase the level of natural or human risks, affecting the condition of ecosystem services within and in the vicinity of an urban region. As a result of these transformations and further exploitation, due to the growing anthropogenic pressure, surface water and groundwater quality can be deteriorated compared to ambient water quality standards (for both chemical and biological pollutants).

Based on land use and land cover (LULC) data retrieved from remote-sensing interpretation, this research computed the changes of ecosystem services values (ESV) associated with the LULC dynamics, water quality and, finally, urban water security during the pre- and post-monsoon periods of 2009, 2014 and 2019 of Kolkata city and its peri-urban wetlands, named East Kolkata Wetlands (EKW) (Chapter 5.2). The area under wetlands has reduced comprehensively during 2009-2019 due to the conversion of wetlands into various other classes such as urban settlements. The quality of surface water bodies (such as river, lake, canal, and inland wetlands) has deteriorated. The groundwater quality is still under control, but presence of iron, arsenic, manganese, and other metals are clear indication of urban expansion and related activities in the area. As a result, there has been a change in the ESV during this time frame. In the pre-monsoon period, there is an increase in total ESV from US$ 53.14 million in 2009 to US$ 53.36 million, and US$ 59.01 million in 2014 and 2019, respectively. In the post-monsoon period, the ESV decrease from US$ 67.42 million in 2009 to US$ 64.13, and US$ 61.89 million in 2014 and 2019, respectively. These changes can be attributed to the peri-urban wetlands and the benefits or services arising out of it that contribute more than 50% of the total ESV.

This study finds that the wetlands has reduced comprehensively in the last decade due to the conversion of wetlands into various other LULC classes in expanding Kolkata city. However, this peri-urban wetland supports the urban water security by providing the enough ecosystem services. Concisely, the transformation in extent of water-related ecosystem is a crucial indicator to urban water security, which also measures the quantity of water contained in various water-related ecosystems. Quantitative analysis of LULC change, hence, is important for studying the corresponding impact on the ecosystem service value (ESV) and water quality that helps in decision-making in securing urban water future and ecosystem conservation.

4. **How do the social, cultural, economic, political, and institutional factors influence individuals' and specific groups' (groups in vulnerable positions from an intersectional point of view) water security in a city?**

Securing water, for both society and environment, accentuates the management of water comprehensively to maintain sustainable growth (Sarvajayakesavalu, 2015; Barbier and Burgess, 2017). Therefore, UWS can be regarded as a '*persistent condition in a limited urban region under which water ecosystems can ensure the adequate access, safety, and affordability of water to meet minimum livelihood standards and human feelings of psychological security'* (Huang et al., 2015, p. 3903).

It also refers to the multidimensionality and the importance of a holistic approach for analysis. Heading towards achieving UWS realizes complex intersecting relations inside and amongst the social, cultural, economic, political, and institutional factors, such as gender, caste, religion, and poverty in urban areas. These intersecting factors vary over steady urban development, shifting socio-cultural patterns of demography, and administration (Brears, 2017). Thus, access to safe and affordable housing, upgrading semi-permanent/temporary settlements in socially deprived areas, investing in infrastructure such as public transport, creating urban public green spaces, and improving urban planning and management in a way that is both participatory and inclusive are all considered objectives of UWS.

This study suggests that the main factors responsible for a water insecurity in a city, despite of presence of no physical water scarcity, are structural inequalities in the society, a lack of comprehensive and efficient water management in places that are already suffering from water stress, as well as a global trend of water consumption that is growing at more than twice the rate of the population increase in the last century (Vörösmarty et al. 2000; Arnell 2004; Hejazi et al. 2014; Myrttinen et al., 2018). The impacts of these dynamics will inevitably vary for different individuals and sections of society, with gender often playing a major, but not exclusive, role in mediating needs, vulnerabilities, and access to coping strategies (Myrttinen et al., 2018). For the purposes of this study, gender refers to the socio-culturally and politico-economically constructed roles, expectations, and responsibilities ascribed to men and women, girls, boys, and persons with other gender identities, which change overtime, are context- and history-specific, and are inseparable from power relations and societal value systems (Myrttinen et al., 2018). Therefore, this study has attempted to address a gender-relational, or intersectional, approach for a city's water security (Chapter 5.3). This approach involves examining the water security of Kolkata city as a concoction of interplays between gender and other identity markers, such as caste, social class, ethnic or religious background or urban/peri-urban/rural setting (along with sexuality, disability, marital status all of which could not be accommodated within the scope of this study and left for future detailed studies). These expectations and cultural norms are constantly co-produced, re-enforced and re-negotiated by and between all members of a given society, with others exercising more definitional power over people who provide certain types of privileges or deprivation in terms of religion, caste, socio-economic classes, and political advantages (Myrttinen et al., 2018).

The research has highlighted the precondition to consider the specific needs and vulnerabilities of sexual and gender minorities including LGBTIQ, for whom violence is a daily experience especially in conflict affected settings more than other gendered counterparts (Castañeda and Myrttinen, 2014). Sexual and gender minorities often face disadvantages due to the existing homophobic discrimination institutionalised in society, government or international institutions or their local representatives (SMUG, 2016). Binary approaches to survey questionnaires or interviews may miss out on seeing the LGBTIQ dimension and subsequently fail to capture such discrimination or additional challenges faced by LGBTIQ persons for enjoying the basic right to water. Investigating local forms of non-binary identities and relationships can help researchers and practitioners to improve their understanding of the nuances of fragility and resilience related to water and peace. Further, such investigation can foster better understanding of the intersectional impact on power and privileges related to water, or the vulnerabilities to violent abuse and support needed. To date, not enough research is open to such nuances, which means that an important dimension is missed out. This can be seen in the examples from Kolkata where LGBTIQ were not considered in any Government report or Census data till date (Chapter 5.1 and 5.3).

Thus, the main take away messages of this study can be summarised as follows:

- Kolkata Municipal Corporation (KMC) area, also known as Kolkata city, has a remarkably high population density of 24,000 people per square kilometre or 63,000 per square mile (according to Census of India-2011). This is one of the world's highest densities. The city itself qualifies as a megacity and covers an incredible amount of surface area that comes to a total of 205 km^2 (79.150 square miles).

- In 1980, the percentage of wetlands within KMC area was 23%, but it has been decreased to 4% in 2019.

- River Hugli is the main source of water supply for the KMC areas. According to West Bengal Pollution Control Board (WBPCB), water in the river does not pass the drinking water standard set by the Government of India. After treatment, it is supplied to households but still about 10% of the recognised household within the KMC area are without any water supply connection excluding the slums.

- According to the latest Census data (2011), there is a serious lack of enough stand post to supply water in these deprived areas. In most of the slum pockets mainly in the centre of the city, the stand post and people ratio are more than 0.04, if in usable condition.

- The similar situation is seen for number of latrines. In centrally located slum areas, one latrine is allocated for more than 25 people; even the quality of that latrine is unmentionable.

- Tube wells are still the common occurrence in slum-households tapping the groundwater beneath the city area, whereas the number of tubewells is extremely low in comparison to the population depending on them. In most slum areas there is only one tubewell for 40 people or more.

- According to KMC report (2019), Kolkata city officially has about 12,000 hand tube wells (hand-pumped) used by especially those living in slums and the floating population that enters and exits during office hours daily and around 2,500 large tube wells mainly catering to multi-storied buildings.

- The city faces high levels of manganese (concentrations exceed 0.3 mg/L) and iron content (even up to 23 milligram per litre in places) in the groundwater which can cause serious ailments. At the same time, however, analysis for arsenic (As) in groundwater samples from across Kolkata, failed to detect As concentrations >10 μg/L from natural processes. That means there is a continuous source of contamination of groundwater from unregulated industrial activities, which is decreasing water security for millions of people slowly but steadily over time.

- Intersecting factors such as gender, ethnicity, religion, and caste matter when it comes to access and availability to toilets and WaSH facilities.

- Gender matters - females stay home and face the tremendous issues with access to WaSH, in the socially deprived areas.

- This issue is even worse for hijra / trans (gender) people. They are not properly registered officially, often live-in high levels of deprivation and poverty and are not able to access work. This means they on the one hand share characteristics and WaSH struggles of those living in poverty but have the double burden of the hostility towards their very way of living and identity. Thus, they often face physical humiliation while fetching water or using the common public latrines.

6.1.3. Recommended Responses

The recommended responses from the study are listed in the following table 6.1.1:

Table 6.1.1: Recommended responses for achieving urban water security (UWS) in Kolkata city excerpted from the study.

UWS issue	Challenges	Recommended responses
Water Availability	Decreasing wetlands and shrinking groundwater level (potentiometric surface)	Determining and ensuring minimum water flows, and regulating the timing of the flows, to maintain rivers and other aquatic ecosystems and their resources and diversity of existing and potential services
		Construction of new wetlands inside the city and at its periphery
		Creating artificial recharge zones
		Promoting, supporting, and developing infrastructures for rainwater harvesting
		Frequent maintenance and protection of piped services and stand posts for water supply in order to avoid leakage and wastage of water due to the missing stopper
		Strict and sustainable urban development policy to plan and implement
		Map out and involve local communities and the varying levels of availability issues along social,

		cultural, economic, and political dimensions and how they overlap with the biophysical.
		Involve communities and representatives from these communities.
		Construct solutions appreciating who is water insecure (deprivation, gender, caste, ethnicity, religion) and how responses affect and resolve issues of inequity in water availability.
Water Accessibility	Less number of inclusive public toilets and insufficient water supply	Implementing policies to control consumer demands for water resources, and specifically managing the distribution of, or access to, water based on needs, including allocating existing water resources according to a hierarchy of neediness, rather than increasing the quantity of available water
		Augmentation of supply of water to all the households
		Increase the number of stand posts to deliver municipal supplied water even to the most remote deprived areas inside, and at the periphery of, the city
		Building new inclusive public toilets and proper management of the existing public toilets for all
		Establishment and management of water ATMs at the important points of the city, e.g. railway stations

		Map out and involve local communities and the varying levels of accessibility along social, cultural, economic, and political dimensions and how they overlap with the biophysical.
		Involve communities and representatives from these communities.
		Construct solutions with appreciation of who is water insecure (deprivation, gender, caste, ethnicity, religion) and how responses affect and resolve issues of inequity in accessibility.
Water Quality	Surface water pollution and groundwater contamination	Reducing the load of contaminants emanating from point and nonpoint sources, including water reuse and recycling and pollution reduction at the source, as well as preventing the entry of such polluting materials into receiving water systems through nonpoint source
		Provisioning sustainable wastewater management
		Restoration and consistent cleaning of the sewage systems, canals, and other inlet points
		Restrict urban and peri urban industries with strict pollution control measures
		Promotion of using biofuels and/or alternative sustainable energy sources to control the heavy metal and other carcinogenic contamination to the nearby waterbodies/aquifer

		Map out and involve local communities to understand how the deteriorated water quality affects populations along social, cultural, economic, and political dimensions.
		Involve communities and representatives from these communities.
Water Risks and Hazards	Increasing rate of seasonal waterborne diseases	Frequent checking and cleaning of roads, waterlogged areas, bushes, and pathways of drainage water.
		An emergency medical team need to be ready, specially, for deprived areas opened for 24x7.
		Map out and involve local communities to understand the health impacts across populations considering inequity and inequality along social, cultural, economic, and political dimensions.
		Involve communities and representatives from these communities to build solutions and responses apt to address issues, build a community wide awareness and sustainable solutions across communities and social strata and in particular in deprived areas, and communities.
	Flooding during the rainy season and water scarcity during dry periods	Routine and appropriate management of the drainage systems to make them ready for, particularly, rainy seasons
		Promotion of rainwater harvesting system

		Creation and restoration of urban wetlands
		Include knowledge about which groups in the populations are already water insecure as a baseline when creating responses to disasters.
		Creating ongoing community involvement with particular water insecure communities which would enable a faster response to and understanding of the impact of disasters and a better ability to respond adequately.
Ecosystem	Rapid urbanisation and loss of green and blue patches	Identifying effects of anthropogenic interventions on service-providing units at different spatial scales
		Consideration of relationships between human, biodiversity and water-ecosystem service provision and management interventions
		Creating, supporting and promotion of infrastructures for vertical and horizontal, wherever applicable urban gardening using harvested rainwater and/or safe grey waters
		Creation of community spaces for meeting, building local knowledge of issues and sustainable solutions e.g., urban garden and spaces for conflict resolutions, these should be accessible to ALL.

6.2. Role of data and statistical analysis for assessment of urban water security in the Global South[6]

Abstract

There is an intrinsic importance of baseline data collection and availability in the public domain at the appropriate scale for the assessment of urban water security. Data at the national level are much easier to access than the city or household level, particularly for emerging countries in the Global South, such as India. Involving citizens in data collection also has potential to resolve this lack of data related to urban water security. The necessity of data availability on urban water security at all levels in the Global South is highly underestimated. Even if data are available, they are either 'summaries' of data or 'representations' of data, which are of little or no use for future research works. Therefore, the value for baseline data collection, cleaning, and further statistical analyses to fill the gaps for further assessments, apart from the need of full data from published works of individuals or departments, are still crucial factors for the sustainable management of the global water resources. This conference paper presents a review of academic literature, policy documents from government organizations and international agencies, and reports from industries and popular media on the role of data collection, utilization and required statistical analyses in key urban water security issues and its worthwhileness, usefulness, and relevance. Amongst issues and concerns to be addressed in this paper are the primacy of institutional responsibilities for data collection, the level and standard of existing data availability with an example from Kolkata, India. This paper also discusses about the existing statistical data analysis options for 'gap-filling' and measurements to provide evidence-based guidance to policy makers and practitioners on securing a city's water future.

Key words: SDGs, data attributes, scales, data attributes, data collection, measurements, indicators

[6] Mukherjee, S., Sundberg, T., Sikdar, P.K. and Schütt, B., 2021. Role of data and statistical analysis for assessment of urban water security in the Global South. *In:* Sahu et al. (eds). *Proceedings of the Virtual International Conference on statistical Tools and Techniques for Research Data Analysis (ICSTRDA -2021)* from 21.01.2021 to 22.01. 2021, organized virtually by Central University of Gujarat, India.

6.2.1. Introduction

Water Security is one of the most *strategic challenges confronting humanity* (ADB, 2016; OECD, 2016; UN-Water, 2017; WE-Forum, 2017; World Bank, 2020). Currently, almost 30% of the world's total population do not have access to an improved and safe water source WHO/UNICEF 2019). More than 4 billion people lack access to improved sanitation (WHO/UNICEF 2019). Water security is *the availability of an acceptable quantity and quality of water for health, livelihoods, ecosystems and production, coupled with an acceptable level of water-related risks to people, environments and economies* (Grey and Sadoff, 2007, pp. 547-548). Water insecurity is increasing, particularly in the Global South and at the same time we have issues of lack of high-quality data that can help us understand the situation and what drives the increase. The issues related to statistical data can be mainly divided into issues around collection of data, lack of skills in analysing data, lack of access to public data (and when accessed it is of poor quality) as well as issues around communicating the results (which in some areas are done very poorly as the analysis is of low quality). Hence, this study considers 5 major dimensions of UWS: water availability, water accessibility, water quality, water risks/hazards and governance to focus on the overview of these issues related to data and measurements.

Water insecurity in urbanized areas generally depends on additional socio-economic factors such as uncontrolled and rapid population growth, poor or inadequate governance and mismanagement of the urban water supply and distribution system. Simultaneously, bio-physical processes such as climate change must also be deemed as a catalyst to the water related threats. Countries in the Global South lack substantial financial capability to mitigate water insecurity issues (Mukherjee et al., 2021). In 2006, Sub-Saharan Africa (31%), Eastern Asia (65%) and Southern Asia (33%) had the lowest coverage of "improved" sanitation (UNICEF, 2006) and the situation has not been improved substantially yet (WE-Forum, 2017). Gender inequality and socio-cultural exclusion factors impact the chance of access to sanitation and hygiene, low income and deprivation are also major drivers in influencing water insecurity in urban deprived areas (Mukherjee et al., 2020).

Impeding our understanding and creating solutions to water insecurity is a lack of good quality data and data analysis. As a result, we are not able to create neither a good understanding of the issues at hand nor the drivers of water insecurity which together leads to difficulties in creating good and sustainable policy solutions to the issues. Disparities among national, regional, and local data availability, accessibility and transparency affect policies and ultimately produce inadequate and inefficient management plans. As a result, management decisions regarding water purification, allocation, withdrawal facilities and reducing loads regarding sewage disposal are flawed or missing (Watkins, 2006).

The overarching aim of this study is to assess issues related to poor quality data and data analysis and to offer strategies to address these. To do so the paper will review academic literature, policy documents from government organizations and international agencies, and reports from industries and media to give an overview of issues and strategies covered.

6.2.2. SDGs and urban water security

Urban areas of the Global South face the challenges of climate change impacts, widening inequities and managing human resources while focusing on employment generation, economic growth, and poverty alleviation (Mukherjee et al., 2021a). A defined time frame is needed to meet national and global aspirations which is also mentioned by the 2015 UN Sustainable Development Agenda Framework. SDG-6 emphasizes on the collaboration between water and water-using sectors. Availability and sustainable management of water and sanitation for all by 2030 is central to the SDG-6 goals. Member states of the UN have agreed to ensure this large task (Mukherjee et al., 2021a). Water scarcity could be a significant brake on economic growth and 40% shortfall in water availability by 2030 is already projected (Bureau of Meteorology, 2017). To achieve global water security through these goals we require a proper set of adequate, standard, and easily accessible database along with the proper statistical analysis of required indicators.

Table 6.2.1. Indicators for global assessment of urban water security in SDG 6.

SDG	*Global indicators*
6.1.1	Proportion of population using safely managed drinking water services
6.2.1	Proportion of population using safely managed sanitation services, including a handwashing facility with soap and water
6.3.1	Proportion of wastewater safely treated
6.3.2	Proportion of bodies of water with good ambient water quality
6.4.1	Change in water use efficiency over time

6.4.2	Level of water stress: freshwater withdrawal as a proportion of available freshwater resources
6.5.1	Degree of integrated water resources management implementation
6.5.2	Proportion of transboundary basin area with an operational arrangement for water cooperation
6.6.1	Change in the extent of water-related ecosystems over time
6.a.1	Amount of water- and sanitation-related official development assistance that is part of a government coordinated spending plan
6.b.1	Proportion of local administrative units with established and operational policies and procedures for participation of local communities in water and sanitation management

(Source: United Nation, 2015; Bureau of Meteorology, 2017; Mukherjee et al., 2021a)

The UN and the World Bank jointly convened the High Level Panel on Water (HLPW). They have released a Water Action Plan in Sep 2016 (UN, 2016) that sets out a detailed approach on steps needed to be taken to avert a future global water security crisis. It has identified access to water data as a key enabling pre-requisite (UN, 2016; Bureau of Meteorology, 2017). Experience from around the world demonstrates that sustainable water management can only be realized with rigorous evidence-based decision making. Thus, we can take evidence-based decisions required for sustainable water management. (Bureau of Meteorology, 2017, pp. 2).

6.2.3. Key attributes of water data required for urban water security assessment

The requirement of data for Urban Water Security (UWS) assessment needs to meet the goals set to reach the objectives (Bureau of Meteorology, 2017). Data attributes are characters by which a data object can be judged and scrutinise its applicability, validity, and comprehensive nature. Data attributes are necessary to know about data and their interrelations with the factors associated with the data. The following list presents the key characteristics on which quality, relevance, and consistency of data rely upon:

1. **Location**: geographical coordinates of the location where measurement is taken
2. **Scale/Level**: at which spatial level the data is taken from
3. **Parameters**: types of data needed for UWS assessment
4. **Temporal Resolution/Frequency**: the time gap between two measurements

5. **Latency**: whether real time or not
6. **Precision level**: the exactness of the data
7. **Legitimacy and validity**: requirements setting the boundary of data governance
8. **Completeness**: how comprehensive the data is fulfilling all the requirements

6.2.4. Scale and urban water security issues

Scale is a crucial component to consider while assessing Urban Water Security (UWS). Recent studies illustrate scalar variability of hydrology affects the assessment of water security where scale is critical (Phare, 2009; Vorosmarty et al., 2010; Cook and Bakker, 2012; Bureau of Meteorology, 2017). The coarse spatial resolution of the study hides significant variables despite its focus on inter-country comparisons (Table 6.2.2) (Phare, 2009; Cook and Bakker, 2012)

Table 6.2.2. Scale factors and issues in urban water security Assessments: crisis and conflicts in different levels.

Scale	***Urban Water Security Issues***
Meta (International)	• Climate Change, • Integrated Water Resource Management (IWRM), • Transboundary water conflict, • Global ecology, • Global economy, • Global politics and international relationship
Macro (National)	• Inter-state water conflict • Intra-state water conflict • Disaster management • Right to equality • National water policy
Meso (Regional/County/State)	• Watershed/River Basin management • Public health • Society • Water tax

	• Waste management
Micro (Household)	• Water accessibility • Water quality • Water-borne diseases • Exposer to risk and hazards • Pollution • Exclusion • Affordability • Waste management

(Sources: Cook and Bakker, 2012; Mukherjee, et al., 2018, Mukherjee, et al., 2021a)

6.2.5. Types of water data needed for urban water security assessment

To assess water security for urban areas, particularly in the Global South, an integrated and comprehensive bio-physical and social framework is needed. To reach the goals set in an integrated assessment framework, the data must be acquired from all possible aspects of environment, society as well as governance. Table 6.2.3 lists the possible parameters to be considered while collecting the data. However, the requirements may vary depending on the objective of the assessment framework.

Table 6.2.3. Types of water data required for urban water security assessment.

Parameters	***Examples***
Meteorologic	rainfall, temperature, wind speed, humidity, radiation, evaporation, transpiration
Hydrologic	surface-water level, discharge, inundation area and depth
Hydrogeologic	groundwater level, hydrostatic pressure, aquifer thickness, hydraulic conductivity, transmissivity, storage coefficient
Storage	bathymetry and level, accessible storage volume, storage inflows, outflows, and offtakes
Usage	amount of supplied water from rivers, aquifers, and other storages, spatio-temporal usage patterns and distribution

Quality	physico-chemical parameters (electrical conductivity, turbidity, temperature, pH, odour)
	bio-chemical parameters (concentration of various metals, non-metals, pesticides, fertilisers, industrial effluents, biologic elements such as algae, virus, bacteria)
Wastewater	volume of wastewater (sewage and sullage), industrial water and stormwater generated
Recycled/regenerated water	volume of wastewater, saline water and stormwater treated, volume of generated potable and nonportable water for reuse
Ecosystem	water needed for maintaining ecosystem needs, health and services obtained from various land use and land cover types
Rights	water ownership, conditions of water license, water transfers (permanent/temporary), water restrictions
Governance	land tenure, number of water connections, household water supply provisions, water revenues and prices, boundaries of water management territories, access to domestic water and sharing rules, inventories of water infrastructure, transboundary water arrangements and treaties

(Sources: Bureau of Meteorology, 2017; Mukherjee, et al., 2018, Mukherjee, et al., 2021)

6.2.6. Use of water data for the urban water security assessment

Use of data for Urban Water Security (UWS) assessment depends entirely on the objectives, priorities and over all requirements of the users (Bureau of Meteorology, 2017). Nevertheless, a general flow of steps for assessing UWS (Table 6.2.4) is followed in the literatures across the broad areas of water security studies. The levels of details and uniqueness needed vary according to the defined criteria and decision-objectives. Analytical tools such as statistical packages are also a decisive factor based on the need of the assessment.

Table 6.2.4. Steps and determinants for urban water security assessment

Step no.	*Step*	*To estimate/determine*
1	**Dimensioning**	- Sufficiency of water storage to fulfil the water demand, - Utilization patterns, - Spatio-temporal variability in usage and distribution of water resources, - Tarde offs between water demand and supply during the extreme events
2	**Reviewing**	- Efficacy of water policy and governance instruments - Water sharing arrangements between upstream and downstream - Allocation of water for environmental water needs - Changes in water quality due to anthropogenic activities
3	**Monitoring**	- Realtime monitoring of water parameters for infrastructures in operation - Hydrometeorological conditions - Allocation of water for various purposes from the storage
4	**Estimating**	- Current and future changes in storage, allocation capabilities, usage and forecasted scenarios - Running the models for prediction and decision making for water demand -supply trade-offs for various scenarios
5	**Designing**	- Selection of appropriate parameters for water infrastructures - Calculation of the optimum size, capacity, and timing for water infrastructure - Idealise and planning for alternatives

6	**Evaluation**	- Measuring accountability of the water system - Maintaining transparency - Necessitating arrangements for water management - Ensuring water security, environmental justice, and sustainable future
7	**Capacity building**	- Providing water literacy - Strengthening people's involvement in decision making process - Public engagement for awareness generation

(Sources: Bureau of Meteorology, 2017; UN, 2017; World Economic Forum, 2017; WMO, 2017; Mukherjee, et al., 2018, Mukherjee, et al., 2020, Mukherjee, et al., 2020a, Mukherjee, et al., 2021)

6.2.7. Sources of water data with their advantages and disadvantages

Data for UWS assessment can be obtained from various sources. Broadly, there are 5 major sources (Table 6.2.5), from which data can be collected by direct measurement, inference from Remote Sensing of stationary (normal handheld photographic camera), airborne (arial cameras) or spaceborne (satellite) platforms, estimation from statistical modelling, government reports or census repots used for administrative purposes and data generated through public/community participation (collective data production). There should be different advantages and constraints associated with these data collection/generation processes related to accuracy, comprehensiveness, spatial coverage, consistency or temporal frequency, acceptability, and cost. However, the assessment framework must determine and prioritise the data required and then its probable sources can be identified and selected.

Table 6.2.5. Sources of data required and their advantages/disadvantages for urban water security assessment.

Provenance	*Methods*	*Advantages*	*Disadvantages*
Direct measurement	- Hydrometeorological measurements - Survey	- Higher accuracy - More representative - Ground truth correction is easy - Higher periodicity - Greater frequency - Higher quality	- Prone to human error - Depends on weather and other biophysical and social circumstances - Instrument calibration and other machinery issues can occur - Time consuming - Sometimes relatively expensive - Difficult or impossible for physically and/or socially inaccessible areas - For sample surveys, representativeness may issue - Need to focus more on detailing than other methods
Remote Sensing	- Active sensor: A measuring instrument in the earth exploration-satellite service or in the space research service by means of which information is obtained by transmission and reception of radio waves (RR) waves.	- Larger area coverage for multiple scales - Repetitive coverage for time series analysis - Access to inaccessible	- Comparatively expensive in most cases - Requires special technological training skills and sometimes expensive. - Prone to have human error

	▪ Visible/Infrared: Light detection and ranging LIDAR ▪ Microwave: 400 MHz to 94 GHz ▪ Synthetic Aperture Radar (SAR) - Passive sensor: A measuring instrument in the earth exploration-satellite service or in the space research service by means of which information is obtained by reception of radio waves of natural origin. ▪ Visible/Infrared: Imagers, cameras, spectrometers ▪ Microwave: 1 000 MHz to 2 500 000 MHz	areas and objects - Wide ranges of usage - Availability of state-of-the-art technology for various analysis and interpretation - Easy and harmless to objects and the environment for data collection - Relatively cheaper in some cases	- Instrument calibration can lead to accuracy error - Difficult for socio-economic data collection and analysis - Storage issues for high resolution data
Estimation from derived variables from statistical models	- Mathematical transformation of a direct measurement (ex: river discharge, water quality index etc) - Gap filling in continuous data records - Predictive modelling for analysis and forecasting - Sensitivity analysis - Model fit	- Low cost - Useful for creation of coefficient - Data gaps can be filled scientifically - Minimal response issues	- Variability of acceptance of terms and usability - Human error can mislead the entirety - Transformation of scale may produce ambiguity - Inefficient or poor analysis produce

	- Uncertainty analyses - Synthesise the large amount of complex information (ex. PCA) for both bio-physical (such as climate models), source apportionment (ex. Sources of Air pollutant identification) and socio-economic (ex. cost benefit analyses) assessment	- User defined outcomes for better analysis - Scientific production	higher and inevitable errors and scopes - Access to metadata and microdata may not be easily available - Usability can be limited
Administrative data collection	- Household and business survey - National/regional census - Tax collection - Administrative documentation through public, legal and business agencies	- High productivity and updating capacity (if possible) - Data collection from different scales can be achievable -	- Low periodicity in many cases, particularly for the Global South - Updating, maintenance and accuracy can be questionable - Missing or low capacity of efficiency in the public sector to handle such data and measurement/analysis techniques - Lack of coordination between departments and agencies - Political will
Participatory data generation	- Focus group survey - Household survey - Community fora - Newspaper reports	- Representative and inclusive data collection - In depth issues can be noted	- Difficult to compress raw data - Subjective, contradictory and opinionated views can create complexities

	- Other communication media posts such as social media posts -	- Local and individual issues which can be absent from the other sources, such as Census, can be obtained - Visually engaging methods for socio-economic data collection - Generation of new ideas and aspects are very likely	- Time consuming - Difficult to organise - Efficiency to conduct the interviews matters highly

(Sources: Rao, 1994; Parvathi, 2011; Bureau of Meteorology, 2017; UN, 2017; World Economic Forum, 2017; WMO, 2017; Mukherjee, et al., 2018, Mukherjee, et al., 2020, Mukherjee, et al., 2020a, Mukherjee, et al., 2021)

6.2.8. The problems and consequences of having inadequate water data and analysis

Across the globe, water management practitioners, water security researchers and other different agencies who deal with water have a common issue, i.e., data. With discrepancies in data, the analytical interpretations vary and become unusable or misinterpreted or inadequate in most of the cases. This problem ultimately reflects on the decision making and finally people suffer. Particularly, in the Global South, the problem is manyfold and when it comes to the mega cities with a few millions of populations within a short spatial boundary, data issues and related water security management becomes a nightmare and stagnant forever.

The problems associated with the poor quality or inadequate data are as follows (Kumar and Ballabh, 2000; Bureau of Meteorology, 2017):

- 'Blindness': When water data lacks information regarding the locations, sources, quality and the end users of the water, identification of risk, taking proper and pragmatic management decision and mitigation strategy fails.
- 'Ignorance': When data are not reliable, inconsistent, and contradictory, wise policy and planning decision cannot be solidified.
- 'Wastage': Poor or inadequate data and resulting issues such as inconsistency, invalidity, and incomplete decision fail to address the problems and finally conclude in less investment in water infrastructure and unsustainable resource allocation. These creates void in generating and integrating environmental, social, and economic values together.

The consequences of the inadequate data and poorly carried out statistical analysis are (Bureau of Meteorology, 2017; Mukherjee et al.,2021):

- 'Mistrust': Inadequate and inaccessible data sources generate confusion and uncertainty among water users, policy makers and national/international communities, making water insecurity at its worst.
- 'Summaries of data': Means, medians, modes, maxima, minima concentrations/water level for a data set, rather than the entire data which denies the reader the opportunity to assess the quality of the data or to use them for further mining of the data/future research.
- 'Non-inclusive': Having no or inadequate data on socio-economic objectives including data on caste, class, gender, sexual orientation which are considered to be separated or excluded in the society, particular in the conservative set up of the governments in the Global South ends up in a silo or fragmented conclusions which lack the completeness of the UWS assessment to achieve the holistic approach.

6.2.9. Strategies for statistical analysis for urban water security assessment in the Global South

To overcome the data and issues related to analysis of Urban Water Security (UWS) assessment in the Global South careful planning and sensible selection of data and thorough execution of strategic framework based on statistical analyses are required. Statistical analyses present quantitative information about the status and shifts in water security conditions based on spatio-temporal changes in adequacy, accessibility and quality of the water resources, the impact of natural events and human activities on the physical and social environment. These tools generate usable knowledge about both the bio-physical and socio-economic instruments, transforming uncertain knowledge with the knowledge of the amount of uncertainty, to help taking essential decisions to mitigate the negative impacts and reinstate water security (Rao, 1994). Cities in the Global South where data is sparse, inconsistent, and mostly inadequate due to various reasons (mainly financially burdened), Statistics play a crucial role providing a range of multi- and interdisciplinary information based on wide variety of data (UN, 2017). Therefore, the logical and methodological steps in statistical analysis required in UWS assessment are suggested in table 6.2.6.

Table 6.2.6. Strategic steps and elements in statistical analysis used in urban water security assessment.

Steps	***Elements***	***Considerations***
Formulation of specific objectives	Prioritising objectives	Setting up an effective Urban Water Security (UWS) assessment strategy for identifying the priority objectives to select the data requirements
Data collection and management	Strengthening institutional arrangements	Identification, selection and establishing collaborative networks with best equipped and important institutions for collection, distribution, analysis, and usage of data already identified for optimise the collective benefits of the stakeholders
	Improving monitoring systems	Setting up or improving the established networks required to gather necessary data
	Standardising data	Maximising the utility values of the data for monitoring, collection, curation, analysis, dissemination and transmission among the stakeholders, institutions, and academia globally with transparent and efficient methods
	Provisioning of access and licensing water data	Recognising and evaluation of policies and governance for data access and licensing arrangements to make the process of data access easy and unburdened
	Designing and operation of information systems	Focusing on maximising the effectiveness of the water data information systems to meet various levels of

		accuracy, feasibility, maintainability, and dependability of the UWS assessment strategy
	Quality management	Assuring the quality for adapting measurements and curation practices for long-term, trustworthy, and efficient use of data
	Participatory activities for data generation, collection, and management	Engaging individuals and community participants in the data collection, generation and management decision making process for the holistic analysis of UWS
Initial exploratory detective analysis	Cross examination of data	Includes detection of outliers, errors, bias, faking, internal consistency, external validation, special features, effective population represented by data
Statistical Modelling	Specification or choice of Stochastic models	Determining how to use expert opinions and findings from the previous experiments through cross validation, Bayesian analysis etc.
Inferential data analysis	Application of statistical methodology based on a chosen stochastic model for observed data	Estimating unknown parameters such as points, intervals etc., testing specified hypotheses, prediction of future observations, regression analysis, discriminant function analysis, Maximally Separated Cluster Analysis, Canonical coordinates, Principal Component Analysis, and other related analyses
Results display and decision making	Presentation of assessment results and guiding future direction	Presenting summary statistics or graphical display, making decisions etc. Communicating the results of the statistical analyses with the public and more importantly to policy makers in a comprehensible manner as well as provide a guideline for future investigation(s).

(Sources: Rao, 1994; Parvathi, 2011; Bureau of Meteorology, 2017; UN, 2017; World Economic Forum, 2017; WMO, 2017; Mukherjee, et al., 2021)

In the field of UWS, statistical analyses are essential to enable a synthesized arrangement of data from various sources, streamlines the complex urban water issues for easy and correct measurements, helps to prioritise the objectives for decision making according to the relevance, and finally integrate the issues together within an umbrella assessment framework reducing redundancy and discrepancies present in the data.

To overcome the challenges associated with inadequate, poor quality and nonstandard databases to meet a range of bio-physical (mainly related to water availability, quality, demand-supply, and infrastructure) and socio-economic (related to marginal population, migrants/daily commuters to the city, economic status etc) objectives, a comprehensive assessment strategy was considered. The comprehensive Urban Water Security Assessment Index (UWSI) was, therefore, designed and computed by aggregating the indicators' value (normalized). This study has considered both simple additive weighting (SAW) and Principal Component Analysis (PCA) methods. The steps are described below (Figure 2). The result is a graphical display (Figure 3) showing the spatial distribution (Borough wise) of UWS Index, within Kolkata Municipal Corporation (KMC) area, which can be used for further analyses and decision making in prioritising objectives for sustainable and secured urban water future of the city.

6.2.10. Conclusions

One of the biggest challenges the Global South face regarding UWS is data. Inadequate, unreliable, low quality, socio-politically as well as technologically biased, non-inclusive and unorganised databases are among the many issues that the Global South experiences regarding data collection, generation and properly assessment through well-selected statistical techniques. Hence, without a strong scientific knowledge on UWS, the cities in the Global South lack proper management of its water resources and the demand of the growing population. With the progress in Remote Sensing technology, global bio-physical databases can be easily available and accessible with cheaper or no cost, but it only provides bio-physical data bases up to a certain scale and without direct data and/or information on the larger socio-economic objectives. Therefore, the UWS assessment is losing its holistic and inclusive properties which can never achieve water security.

Steps for identification, collection and analysis of data and statistical tools for UWS assessment need to start with prioritising water security objectives. Thus, strengthening water data institutions, establishing sustainable water data monitoring systems, adopting water data standards, and embracing an open data approach to water data access and licensing are essential. Employing water data quality management processes and generating different scenarios for future data requirement, management and archiving through sophisticated and advanced research based on well-selected statistical analyses are proven to be important. Therefore, this review concludes with a note on implementing effective water data information systems and engaging communities for participatory activities for data generation, collection, and management must be prioritised for the assessment of UWS for a sustainable water future of the cities in the Global South.

6.3. Sustainable governance of groundwater as drinking water in the Post CoViD-19 World: An urban water security perspective[7]

Abstract

Groundwater is a finite and irreplaceable resource that is fundamental to urban water security and only renewable if well-managed. An inclusive urban groundwater governance, which includes clear policy, regulations, and guidelines, is mandatory for the well-coordinated and sustainable use of this precious resource by different stakeholders. The coronaviruses (SARS CoV, MERS and SARS-CoV-2) have not been detected in groundwater yet but has been detected in the faeces of individuals infected with coronavirus. Therefore, the spread of coronaviruses is closely related to wastewater and sanitation. Secured provision of safe water, sanitation and hygienic conditions is essential for protecting human health during this pandemic outbreak, especially in urban areas, already under stress due to the higher water insecurity. Thus, protecting wellheads, maintaining safe distance from septic tanks or sewer lines, reusing and recycling of water, reducing wastage of water, managing the quality to be used as drinking water and ensuring the safeguarding from any contamination can have a positive impact during and after the CoViD-19 pandemic. This chapter aims to summarize and analyse the adequacy of the already existing governance frameworks for allocation and management of groundwater for the purpose of its use as drinking water, by assessing the various international policies, regulations, guidelines as well as management practices for both the current pandemic situation and post CoViD-19 world in the light of urban water security. The objectives are to investigate the criteria and considerations for effective groundwater governance and exploring the gaps in existing policy-guidelines to overcome the barriers to inclusive groundwater governance for the time of pandemic and beyond, particularly in the urban system.

Key words: Human Rights, Contamination, Excessive and illegal extraction, Land Subsidence, Groundwater Sustainability Plan

[7] Mukherjee, S., Sikdar, P.K. and Pal, S., 2021. Sustainable Governance of Groundwater as Drinking Water in the Post CoViD-19 World: An Urban Water Security Perspective. Legacy, *In:* Mohapatra et al. (eds). *Legacy, Pathogenic and Emerging Contaminants in the Environment*. CRC Press. (in Press)

6.3.1. Introduction: CoViD-19 pandemic and urban water security

COVID-19 (Novel Coronavirus Disease 2019) is a respiratory infectious disease caused by a newly discovered or 'novel' coronavirus. There is no evidence as of now to prove COVID-19 is related with drinking water. Neither the novel coronavirus has been detected in drinking water. To keep the drinking water protected from any contamination and maintain its quality, guidelines for drinking water, in general, employ a multi-barrier approach to ensure safe and quality drinking water for the citizens. They are designed to safeguard savouring drinking water from three different aspects:

1. Safeguarding source water: Water utilities get their drinking water from the best quality and most secured sources possible. This lessens or eliminates the danger of contaminating from entering the water system in any case.

2. Treatment: Water utilities use filtration and additional purification with chlorine to treat drinking water whenever necessary. Chlorine is exceptionally compelling in killing biological organisms including virus and new research suggest that this method will be compelling in eliminating COVID-19 too.

3. Monitoring: Water utilities assemble water test samples at any rate from hourly to monthly. In case any possible contamination is detected, the guidelines and further planning can be shaped to advise the beneficiaries and recommend steps necessary to guarantee their security. Unfortunately, numerous water systems utilizing groundwater wells do not have perpetual purification techniques in built in India (Ghosh, 2010; Singh, 2017). This does not imply that these sources are in danger, yet they may show even more challenges to manage as the extra hindrance may be fatally disruptive for the recommended Water, Sanitation and Hygiene (WaSH) guidelines during and after Covid-19 pandemic (DOH, 2020).

i. Groundwater as drinking water

A recent study shows that globally around 2.5 billion individuals exclusively depend on groundwater to meet daily drinking water requirements (Grönwall, and Danert, 2020). The dependence on this subsurface resource and its centrality to appreciate the basic right to 'safe' drinking water has increased profoundly. Nevertheless, this appreciation has not been widely recognised at the national level by the governments and policy makers. Utilization of groundwater has been fundamental to human development, from both cultural and ecological perspectives, for their reliance on groundwater and its related ecosystem services since the beginning of the human history (Singh, 2017; Velis et al., 2017). For example, production of food and energy from groundwater fed agriculture, groundwater as a main source of safe drinking water, sanitation, and hygiene as well as recreational and cultural activities including some religious rituals associated with the oasis in the dry desert areas (Machard de Gramont et al. 2011; Velis et al., 2017). Its vital significance for worldwide water and food security is most likely to get intensified under rapidly shifting environmental as well as socio-cultural scenarios as more continuous and serious climate change related fluctuation in precipitation, surface water availability and soil moisture will occur more frequently (Velis et al., 2017). The dependence on water from subsurface water sources, such as springs, has stretched out more complexed way over the past 50 years, with the advancement in technology to drill and pump (for example: introduction and augmentation of better developed techniques such as jetting, percussion, auger and sludging) for an instantaneous access to groundwater (van der Wal, 2010; World Bank, 2010). The general increase in public health awareness and related societal values should have been more moved essentially towards the conservation of this vital resource. In many places on earth, the comprehension of the asset's vitality is exceptionally limited, especially the issues related with the availability, the maximum level of abstraction and the recharge to replenish even among the decision makers. Lack of information implies that data on groundwater stays as obscure as the resource itself. These result in jeopardy as behaviour and extent of the contamination present in groundwater, their interrelationship and interaction with the present and shifting patterns of land use and land cover over the ground, and prediction of the emerging contaminations in the drinking water are all not clear and confirmed yet. Till date, groundwater is being extensively used as the main source of drinking water worldwide, but a proper level of awareness and account for groundwater quantity and quality has not been achieved (Grönwall, and Danert, 2020).

ii. Crisis: pandemic-issues and water insecurity

A widely available and accessible WaSH (Water, Sanitation and Hygiene) provision is essential for the concealment and treatment of Covid-19 (Cooper, 2020). Coronavirus is an infection with no demonstrated treatment or drug intervention and no demonstrated antibody detected so far. In such conditions, care and prevention are all we have. The part of handwashing in the avoidance of transferable diseases has been known for longer than a century, yet it remains seriously ignored as a general wellbeing mission, to be occasionally resurfaced during pandemic-scale diseases. Over 26% of the worldwide populace has no provision to a handwashing mechanism in their houses (Ray, 2020); for some developing nations, this extent rises to even over half of the total population (Ray, 2020). In some cases, the clean water is unreasonably expensive, or the compliantly has been stopped by virtue of unpaid bills (Mukherjee et al., 2020; Ray, 2020). In any case, when there is no water in the home or nearby premises, or no system for ensuring enough and safe water, widely advised handwashing is just incredibly difficult (Mukherjee et al., 2020; Ray, 2020). Even before COVID-19, various analyses worldwide already showed the fallacy of absence of necessary funds, lack of investment in providing enough WaSH provisions and the low number of people under the available schemes for the benefits of having WaSH provisions at their acceptable range (Trémolet and Trémolet, 2011; UN, 2014; WWAP, 2018; Mukherjee et al., 2020), indicated the crisis from a different point of view which this current pandemic took advantage of and spread more widely. This aspect is not a local issue any further and proved to be the essential for international governance and investors to organize and substantially reserve reliable, affordable, acceptably safe and enough water to be supplied to the deprived areas of the world. Covid-19 pandemic is an unprecedented global phenomenon and needed to delt with enough dignity, respect, and considerations (Cooper, 2020).

This chapter analyses the present pandemic strategies and endeavours to identify the groundwater as drinking water within the framework of urban water security issues, focusing on India, which may face problems relating to groundwater and subsequently become a crucial factor for drinking water shortage in the vicinity. This study attempts to delve into governance aspects mainly that govern groundwater availability, accessibility, quality, and related environmental risks in any urban India.

6.3.2. Groundwater related issues for urban areas

i. *Availability*

The availability and occurrence of groundwater in the Indian sub-continent is overly complex because of the existence of differentiated geological formations with significant variations in lithological and chronological characteristics, complex tectonic background, climatological variations, and several hydro-geo-chemical conditions. Previous researches have showed that aquifer groups in alluvial or soft rocks even exceed the surface basin boundaries (CGWB, 2012). Some of the major basins (for example: Brahmaputra, Ganga/Ganges and Indus basins) in India (broadly, the Indian subcontinent) accommodate potential aquifers with high yielding capacity (Mukherjee et al., 2015). Nevertheless, the distribution of usable groundwater in the region varies considerably and the continuous availability of safe water from many of these aquifers (for example, part of Brahmaputra and Ganga Basin in West Bengal, known as Bengal Basin) is hindered by the presence of natural contaminants (Sikdar, 2018). Moreover, the trans-boundary nature of some of these aquifers makes groundwater resource a potential politically sensitive issue. Being one of the most densely populated areas in the world, the use of groundwater is also extremely high in the Bengal Basin (Mukherjee et al., 2015). The major hydrogeological units in India are depicted in figure 1. For details, please see Jain et al. (2007) and the Aquifer Atlas of India by CGWB (2012).

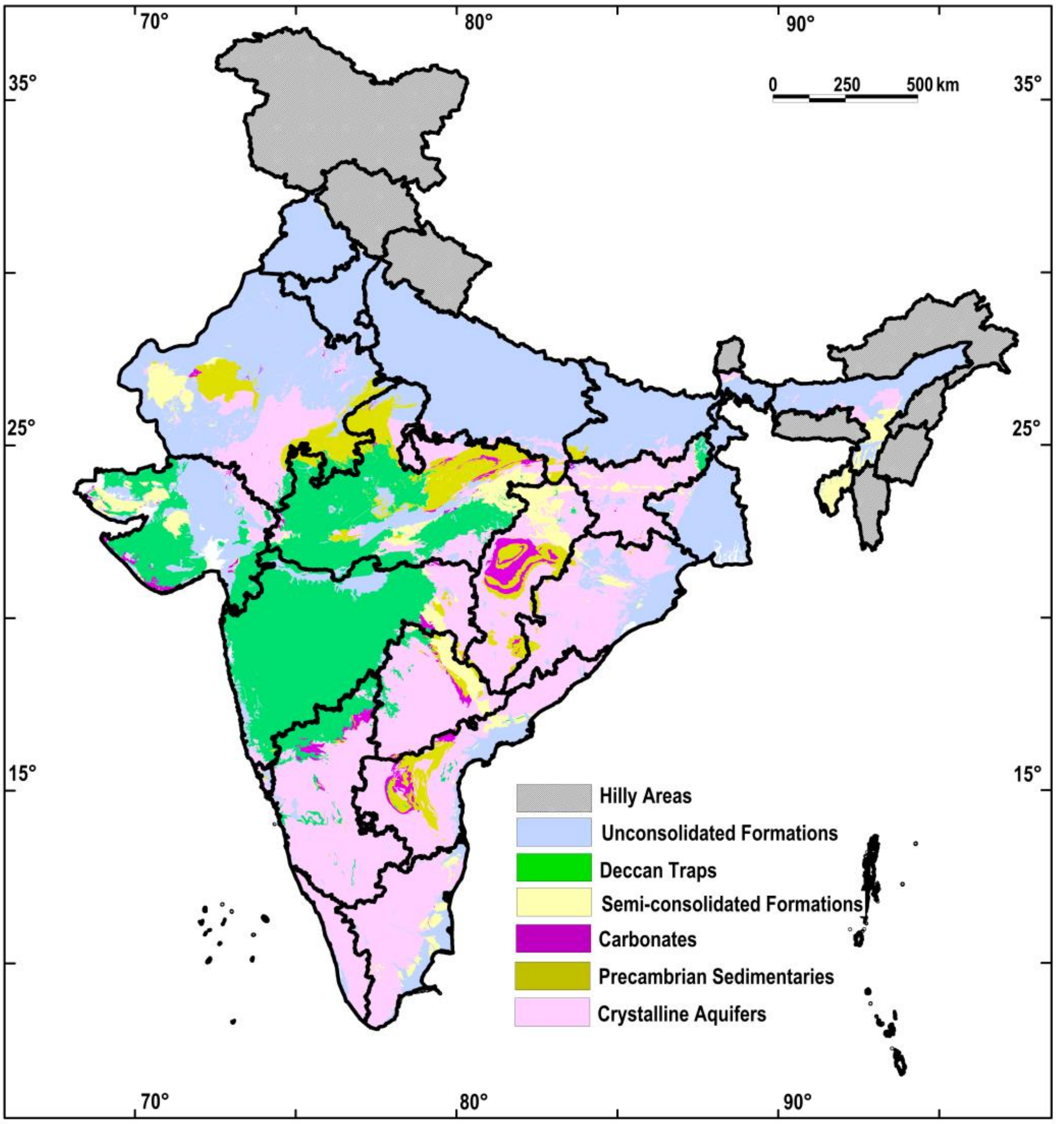

Figure 6.3.1. Major hydrogeological units in India. (Adapted from the Aquifer Atlas of India. Data source: CGWB, 2012.

Preventing and curing a pandemic requires enough safe water for all as hand hygiene is critical for lessening transmission of contagious diseases like Covid-19 and handwashing with polluted water may increase the risk of infection (Hannah et al., 2020). Therefore, water demand for all will increase during a pandemic for both the health issues as well as the general consumption. Demand for clean water increased during the previous global health crises such as Ebola plague in West Africa during 2014 (Cooper, 2020a). This increased demand for water for domestic purposes and public health could pressure on both downstream for wastewater generation and upstream for negotiating trade-offs between agriculture and other industries (Joshi and Nicol, 2020). Redirecting water from agroindustry for use in urban communities could influence food creation, while keeping up water for farming could imply that urban areas do not have sufficient supplies to battle pandemics. The actual picture of the reliance on groundwater and its extent in the Indian urban areas is not still clear due to the lack of proper and valid data at the household level. In Indian urban households, groundwater is supplied through three main methods: a) public supply by the local urban authority which is solely dependent on groundwater for the source of water or, b) private access to bore wells or shallow wells inside /close to premises, and c) semiformal and casual trading of direct groundwater (Narain, 2012a). While, the official documents from the responsible authorities (including Central Ground Water Board and the Ministry of Water Resources, River Development and Ganga Rejuvenation) on urban water supply and its reliance on groundwater are having disagreements regarding actual and estimated demand-supply of water and generation of wastes (Grönwall et al., 2010), researchers found that more than half of the urban households in 71 studied urban areas in India during 2011-2012 were reliant on groundwater for various purposes including drinking (Narain, 2012b). Furthermore, almost 33% of households across India are legitimately dependant on groundwater for drinking purpose, and the households in smaller urban areas are occupying maximum portion of it.

This sudden and huge increase in water demand may also increase more struggle among the already contesting drivers such as rapidly growing population, sporadic urbanization, and shifting pattern of consumption (WWAP/UN-Water, 2018). Every year, water demand is raising at a rate of about 1% and the most of it goes for agriculture (WWAP/UN-Water, 2018). With the increasing pressure from the rapidly changing climate, continuous deforestation for both commercial and agriculture and encroachment of lands turning into paved areas are already put several burdens on the water availability and quality worldwide and the gravity of danger can already be felt during this pandemic (UNEP, 2016). Natural environmental change is reshaping the worldwide water cycle bringing about magnified unpredictability in freshwater availability, most of which is sourced from the groundwater. This incorporates shifting patterns of precipitation designs, melting glaciers, changing river courses and extended surge in both water scarcity and quality; and inevitably, resulting stress (Smith et al., 2019; Cooper, 2020a).

The reliance on groundwater is essentially based on the subsurface geology of the urban areas. Urban areas situated on the alluvium plains and with canals have the best natural aquifers underneath and potential to high groundwater recharge capacity. On the contrary, urban areas on the unfractured crystalline rock are not capable of natural development of sub-surface water table (Banks et al., 2002). Therefore, these urban areas are bound to depend on surface waterbodies more than groundwater. Urban areas from the Decan Peninsula are the distinct examples of this later type (Patel and Krishnan, 2009).

The urban areas (cities/towns) in India situated on the rocky aquifers such as crystalline rocks, basalt and limestone, covering 30%, 15%, and 3%, respectively of total geographical area of the country (Patel and Krishnan, 2009), lack enough groundwater to use and hence, these urban areas widely depend upon surface water (Table 6.3.1).

Table 6.3.1. Relationship between aquifer and reliance on groundwater

	Aquifers					
	Alluvium and Sandstone discourse	Aquifer in Hilly Areas	Basalt	Crystalline Rocks	Extensive Alluvium	Limestone
No. of Towns	78	19	43	70	84	2
Average of groundwater supply in overall water supply	44.1	47.34	8.23	21.1	74.84	42.12

Source: NIUA, 2005; Patel and Krishnan, 2009

Consequently, rapid, and sporadic urbanisation in these areas put direct stress on surface water which ultimately pressure heavily on the nearby irrigation reservoirs. These phenomena directly impact the water productivity through the inefficient use of water for the urban households and industries, as well as indirectly impact the groundwater storage and quality because the growing urban area surpass the supply capacity of the local aquifer, mainly for the drinking purposes; the quality of groundwater deteriorates with increased contamination through geogenic processes. Thus, inadequate (in both quantity and quality) local groundwater sources drive the urban areas to import water from outside the urban limits (World Bank, 2003).

Table 6.3.2. Basin wise groundwater supply in India

		Number of Cities/Towns	Average groundwater supply (%)
Basin	Barak	5	11
	Brahmani-Baitarn	3	66.7
	Brahmaputra	5	21.8
	Cauvery	17	7.4
	Ganga	109	67
	Godawari	18	5.4
	Indus	21	66.0
	Krishna	26	14.0
	Luni	16	36.0
	Mahanadi	5	27.6
	Mahi	4	51.0
	Narmada	5	28.2
	Pennar	8	48.0
	Sabarmati	3	40.9
	Tapi	5	0

Source: NIUA, 2005; Patel and Krishnan, 2009

Basin wise groundwater supply of the urban areas in India (Table 6.3.2) reveals that Ganga, Indus and Brahmani-Baitarn basins have the highest groundwater supply (> 60%). Among other basin level urban areas in India, Tapi river basin has no groundwater supply. Nevertheless, Mahi, Sabarmati and Pennar have adequate groundwater supply (> 40%). As groundwater supply heavily depends on the aquifer characteristics as mentioned earlier, Krishna, Cauvery and Godavari river basins which majorly pass-through rocky aquifers in the Decan Peninsula, due to the less retention capacity of subsurface, groundwater supply is poor (Patel and Krishnan, 2009).

ii. Accessibility and human right to water

While groundwater is used practically to meet up 50% of all drinking water worldwide, around 2.5 billion individuals rely exclusively upon this asset to fulfill their daily water requirements (Kulkarni et al., 2015; Mukherjee et.al., 2020a). Accordingly, it is essential to apprehend groundwater reliance, quantity and quality issues and estimate the requirement. However, such information is likely be an underestimation as valid measurement often lacks data on all sources utilized at the household level (World Bank, 2006). While almost 85% of the Indian population depends on groundwater for drinking, hand pumps or bore wells are the main sources of drinking water in rural areas of both India and Bangladesh (World Bank, 2006, 2010; WWAP/UN-Water.2018). In developing sub-Saharan nations, including Somalia, Central African Republic, Burkina Faso, Nigeria, Chad, Ethiopia, South Sudan, Uganda etc groundwater is the only source of drinking water for almost 80% of the total households (Grönwall and Danert, 2020). In wealthy countries, such as the USA, 38% of the population directly relies upon groundwater for drinking water purposes. The demand is met either from public well or privately installed wells. In Southeast Asian and Pacific countries, 79% of the population drink groundwater (WWAP/UN-Water.2018; Grönwall and Danert, 2020).

Groundwater for domestic use can be drawn from various ways, particularly for deprived urban areas, commonly known as *slums*. It may be drawn or siphoned from a solitary well (i.e., scoop openings, burrowed wells or shallow or profound boreholes/handpumps etc.) which is either private or shared with a network, a neighbor, or a non-governmental organization (NGO). The well may be associated with a 'water ATM' (a computerized machine controlling drinking water abstraction) or groundwater may be conveyed through water-booths, standpipes or casual delivery trucks and big haulers (Mukherjee et al., 2018; Mukherjee et al., 2020). It can be devised to be disconnected from tubewells, bore-wells or springs and provided as a major part of a public and/or private water supply framework. In any case, individual groundwater-based water system should not be encouraged and must be widely controlled by the governments or regulatory bodies in order to minimize the exploitation and increase the accessibility even to the poorest. Often, groundwater is utilized distinctly for other household purposes than drinking, consideration and control should be there on both quality and quantity which are mostly ignored or overlooked for the deprived areas, especially during the pandemic. Other than that, the human rights to water and related legal issues with groundwater should be confirmed and governed by the public authority(s) or responsible vendors acting on behalf of public-private partnership arrangements, with the end goal that is 'self-provided' (Mukherjee et al., 2020).

Standard approaches of mainstream policy recommendations do not consider groundwater as the most critical source for drinking water for households. The significance of groundwater as a vital resource is not extremely obvious in the discourses on how the world is going to ensure enough, affordable, and safe drinking water for all by 2030 or achieve the overall Sustainable Development Goals (SDG). Additionally, scarcity of good and reliable data on groundwater from the valid sources also play crucial role in proper assessment and absence of which can result in under-researched or incomplete policy documents. This crucial gap in groundwater data has jeopardized the research and policy documents and normative statements from the reputed international agencies such as the United Nations (UN) by prohibiting reports like *United Nation (UN) World Water Development Report for 2022 on groundwater.* The World Bank has made a thorough study on this data crisis in 2019 and reflected their concern over groundwater data availability and reliability issues (Mukherjee et al., 2020).

It is the human right that everyone should have physical access to sufficient, acceptable, affordable, and safe water for individual and household use. Alternatively, human right to sanitation (*a system for collection, transport, treatment, disposal, or reuse of human excreta and associated hygiene* according to UN, 2014) empowers everyone to have physical access to safe, protected, hygienic, affordable, socially, and culturally acceptable sanitation services which, most importantly, provide privacy and ensure dignity (UN, 2014; Mukherjee et al., 2020). Decades-long opinion about the content and implications of these rights has been formally recognized as the human right to water and sanitation (HRWS) in 2010 by UN member states (Mukherjee et al., 2020). According to the recent literatures, water security can be referred to "the secure, adequate, and sustainable access that people and ecosystems have to water, including the equitable distribution of advantages/disadvantages related to water use and development opportunities, the safeguarding against water-based threats, and the ways of sharing decision-making power in water governance" (Grey and Sadoff, 2007, p20; Boelens, 2013, p238). Right to water security includes rudimentary rights and benefits, conceptualized in accordance with a given frame for interpreting them. Although lack of detailed data on groundwater fails the right that can respect, protect and fulfil groundwater use and management from the aspects of the specific content of the right or the responsibilities of governments (Grönwall and Danert, 2020).

iii. Quality

Presence of contaminants in drinking water is one of the most concerning issues for every household. The sources and pathways of these contaminants as well as pathogens (including the novel corona virus/SARS-CoV-2) are many (Kumar et al., 2020a; Kumar et al., 2020b, Mohapatra et al., 2014, Mohapatra et al., 2020). It can come from the supplied water itself to the households due to the leakages in pipes or even old age of the entire pipe system which is a common phenomenon in the older urban areas across India (Roy, 2013; Kumar, 2014; Varma, 2014; Sharma, 2014). Although, public water supply systems are accountable for and bound to check the filtration and distillation system thoroughly before the supply, whereas, for the private supply agencies this accountability is not always guaranteed. For the households, where groundwater is directly used for drinking, the sources of contamination are different. The sources can be traced in the associated aquifers in these cases. Since traces of corona virus have been found in wastewaters, it is crucial to notice that direct outlets of wastewater in the surface waterbodies, such as lakes, canals, rivers can also pollute groundwater in the nearby unconfined aquifers. Possibility of this sort of pollution can be higher in the megacities or areas where excessive and illegal pumping groundwater occurs.

Besides many anthropogenic sources, such as contaminations through leakages in domestic sewage system underground or dumping of wastes in the surface waterbodies (for examples, lakes in mega cities like Bengaluru) where artificial groundwater recharge system is installed (Gronwall et al., 2010; Kozhisseri, 2005; Singh et al., 2010; Wankhade et al., 2014), some natural traces of contaminants are also found in the aquifers. Geogenic substances like flouride and arsenic in aquifers are a genuine reason to worry in parts of West Bengal, Andhra Pradesh, Rajasthan, and Gujarat (Chowdhury et al., 2000; Andezhath and Ghosh, 2002; Sikdar, 2018). Additionally, effluents from the industries, such as dyeing and bleaching industries in Tirupur (Senthilnathan and Azeez, 1999), small, medium, and heavy industries in Ludhiana (Kakarand Bhatnagar, 2008) and Coimbatore (Mohanraj et al., 2000) pollute aquifers significantly. Other than these, anthropogenic pollutants like organochlorine pesticides including prohibited ones like DDT and HCH were detected in the groundwater of Delhi (Mukherjee and Gopal, 2001; Mutiyar et al., 2011), Hyderabad (Shukla et al., 2006), and Jaipur (Bakore et al., 2004).

Lack of infrastructural facilities can be linked with contamination in groundwater. Open defecation or existence of pit latrines can be the source of organic contamination in the nearby aquifers particularly when the groundwater table is higher during the monsoon in India. These examples can be found in the added areas of a megacity or urban fringe areas. Moreover, there is the chance of contaminating drinking water inside the house even with improved public sources. Studies show that there is probability of water pollution associated with storage systems at the household level (Jensen et al., 2002; Wankhade et al., 2014). Particularly in the deprived areas (generally designated as slums) in a city, this problem is more critical even if the source of the collection of the publicly supplied treated water is safe and properly monitored (Palit et al., 2012; Wankhade et al., 2014). According to the government and other international official reports, just half of the urban households have water filters or similar facility (IIPS, 2007; NSSO, 2013). Lack of data and information available on the public domain regarding the quality issues of supplied and used drinking water also aggravates the severity of the urban water security issues.

iv. Environment and risk factors

At the household level, groundwater extraction from the private wells is the cheapest and the most reliable way for access to drinking water when there is either irregularity in public water supply services or affordability is an issue in case of private water vendors (Wankhade et al., 2014). Most of these private wells are not even been known or notified by the outsiders than the household(s) or the locality involved in the illegal existence and usage of the private wells. In Chennai, it was found that the price of the water from the privately owned tankers was even 50 times more than the municipal water supply or using a private well (Srinivasan et al., 2010). It is surely a question of affordability even for the owning of a private well for many households. It is also an issue of land, particularly for the deprived areas where land tenure is a big issue of insecurity. Despite of having enough surface water for supply, to reduce the price for the treatment and related maintenance costs and heavier investment requirements, sometimes, public supply services also directly distribute groundwater to meet the increasing demand of growing urbanization (World Bank, 2010; Mukherjee et al., 2018; Mukherjee et al., 2020).

Thus, without sufficient and regular public water supply facilities, informal and illegal groundwater markets have been developed in certain pockets of the urban areas across India. These informal and basically unorganised business sectors have not been sufficiently studied and focused yet for further development at the policy level. Therefore, these unorganised and overlooked sectors continue to remain outside the domain of policy and planning guidelines. Nevertheless, departments of urban water in both Chennai and Kolkata municipal corporations have arranged private distributors to pay for groundwater for supplying in the added peri urban areas in the vicinity of the main city through tankers (Srinivasan et al., 2010; Wankhade et al., 2014) to lessen the pressure on the existing and depleting water tables.

This widespread and almost abundant reliance on groundwater can be linked to some laws that authorize the landowners of households or private company or even from the public body to extract unlimited water from aquifers. In the Easement Act of 1882 water has been recognised as an easement of added benefit inseparably linked with land. This is further strengthened by the Transfer of Property Act of 1882 and the Land Acquisition Act of 1894 (Iyer, 2007; Saleth, 2009; Wankhade et al., 2014). It has been an uphill task for the Central Groundwater Authority to regulate such indiscriminate withdrawal due to large number of bore wells and non-availability of alternate sources in many areas (Narain, 2012a). Meanwhile, cities are increasingly going beyond their administrative limits in search of groundwater. For example, the water utility service in Chennai pays for groundwater to the farmers in peri-urban areas (Wankhade et al., 2014).

The increasing reliance on groundwater has numerous negative outcomes: the most obvious outcome is falling of urban water table (Lalchandani, 2011; Ghosh, 2012; Wankhade et al., 2014). Water tables are typically depleting in newly added areas which are profoundly reliant on groundwater because of the lack of infrastructural facilities or services, while water levels can rise or stay unchanged in the other parts, predominantly the older parts where the water services are comparatively stable and often connected with piped water supply. This increase in groundwater reliance has a few outcomes: the most unmistakable one being exhaustion of metropolitan springs. With regards to metropolitan groundwater, the predominant story one finds in the mainstream media is one of quickly draining metropolitan springs (Lalchandani, 2011; Ghosh, 2012; Wankhade et al., 2014), but considerably more nuanced. Inside a similar urban area, water tables are normally depleting in those areas which are intensely subject to groundwater, as water levels are ascending in the more seasoned areas which mostly connected with piped supply. This variety is fundamentally a result of high paces of spillage from supply pipes and wastewater pipelines (CGWB, 2011). Comparatively smaller urban areas (towns) than megacities, like Lucknow in Uttar Pradesh (Foster and Choudhary, 2009), Jodhpur (Paliwal and Baghela, 2006) and Ajmer in Rajasthan (Jat et al., 2009), Pune and Solapur (Naik et al., 2008) in Maharashtra, Hubli-Dharwad (Hollingham, 2008), Bangalore (CGWB, 2008; CGWB, 2010; Narain, 2012a; Wankhade et al., 2014) and Mulbagal (Nadhamuni,2012; Sekhar, 2011) in Karnataka appear to adjust to this characterisation (Wankhade et al., 2014).

Excessive and unplanned groundwater extraction pressures on the aquifer continuously even beyond its limit (Wankhade et al., 2014). Mostly, coastal urban areas which are intensely reliant on groundwater face the danger of saltwater intrusion because of the sudden change in pressure brought about by continuous and increasing groundwater extraction. There are many evidence of the saltwater intrusion along the coastal urban areas in India for the last few decades, such as Tamilnadu (Ramesh et al. 1995), Kerala (Raju et al., 2007) and Gujarat (Moench,1992; Shah,2008). Extreme extraction of groundwater can equally cause interruption of polluting surface water from rivers, canals, or lakes (Foster and Choudhary, 2009). Furthermore, the pressure on the groundwater is increasing becoming the reason for land subsidence in the urban areas, consequently (Sikdar et al.,1996; Sahu and Sikdar, 2011).

6.3.3. Perspectives of groundwater as drinking water in urban India: SDGs, drinking water standard and groundwater laws

Over the past years the development pathway of India has been directed by the key priorities of generating employment, enhance economic growth, meeting food, water and energy security, disaster resilience and poverty alleviation. Restoration of its natural capital and adopting transparent and robust governance following democratic lines have also been attempted (Mukherjee et al., 2018). Emerging challenges such as impacts climate change, increasing inequities, and lagging human development indices are also well recognised by both the citizens as well as the government. The post 2015 UN Sustainable Development Agenda framework offers an opportunity to regenerate and incorporate attempts to meet national and global objectives in a specified timeframe (Mukherjee et al., 2018; Mukherjee et al., 2020).

SDG 6 demands for collaboration between the water and water users and shift beyond their conventional disintegrated ‘silos’ to integrate the ecosystems in consideration and manage water to achieve the already defined impact-oriented goals. For example, SDG 6.6 specifically requires nations to “protect (by 2020) and restore water-related ecosystems, including mountains, forests, wetlands, rivers, aquifers, and lakes” (Mukherjee et al., 2020).

While the overall proportion of households in India with access to improved sources of clean water was 68% in 1992-93, after almost two decades the figure has increased to 90.6% in 2011-12. On the other hand, still 8% of urban households did not have access to improved sanitation facilities in 2012. The number of open defecations in India was almost 600 million– the highest in the world. Improving sanitation is a key priority of the government (Wankhade et al., 2014).

i. Drinking water quality

Drinking water includes treated or untreated water supplied or procured for human consumption. While specifications for drinking water quality in India (IS 10500:2012) is prescribed by the Bureau of Indian Standards surface water classification for designated best use based on quality (Table 6.3.3) is provided by the Central Pollution Control Board (CPCB).

Table 6.3.3. Surface water Classification based on designated best use set by the Central Pollution Control Board, India.

Designated-Best-Use	**Class of water**	**Criteria**
Drinking Water Source without conventional treatment but after disinfection	**A**	• Total Coliforms (TC) ≤ 50 MPN/100 mL • 6.5 ≤ pH ≤ 8.5 • Dissolved Oxygen (DO) ≥ 6mg/L • Biochemical Oxygen Demand (BOD) (5 days 20°C) ≤ 2 mg/L
Organised outdoor bathing	**B**	• TC ≤ 500 MPN/100 mL • 6.5 ≤ pH ≤ 8.5 • DO ≥ 5 mg/L • BOD (5 days 20°C) ≤ 3mg/L
Drinking water source after conventional treatment and disinfection	**C**	• TC ≤ 5000 MPN/100 mL • 6.0 ≤ pH ≤ 9.0 • DO ≥ 4 mg/L • BOD (5 days 20°C) ≤ 3mg/L
Propagation of Wildlife and Fisheries	**D**	• 6.5 ≤ pH ≤ 8.5 • DO ≥ 4 mg/L • Free Ammonia (as N) ≤ 1.2 mg/L
Irrigation, Industrial Cooling, Controlled Waste disposal	**E**	• pH between 6.0 to 8.5 • Electrical Conductivity (EC) (at 25°C) ≤ 2250 µS/cm

		• Sodium absorption Ratio ≤ 26 • Boron ≤ 2 mg/L
	Below-E	Not meeting any of the above criteria

Indian Sub-Continent has diverse geological formations from oldest Achaeans to recent alluviums (CGWB, 2012). Various parts of the country are characterized by varying climatic conditions as well. Sub-surface geological formations and depth of the sediments through which groundwater remains in contact influence the natural chemical content of groundwater. In major part of the country, groundwater is of as such of good quality and suitable for drinking, agricultural or industrial purposes. Groundwater in shallow aquifers, predominantly of calcium bicarbonate and mixed type, is generally suitable for use for different purposes. Other types of water (such as sodium-chloride type water) are also available (CGWB, 2012). Although groundwater quality in deeper aquifers similarly fluctuates from place to place, it is usually found appropriate for public uses. Salinity problem in the coastal tracts and high incidence of geogenic contamination (fluoride, arsenic, iron, heavy metals etc) in different pockets have also been reported. Table 6.3.4 provides a list of various geogenic contaminants found in groundwater in different parts of the country along with their health implications.

Table 6.3.4. Various geogenic contaminants found in groundwater according to Central Ground Water Board (CGWB). Data source: CGWB, 2012.

Contaminants			Situation
Salinity	inland salinity	• Prevalent mainly in arid and semi-arid regions of Rajasthan, Haryana, Punjab, Gujarat, Uttar Pradesh, Delhi, Andhra Pradesh, Maharashtra, Karnataka, and Tamil Nadu • EC ≥ 10000 mS/cm at 25°C in several places in Rajasthan and southern Haryana • Can also be caused due to surface water irrigation without consideration of groundwater status • Gradual rise in groundwater levels leads to water logging and heavy evaporation in semi-	• Makes ground water non-potable • Well water used directly for salt manufacturing by solar evaporation

		arid regions lead to salinity problem in command areas.	
	coastal salinity	• Dynamic coastline of India is ~ 7500 km • Western coast: characterized by wide continental shelf and marked by backwaters and mud flats • Eastern coast: has narrow continental shelf; characterized by deltaic and estuarine landforms • Groundwater in coastal areas occurs under unconfined or confined conditions in a wide range of unconsolidated and consolidated formations • Origins of saline water bodies: entrapped sea water (connate water), sea water ingress, leachates from navigation canals constructed along the coast, leachates from salt pans etc.	• Salinity problems observed in a number of places in most of the coastal areas • Following situations are encountered in coastal areas: a. Saline water overlying freshwater aquifer b. Fresh water overlying saline water c. Alternating sequence of fresh water and saline water aquifers
Fluoride		• At places found in high concentration in groundwater beyond the permissible limit of 1.5 mg/L	• Consumption of fluoride rich water poses health problem
1) Arsenic		• Occurs naturally in the environment as an element of the earth's crust • Combines with other elements such as oxygen, chlorine, and sulphur to form inorganic arsenic compounds • Arsenic and its compounds are widely used in agriculture, livestock feed, medicine, electronics, metallurgy, chemical warfare agents etc. • Introduced in soil from parent rock during pedogenesis and further in groundwater during weathering of rocks followed by leaching • May also be introduced from human-induced sources such as arsenical pesticides, fertilizers,	• Transport and distribution of arsenic in environment is complex continuous cycling of different forms of arsenic through air, soil and water • In groundwater inorganic arsenic is present, commonly as arsenate (As V) and arsenite (As III)

	irrigation, dust from burning of fossil fuel and disposal of industrial and animal wastes • Reported in elevated concentrations in groundwater particularly affecting the large parts of the Ganga- Brahmaputra Plains • Found in high concentration beyond permissible limit of 0.01 mg/L in groundwater in 18 States in India • Aquifers in the alluvial plains embedded within the Late Quaternary deposits are reportedly affected with a few exceptions in Chhattisgarh and Karnataka where hard rock aquifers are also affected • Concentration in groundwater is marked by wide spatial variability • Depth wise contaminated water is generally found to be confined within 100 m in alluvial aquifers.	
Iron	• Observed in high concentration of (>1.0 mg/L) in groundwater in more than 0.11 million habitations in India, including states of Andhra Pradesh, Assam, Bihar, Chhattisgarh, Goa, Gujarat, Haryana, J and K, Jharkhand, Karnataka, Kerala, Madhya Pradesh, Maharashtra, Manipur, Meghalaya, Orissa, Punjab, Rajasthan, Tamil Nadu, Tripura, Uttar Pradesh, West Bengal and UT of Andaman and Nicobar.	
Nitrate	• Quite common constituent especially in shallow aquifers groundwater • Main source is anthropogenic activities • Found in high concentration in groundwater in almost all hydrogeological formations in India	• Consumption of water having concentration beyond the permissible limit of 45 mg/L poses health problem

ii. The National Water Policy (NWP)

India had revised the NWP in 2002 with the following significant elements relevant with urban water security:

- Formation of National and State level data banks to observe and scrutinize the demand and supply;
- Supporting the conversion of available water resources into utilizable water;
- Unconventional and improved methods for efficient water use;
- Supply of water from water excess areas to water scarce areas;
- Judicious allocation of water for diverse uses and pricing of water to secure sustainable development;
- Regulation on ground water exploitation and monitoring of water table using modern, improved and efficient scientific techniques;
- Sustainability of existing water bodies, involving all the stakeholders specially local communities at all levels;
- Private-Public Partnerships (PPP) for water resource development and distribution;
- Master plan for flood control, by linking different rivers and promoting soil conservation measures;
- Development of drought prone areas through watershed development, afforestation and sustainable farming practices;
- Interstate water sharing policy and timely addressing of disputes.

iii. State Acts and Regulations of groundwater

Most States and the Union Territories in India have either enforced laws regulating use of groundwater or have Bills pending final approval. However, such legislations are limited in applicability to certain notified geographical areas. The system is generally based on the setting up of State level authorities for implementation, and on user registration and prior approval of licenses.

In India, the groundwater right is not vested within the government and its authorities, neither considered as the Central Government’s prerogative. It is a State subject and only individual States, and Union Territories are responsible for legislation on water (both surface and groundwater) related issues (except the irrigation sector). The following list shows laws, regulations, and Bills (the legislature has been adopted but not yet passed or received the final assent) enacted by individual States, also including the Union Territories, in India:

- Andhra Pradesh Groundwater (Regulation for Drinking Water Purposes) Act, 1996, and the Andhra Pradesh Water, Land and Trees Act and Rules, 2002;
- Assam Groundwater Control and Regulation Act, 2012;
- Bihar Groundwater (Regulation and Control of Development and Management) Act, 2006;
- Chennai Metropolitan Area Groundwater (Regulation) Act, 1987;
- Delhi National Capital Territory (NCT) Groundwater Regulation Directions, 2010;
- Goa Groundwater Regulation Act, 2002;
- Himachal Pradesh Groundwater (Regulation and Control of Development and Management) Act, 2005;
- Jammu and Kashmir (J and K) Water Resources (Regulation and Management) Act, 2010, and J and K State Water Resources Regulatory Authority Regulations, 2013;
- Karnataka Groundwater (Regulation for Protection of Sources of Drinking Water) Act, 1999, and the Karnataka Groundwater (Regulation and Control of Development and Management) Act, 2011;
- Kerala Groundwater (Control and Regulation) Act, 2002;
- Lakshadweep Groundwater (Development and Control) Regulation, 2001;
- Maharashtra Groundwater (Regulation for Drinking Water Purposes) Act, 1993, and the Water Resources Regulatory Authority Act 2005, Maharashtra Groundwater (Development and Management) Bill (yet to be notified), 2009;
- Puducherry Groundwater (Control and Regulation) Act, 2002;
- West Bengal Ground Water Resources (Management, Control and Regulation) Act, 2005.
- Chhattisgarh Groundwater (Regulation and Control of Development and Management) Bill, 2012 (pending);

- Haryana Groundwater Management and Regulation Bill, 2011 (pending);
- Odisha Groundwater (Regulation, Development and Management) Bill, 2011 (pending);
- Uttar Pradesh Groundwater Conservation, Protection and Development (Management, Control and Regulation) Bill, 2010 (pending).

6.3.4. Groundwater governance framework: towards an integrated and inclusive framework during- and post- CoViD-19 related to groundwater crisis in a city

There is a need to make a differentiation between management and governance of groundwater resource. Management approach is based mainly on the daily activities necessary for intrinsic and spontaneous tasks to fulfil certain objectives to reach the organised achievement or goals. Consequently, the management supports the useful and compelling approaches to accomplish certain objectives or destinations but holistic. On the other hand, groundwater governance provides a system that can help in viable administration of water assets through advancement of capable aggregated activity to guarantee socially manageable usage and successful assurance of groundwater resource to support both human and environment. The fundamental principles of groundwater governance are transparency in legality and data, investment, participatory decision making and the accountability for both the users and the controller of the resource.

Groundwater is a non-renewable resource; thus, vulnerable against extreme use and abuse by stakeholders who may attempt to utilize it for their own momentary gains instead of contemplating long-haul sustainable necessities for others. Groundwater as a non-renewable resource along these lines requires the hands-on utilization of a strategic framework that incorporate contemplations such as transparent demarcation of limits through a clear set of resource assessment, management strategy and distribution policy, obligation, stakeholder interest, data accessibility, straightforwardness, and legality. Groundwater governance accordingly incorporates components of socio-hydrogeological settings while making associations and coordinated efforts to protect and sustainable use of aquifers.

Groundwater governance requires considering the geographic scale at which decisive strategies should be prepared. Even though groundwater aquifers are generally widely distributed, there is a need to have a clear demarcation of the system boundary to implement the appropriate governance over the resources at different levels of geographical scales. As groundwater is not bound to a particular administrative boundary or, even, geographical area, the implementation of strategic governance arrangements can be, most likely, influenced by both physical environmental and socio-political factors to deal with the crisis of groundwater exploitation. In a country like India, it is exceptionally challenging to design at the state or provincial level as hydrogeological settings are varied even inside a single state to govern groundwater distinctively without ignoring the requirements at the other administrative levels. Additionally, because of complex hydrogeologic distribution and characters, in many cases, it is more important to comprehend the aquifer characteristics at the local level instead of the higher geographical levels to plan for the governance strategies.

The difficulties to overcome the overburdened, and ever increasing, reliance on groundwater, mainly for drinking purposes, in India are numerous where groundwater over extraction is not just prompting fast exhaustion of the resource itself, yet additionally offering ascend to water quality issues in a circumstance where the reaction at the degree of governance strategy keeps on being non-decisive. Current governance and management policy framework for groundwater in India for conjunctive use and management of groundwater is given in figure 6.3.2.

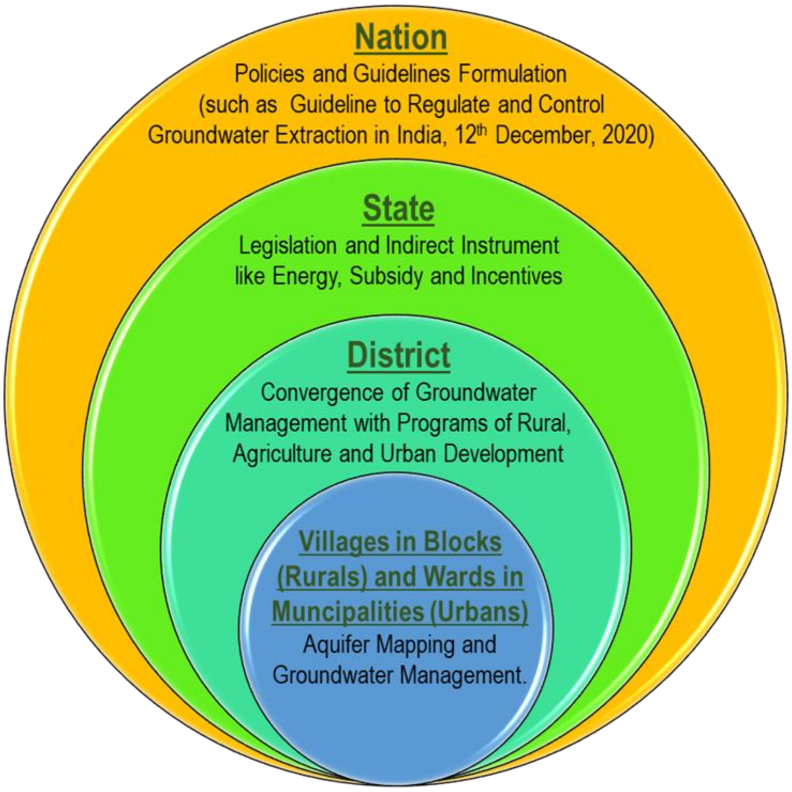

Figure 6.3.2. Current governance and management policy framework for groundwater in India. Data source: Kulkarni et al., 2015.

Since aquifers are the crucial level at which groundwater governance should be outlined, there is next to no awareness and reliable data about the study of hydrogeology and aquifers among the individuals, the ones who are the most reliant on groundwater and use it to meet their daily water needs, particularly for drinking purpose. Then again, hydrogeology and the data on aquifers has stayed limited to formal scholastic circles who have had remarkably less association with its application at the individual level. The comprehensive knowledge on hydrogeology and aquifers hence needs to shift from the areas of simple scholastic understanding to deciphering and interpreting it for individuals in a multidisciplinary and inclusive way for even the lay persons to be included in the governance framework for groundwater as an important stakeholder. Thus, a continuous effort needs to be implemented for capacity building through participatory processes.

The requirement for robustness at the aquifer-level data for comprehensive understanding of the ground level scenarios is especially significant for structuring groundwater governance strategies. Additionally, the challenge of scaling up this data from the individual to higher geographical scale levels to design and draft suitable governance strategies for groundwater is a crucial task for a sustainable future. Data accessibility regarding availability of groundwater (such as aquifer mapping) and potential discrepancies at the national level to be easily accessible at the individual level would be another challenge for the decision makers. Transparency and accountability are the two important aspects in this regard which need to be properly addressed in the strategic framework of groundwater governance. This attempt to create an easily accessible data pool can also be advantageous for effective planning and management of the resource. Engaging local communities and increasing the ways of stakeholder participation in the entire planning process of groundwater governance would benefit the process of generating and validating local level data which in turn ease the difficulties for various decision making at the management level.

Coordinated efforts and bridging communication gaps within the partners and their allies are hence crucial for a successful governance of groundwater at its spring-shed level scale. Silo approach at the policy level to envision the challenges as compartments segregate groundwater from its vital components such as surface water. Considering them as a single entity will also be helpful for governing the entire water resources prioritizing their horizontal connectivity, such as connection between aquifers with watersheds and other essential components of surface waterbodies, ecosystem to manage the upstream and downstream water demand and usages, more holistic way.

There is a need to quit working in storehouses and move away from the compartmentalized methodology at the arrangement level that manages groundwater and surface water as two separate assets. We additionally need to get that while we centre around vertical level network of springs while getting them, the even availability of springs, for instance, their associations with watersheds, surface water, environments, just as upstream and downstream water should be perceived and considered. In this regard, quality issues, a critical source of risk to both public and environmental health, need to be properly referred since a continuous overexploitation of groundwater aggravates the contaminants to be present in the water. It possesses a great threat especially during this time of pandemic. Therefore, even at the spring-shed level scale data collection, management and analyses should be involved with reliable water quality data. Capacity building to regenerate awareness about water quality issues at the individual and community level scales is hence non-negotiable for good governance of groundwater resources.

Institutional mechanisms are necessary to meet the challenges regarding groundwater governance (Karar, 2017). The key role of stakeholder participation, their rights and reliable data are significant parts in the legitimate usage of the groundwater governance framework. Often stakeholders are neither involved in selection of project ingredients nor encouraged to participate in various project activities (Mechlem, 2016). The current groundwater management framework in India (figure 2) at both the administrative (governance) and watershed levels involves only Government departments and their favoured Contractors with a clear top-down approach neglecting the involvement of watershed communities. This lack of co-ordination and co-operation has resulted in overlooking local needs resulting inefficient implementation and inadequate sustainability.

The stakeholder participation should be incorporated directly at the necessary stages of the local, state, and national levels of decision making (Karar, 2017). It is a fact that the engaging local level of governance always emphasise to enable the public participation more intrinsic from the technical/hydrogeological knowledge perspective. Capacity building for a strong collective decision making with different stakeholders with local, academic, and technical knowledge should be encouraged and involved in the production of data for further analyses and management of groundwater resource for the urban areas.

Since groundwater is an exceptionally confined resource, suitable establishments may need to be formed, authorized, and given rights to implement the strategic measures particularly at the ground level with a strong and integrated collaboration with individual/communities/city levels using government instruments. This local information can be used to generate reliable and evidence-based data which should be incorporated at every level of decision making and steadily through the inclusive bottom-up approach. This way, various alternatives can be taken care of at the decision-making level to address the existing gaps that exists between the local level factors and alternatives or steps taken at the strategy level. Thus, administrative uphold for simple admittance to data is fundamental alongside consistent and decentralized information assortment and dynamic management of groundwater resource. Likewise, discovering methods to coordinate information from different non-governmental organisations (NGOs), academia and research institutions and legislative councils and publish for public for further enhancing and refining are required.

Training and capacity building at each level of governance and over a scope of areas and partners is significant for guaranteeing solid cooperation in reconciliation of groundwater the board and administration techniques at different levels across different socio-hydrological typologies in India. These need to take care of into the process of ratification that hold the comprehension of groundwater as a vulnerable and essential resource as opposed to following just the order and control mechanism only. Strategy rules and regulations to govern groundwater resource, whether through social standards or through formal law-making, must be created with the point of securing the resource itself as well as building capacity among the end-users that incorporate various methods and instruments which advance impartial and productive utilization of groundwater resource. Control mechanism, wherever applicable, must also be able to compliment participatory nature of groundwater governance.

Groundwater governance needs to perceive the linkages of groundwater exploitation with land use change due to urbanisation, impacts of climate change, and other external drivers, such as, changing drinking water guidelines for urban water system and industrialisation. It is imperative to recognise that the issue of groundwater exploitation is always associated with shifting nature of the intensive socio-economic and political issues above ground. Here the role of science and technology based, and solution-oriented research can have an important contribution. Innovative scientific approach can explore the extent of groundwater beyond its visible geographic area and examine the position of socio-economic and political realm comprehensively. Therefore, the groundwater crisis can be related with a greater extent of political economy issue which governance should investigate and address in the policy to establish the interlinkages within the society and its continuous shifts. In this way, laws, and regulations for protecting groundwater can be tailored to effective and representative groundwater governance strategies. Strategy guidelines, regardless of whether through accepted practices or through proper law-making, should be created with the point of securing the resource enabling best management practices that incorporate methods which advance fair and proficient utilization of groundwater resource. Guidelines should likewise have the option to approve participatory nature of groundwater governance.

Since groundwater is a vulnerable resource, planning and policy guidelines, systematic allocation, and management strategies at each level of governance are significant. It is noteworthy to mention that the equity in participation and equal representation from every class, caste, gender, sexual orientation, economic groups should be highly encouraged and heard while crating for a participatory capacity building for good governance of groundwater in the city. Extending discoursed and guaranteeing everyone’s portrayal at each level will guarantee majority rule interest in multi-layered groundwater administration instruments even in the most deprived or under-represented areas, which are essential for Indian cities keeping in mind their enormously crowded and diverse nature. Accordingly, strong coordination in participatory actions and decision making for knowledge generation at every level of governance can be more effective in transparent, independent, and accountable community driven strategies to prepare for sustainable management of groundwater resource.

Hence, the current policy and governance framework for groundwater management can be modified to include the watershed level management at each of the policy level. Watershed is an area above a given drainage point on a stream that contributes water to the flow at that point (Ferguson and Maxwell, 2010). The watershed is, therefore, a geo-hydrological unit or a piece of land that drains at common point. Groundwater management at the watershed level necessitates the rational and optimal utilization of land, vegetation, and water resources with minimum risk of hazard to natural and human resources. Thus, combining existing administrative governance framework with the watershed management can ensure inclusive guidance and management of sustainable use of groundwater resources to provide desired goods and services for all without adversely affecting the environment in an urban setting (the same can be argued for rural setup as well). A proposed comprehensive and inclusive framework for management and governance of groundwater resources is shown in figure 6.3.3. This framework can also be used for risk assessment at various spatial, administrative and policy levels, to investigate, analyse and determine the potential fallacy in the current management of groundwater and mitigate the problems, specifically for the emergency such as Covid-19 pandemic.

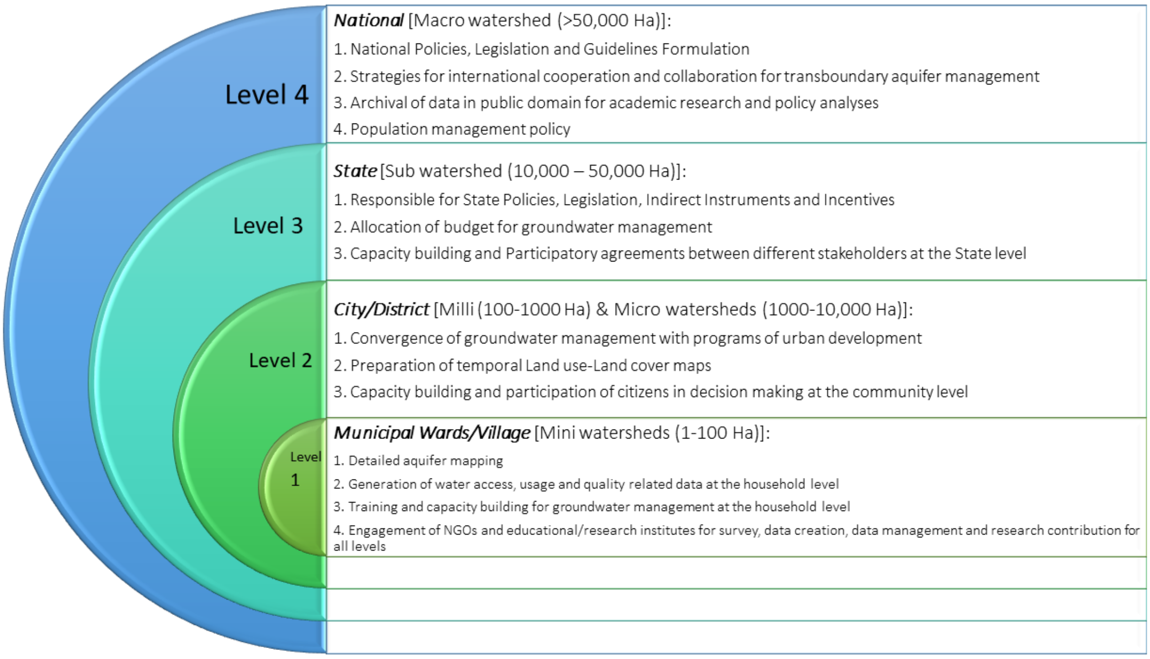

Figure 6.3.3. Proposed framework for comprehensive management and governance of groundwater resources.

6.3.5. Best practices for governance and management of groundwater in a city during the Coronavirus pandemic

Everyone is spending more time at home due to the Covid-19 global pandemic and being advised to keep washing hands and follow safe and legal practices for disposal of medicated stuffs used in the household to avoid further contamination. There are important guidelines to follow to protect public health and contaminating water system. In addition to the potential human health impacts of leftover medications, these compounds can contaminate surface water and groundwater—when flushed, disposed in to drain, or discarded in the trash. Most of the conventional water treatment facilities are not equipped to remove these compounds. Therefore, protective, and conservative measures may be adopted:

1) Well casing should essentially be provided with a proper sanitary seal around to stop migrating contaminants from the land surface to enter the water table, bypassing the unsaturated zone that naturally helps cleanse groundwater.
2) Human enteric viruses (that can replicate in the human intestinal tract) are of greatest concern in well water microbial contamination as they shed in human excreta in enormous numbers and commonly tied to disease outbreaks. Usually there are three processes that

dictates the reduction of pathogens in the subsurface: filtration, adsorption, and die-off/inactivation.

a) Filtration is effective when pathogens are large enough to fit through the soil or aquifer pores and cracks. Thus, due to extremely small sizes of viruses' physical removal by size exclusion is not highly effective for viruses. Efficiency of filtration is regulated by the type of soil and rocks through which groundwater flows. Likewise, silts are more effective than sands at trapping microorganisms (Velonakis et al., 2014).
b) Adsorption takes place when microorganisms get attached to particles, and either removes or delays their transport in water medium. Adsorption of viruses onto sediment grains is the primary removal mechanism in soils and groundwater. Complex dependence on the chemistry of the sediment and water governs such adsorption processes.
c) Survival of the viruses, or the extent of their infectivity can be reduced by increasing the residence time in the subsurface. Temperature, pH, and other factors also have profound influence on the survival of viruses in water media.

3) Soils have been found to be effective at virus removal. Removal efficiency depends on soil characteristics such as texture, composition, and reactions that occur within soil layers. On the other hand, wells in certain types of aquifers, such as karst and fractured rock, are susceptible to enhanced virus transport.
4) Decentralized wastewater treatment (septic tanks) systems and open or leaked sewer lines are the potential sources of viruses for private wells. Hence, septic systems should be meticulously designed and operated to protect wells from pathogenic cross contamination otherwise outbreaks associated with septic systems will continue to be reported especially in areas having high septic system densities.
5) A second line of defence is well and septic system maintenance. Cracks in the well casing, riser, and apron around the wellhead may allow floodwater to enter the well and the annular space around the casing below ground during flooding. This will make wells more vulnerable to microbial contamination after flooding as stormwater can carry loads of microorganisms including viruses and other pathogens. The severity is more in case of shallow wells and that are dug or bored or submerged by floodwater for long periods of time. In such cases through disinfection of well water is essential to eliminate any microbial contamination and subsequently, the quality of the well water should be tested by certified/licensed laboratories.

6) Since 2000, despite the huge change in the socio-economic and political scenarios of India, the expected progress in the water sector has not yet been developed at the same pace. Therefore, it is proposed to bring changes in the National Water Policies to ensure Urban Water Security:
   a) Domestic Sector
      i) Introduction of a policy for mandatory rainwater harvesting in cities;
      ii) Propagation of efficient water usage;
      iii) Creation of awareness about water conservation among common public.
   b) Industrial Sector
      i) Encourage recycling and treatment of industrial wastewater through regulations and subsidies;
      ii) Encourage introduction of new technologies which consume less water
7) Finally, proposed framework for comprehensive management and governance of groundwater resources for achieving Urban Water Security (Figure 3) ensures
   - **water conservation** through development of watersheds and increase in storage capacity (Koop et al., 2019),
   - **effective water uses** through improved recycling of wastewater (Koop et al., 2019),
   - **deterring contamination of water** by prohibiting the discharge of city's raw sewage and waste in river, wise use of agro-chemicals for urban gardens and supervision on over-exploitation of groundwater (Koop et al., 2019),
   - **water resources management** and distribution through proper and safe piped system, rainwater harvesting and artificial recharging of aquifers, metered water supply and pricing of water for sustainability (Koop et al., 2019; Mukherjee et al., 2020),
   - **awareness and orientation of water users** for conservation of water and change in lifestyle (Koop, 2019; Mukherjee et al., 2020),
   - **equitable access** to safe and enough water for all (Mukherjee et al., 2020).

6.3.6. Conclusions

This chapter analyses the interface of urban water security, as related to the agreements, liabilities, and tasks of different stakeholders, in relation to groundwater planning, management and concerns for security as drinking water during and after Covid-19 pandemic. Usage of groundwater as drinking water from borewells or tubewells poses a minimal risk for coronavirus contamination, particularly contrasted with direct human-to-human transmission or by contacting an infected-surface. Anxieties about the coronavirus in groundwater serve as a token of significance to ensure from contaminants/pathogens through legitimate consideration and preservation of wells and infrastructures of urban septic system. Reviewing the literature, this chapter discoursed the State's and individual's duties to respect, reserve and realise the right to water and sanitation especially in relation to the human right to use the available groundwater resources; the management and guideline of private service-providers and health and safety issues. Recognizing the public institutions' responsibility to deliver through direct drinking water service provision, this book chapter recommends that self-provision is the fundamental mean to enjoy the basic human right to water and sanitation. This has substantial connotations for the role of the governance in generating awareness and building capacity for safeguarding point-sources and allocating aquifer recharge. Disregarding self-provision, the governance will miss tremendous prospect of groundwater management by jeopardizing the water security of the urban areas for the future generations.

Last but not the least, it is difficult to ignore the necessity to control population growth in India. By the middle of this century, India will have 1.67 billion people. Currently the available groundwater resources can sustain only a population of 1.50 billion people, if we immediately stop wasting and polluting the water with a condition that monsoon would never fail in the future, which is unlikely to meet (particularly in this rapidly changing climate era). Therefore, best practices for governance and management of groundwater in India, must also include the population management strategy at the national level for the sustainable groundwater future for urban India.

7. Conclusions

This doctoral thesis provides a qualitative snapshot on the effects of land use-land cover change and water management strategies to urban water (in)security in Kolkata Municipal Corporation (KMC) area during the last four decades. Water has social, economic, and environmental values which are crucial to achieve sustainable development. Unprecedented population growth, changing climate, rapid urbanization, expansion of infrastructure, migration, land conversion and pollution translate into changes in the water fluxes, water pathways and water stores. Population density and per capita resource use have increased dramatically over the past four decades in KMC area; parallel, urban ecosystems have undergone significant modifications that affect the vitality, quality, and availability of the water resources in KMC. The trends observed in land use-land cover change in the KMC area reveal the drivers of the environmental changes which indirectly, sometimes directly, affect the urban water security of KMC. Major driver is uncontrolled urbanization. Increased water use associated with domestic and small-scale industries and real estate business is leading to changes in water supply infrastructure, high rates of groundwater discharge, and new water conveyance networks. Collectively these changes lead to cumulative effects on water quality and quantity of available water resources. Hence, the review envisages the relationship between urban water-based livelihood, water pollution, stakeholder interventions and institutional responses. Selection, quantification, and integration of responsible bio-physical and socio-economic factors are needed to be studied in detail in the future and transferred into the policy that combines bio-physical and social dimensions of the urban water security and governance.

7.1. Urban water security is a complex system

Urban water security (UWS) is a complex system where multiple actors and factors are at play. It is a difficult task to address water insecurity issues disentangling this web of factors. The assessment framework has been conceptualized to facilitate active discussion and mitigation approaches between participating experts and the stakeholders. This inclusive conceptual framework is proposed to consider the strategies for cities that assure water security for all but not in exchange for ecological integrity. It needs to be formed at a micro level to identify the best measurements for a holistic development. Furthermore, it can be scaled up to regional and national levels to be incorporated in planning and management decisions. Engaging wider public in debates on emerging scientific issues such as UWS is required to provide a successful adaptive plan for capacity building and making the society more resilient to the climate change related disasters in developing and emerging countries. It also underlines the importance and relevance of science for policies. Through this strong linkage, it will be ensured that the citizens keep informed on the development and the role of the scientists. Simultaneously, the policy makers will play in broadening the understanding of the needs in making the city more sustainable providing the assurance to achieve water security for all.

This research forms part of a critique of those applying the concept of slum, in general, as a fixed entity. It has been shown that social, economic, and political exclusion vary within and across both, wards defined as slums as well as other wards within and across the city. Previous literature has analysed discreet issues of water injustices in areas defined as slums, focusing on socio-economic and physical characteristics along with different policies, frequently leading to a partial view of slums. However, these different issues are all interrelated at various spatial levels. Therefore, the interdisciplinary and intersectional approach applied in this thesis is required to fully understand the multifaceted issues influencing and shaping water security in these areas. This will help achieving an aim to develop appropriate policies and to improve the livelihoods of those living in deprived areas.

7.2 Peri-urban wetlands support securing Kolkata's urban water and related ecosystems

This study shows that it is impossible to disregard the role of peri-urban wetlands and the benefits or services from its ecosystem for securing a city's water and environmental security. For mega cities like Kolkata the need is more vigorous. The process of rapid urbanization has blurred the distinction between the 'urban' with the 'peri-urban' zones which used to play a role as intermediary between urban and rural areas. There is a need to understand and document social, economic, and institutional characteristics of peri-urban regions in a better way. An understanding of these unique characteristics is essential to develop new and innovative ways of addressing peri-urban challenges, cutting across the frontiers of rural and urban governance. The unplanned and unregulated development process in Kolkata Municipal Corporation areas has proved to be quite unsustainable and has turned out to be a serious threat to the city and its environment. The growth has affected basic amenities, especially water supply for the increasing population in the newly developing areas. Peri-urban wetland areas of Kolkata city are under stress because of expanding urban settlements which hamper natural water cycle and its regulatory functions. This compromises the natural protection of controlling flood, recharging the shallow aquifer and natural waste management of the city itself. The entire transformation may introduce new pollutants such as wastewater, arsenic or pesticides ultimately affecting the entire water security of the urban area.

River Hugli is the main source of drinking water for Kolkata, and it is the main distributary of river Ganges since ages. Historically this river has been the lifeline of this mega city in the eastern hemisphere. This study did not consider the stretch of the river while calculating the ecosystem services valuation as there was no recent change in the course of the river Hugli. Rather, this study considered its water quality issues in the analysis which is crucial while discussing Kolkata's water security. The Ganga-Hugli river system contributes significantly towards the transport of pollutants of the coastal areas of the Bay of Bengal. The deterioration of water quality is closely related to inefficient water management, non-functioning of wastewater treatment facilities and lack of environmental planning and coordination. Coliform counts in the river water sampled result from microbial contamination by municipal waste sources. Results of the water quality study show that most physico-chemical features may be appropriate for domestic water supply after traditional water treatment. However, bacteriological quality observations revealed a high degree of contamination from domestic and animal wastes.

7.3. Social exclusions insecure urban water

Struggle against climate change will set off substantial opportunities for the economy, specifically in the Global South. In the future, researchers should adopt circular production systems in a water efficient way. As the global population grows, so does the demand for water, settlements, and urban infrastructural development. These, in turn, deplete natural resources and damage the environment in many places. Solutions include protecting carbon sinks such as green cover and wetlands, adopting climate-smart agricultural techniques, rainwater harvesting and artificial recharge, and increasing the safe reuse of wastewater in urban areas. Water is our most precious resource – further research must use it more conscientiously. The significant trade-off between human's water needs and its security will protect everyone from being left behind. In this context, it is also important to ask how much water the ecosystem needs to ensure its own water security within an urban space. Urban water security research needs to go deeper to know how complex ecosystems behave at vastly different scales and under the stresses of changing patterns of climate and water availability along with the increasing water demand.

The study shows that there are vulnerabilities to water security in terms of WaSH in socially deprived and excluded areas; however, there are also variations within these geographical areas. This doctoral research identified that within areas characterized by deprivation and social exclusion, based on ethnicity, religion, socio-economic standing, and gender matters, in determining who is more water insecure. In consequence, water and sanitation experts should take not only bio-physical factors into account conducting the WaSH infrastructure planning, but how they are associated with socio-economic, cultural, and demographic characteristics. Hence, multi-dimensional vulnerability to water insecurity should be considered in water security research.

7.4. Urban water security assessment requires interdisciplinary approach

The results indicate that there is a need to analyse and address water security issues with a lens that appreciates across and within city and ward variations to understand water and sanitation issues. Research in water security (particularly for urban areas) needs to be focused on understanding the link between this spatial heterogeneity and water accessibility issues. This understanding is crucial for the management of current urban water systems as well as for the planning of sustainable development and policies on urban system structure and function. Cities function as a melting pot for people with differing cultural backgrounds, religions, interests, and social statuses. As the results show that ethnicity, religion and language are crucial in influencing and understanding who are water-insecure, more research is needed on these aspects to fully understand the complex interactions especially because cities are not only growing in population but are also becoming increasingly diverse.

The findings show the importance of interdisciplinary approaches to enhance understanding of the complexity of water security on the one hand. On the other, they shed important knowledge to be incorporated into water security management and policies. Solving WaSH issues needs to address and include policies that can support marginalized groups across the gender continuum, ethnic and religious groups as they are particularly vulnerable to WaSH issues. Furthermore, it also shows the importance of understanding within city and within ward variations, so that policies do not solely target specific areas defined as slums but incorporate flexible and intelligent solutions which looks at urban water security in the city as an organism, with complex divisions and relations, which cannot be solved by addressing issues in a single area.

In early days, Kolkata was a water blessed city, with the mighty River Hugli flowing in the west, East Kolkata Wetlands in the east and vast groundwater reserve. At present, changes in freshwater resources and urban land use, increasing water demand owing to population growth, poor sanitation and lack of enough water treatment facilities coupled with mismanagement aggravated the water insecurities in Kolkata. Particularly for the emerging and developing countries like India, these challenges affect urban dwellers, who experience difficulties in meeting daily water needs. The gap between the availability, supply and demand for fresh water will widen even further in mega cities in emerging countries, where this unequal state of urban water security affects mostly the people residing in the societal margins considering the consequences for public health, livelihoods, wellbeing, and gender disparities. Municipal governments, as a result, need to constantly reconcile available water supply with growing demand in an equitable manner.

7.5. Quantitative urban water security assessment framework

This study provides a unique quantitative assessment framework to quantify UWS at the borough level and to define practical dimensions that identify water-insecure areas in both spatially and socially against others and allocate limited resources prudently, particularly for the Global South. This novel quantitative approach would help policy makers and water stakeholders to fix their objectives to manage their available water and social resources judiciously toward achieving UWS managing the trade-offs and equity challenges.

The focus of the integrated assessment framework of UWS is to associate and amalgamate human-oriented and environmental perspectives to achieve the goals of UWS. The bottom-up concept of the assessment fosters the idea of integration through a decentralized and holistic management technique. Integration of local ideas have been involved in the procedure to touch the various aspects of needs, demands, risks and developmental perspectives. This way, the ‘integration’ bridges ‘people, planet and profit’.

The inclusive framework for urban water security assessment frames the challenge of UWS of Kolkata city beyond the traditional indicators such as quantity of supplied water, water accessibility and sanitation or water quality. Rather, it captures the issues of water insecurity holistically along its four major dimensions of UWS—availability, accessibility, quality water-related risk and hazards, and, essentially related them with society and the individuals—to reach at the conclusion: how and where a city is becoming water insecure. Hence the empirical approach of the study focused on the spatial analysis of all the components of UWS with a megacity perspective from emerging economies. The findings also suggest empirical evidence that water insecurity of a city cannot be only due to the malfunction or inadequacy of city's water system but also from the disparity, inequality and exclusion in the society which hampers the overall wellbeing of the city. Hence, along with conventional quantifiable components of bio-physico-chemical dimensions, social capital was considered as a key dimension of UWS with the anticipation of capturing the entirety by individual socio-economic groups for the policy measure to improve water security.

7.6. Adequate and quality data are crucial

The biggest challenges the Global South faces regarding UWS are inadequate, unreliable, low quality, socio-politically as well as technologically biased, non-inclusive and unorganised databases. Hence, without a strong scientific knowledge on UWS, the cities in the Global South lack proper management of its water resources and the demand of the growing population. With the progress in Remote Sensing technology, global bio-physical databases can be easily available and accessible with cheaper or no cost, but it only provides bio-physical data bases up to a certain scale and without direct data and/or information on the larger socio-economic objectives. Therefore, the UWS assessment would lose its holistic and inclusive properties which can never achieve water security.

Steps for identification, collection and analysis of data and statistical tools for UWS assessment need to start with prioritising water security objectives. Thus, strengthening water data institutions, establishing sustainable water data monitoring systems, adopting water data standards, and embracing an open data approach to water data access and licensing are essential. Employing water data quality management processes and generating different scenarios for future data requirement, management and archiving through sophisticated and advanced research based on well-selected statistical analyses are proven to be important. Therefore, this study concludes with a note on implementing effective water data information systems and engaging communities for participatory activities for data generation, collection, and management must be prioritised for the assessment of UWS for a sustainable water future of the cities in the Global South.

7.7. Inclusive and acceptable policy decision and management approach

This doctoral research analyses the interface of urban water security, as related to the agreements, liabilities, and tasks of different stakeholders, in relation to groundwater planning, management and concerns for security as drinking water during and after Covid-19 pandemic.

Usage of groundwater as drinking water from borewells or tubewells poses a minimal risk for coronavirus contamination, particularly contrasted with direct human-to-human transmission or by contacting an infected-surface. Anxieties about the coronavirus in groundwater serve as a token of significance to ensure from contaminants/pathogens through legitimate consideration and preservation of wells and infrastructures of urban septic system. This research discoursed the State's and individual's duties to respect, reserve and realise the right to water and sanitation especially in relation to the human right to use the available groundwater resources; the management and guideline of private service-providers and health and safety issues. Recognizing the public institutions' responsibility to deliver through direct drinking water service provision, this part recommends that self-provision is the fundamental mean to enjoy the basic human right to water and sanitation. This has substantial connotations for the role of the governance in generating awareness and building capacity for safeguarding point-sources and allocating aquifer recharge.

7.8. Securing human right to water by securing urban water

Just as the 'right to life' means the right to live with dignity, so the 'right to the city' means the right to live with dignity by living and working in the city with healthy work and living environment and enough safe water to access, contrary to the deprived areas currently overwhelmed in Kolkata and in the cities of India, in general. Many cities and its deprived areas do not have even a drop of basic civic services such as drinking water and toilets. Crowded muddy alleys, water taps, or bathroom lines often create an inhuman condition. The situation will not change if they are not recognized as urban dwellers. Some states in India have enacted laws on the rights of city dwellers, although it is problematic. It is meaningless to formulate any policy of 'smart city', 'green city' or city development without giving space to the plan of safe and legal housing for all the city dwellers, especially for those who live in the deprived areas. Solving this issue should be the first concern. Otherwise, one-third of the people in this city will go to sleep on the road every night without having any secured water for drinking, sanitation, and hygiene in this pandemic-clad world!

7.9. Recommendation and future direction of research on urban water security

More research on critical water-related ecosystem services is required to encourage additional policy momentum, business commitment, and investment in the conservation, restoration, and wise use of wetlands. They must show how recognizing, demonstrating, and capturing the local values of ecosystem services related to water and wetlands can lead to better informed, more efficient, and fairer decision-making for a sustainable urban planning. It is evident from the literature that the poorer sections of the society suffer the most when biodiversity is lost, as their survival depends on the multitude of nature. When wetlands are destroyed, nature's water cycle and its ability to provide water for households and farms are disrupted, and the suffering of the poor exacerbates inadvertently. Thus, restoration and protection of water-environment is vital to address today’s most pressing challenges of water (and food security), climate change, and poverty in urban spaces.

This study used social exclusion as an overarching concept to understand vulnerabilities and exposure to water insecurity in urban slums. The findings show that the study can explicate some of the variabilities in the provision of WaSH from the context of urban water security within and across areas defined as socially deprived areas within Kolkata. Water security solutions exist that can make significant strides in combating disease and mortality, and further research should be done with an interdisciplinary, intersectional approach to understand how policies, management, and behaviour can be directed to secure water security. Further, creating community groups for women and other marginalised community members to learn about using point-of-use water treatment methods, decreasing pathways of contamination, and mobilizing communities to work towards sustainable clean water systems would be suggested.

Last but not the least, it is difficult to ignore the necessity to control population growth in India. By the middle of this century, India will have 1.67 billion people. Currently the available groundwater resources can sustain only a population of 1.50 billion people, if the entire nation immediately stop wasting and polluting the water with a condition that monsoon would never fail in the future, which is unlikely to meet (particularly in this rapidly changing climate era). Therefore, best practices for governance and management of groundwater in India, must also include the population management strategy at the national level for the sustainable groundwater future for urban India.

7.10. Relevance of the research

Research on UWS is essential for areas where available water resources are abundant but poorly managed, causing water insecurity at household levels. Geospatial technology can play a vital role in supporting sustainable management approaches through combined geospatial techniques integrating and fusing bio-geophysical and social data. This can help to develop a socio-eco-hydrological vulnerability index as a function of the exposure. Additionally, it can provide support to assess sensitivity and adaptive capacity of a region to ensure access of humans to water and to create resilience to natural disasters due to ongoing climate change effects. Geospatial based socio-eco-hydrological framework can be useful for vulnerability mapping and assessment in different spatial and temporal scales and will help to identify socially and bio-geophysical fragile areas and will assist with the implementation of climate change adaptation strategies where required.

The research serves a critical link by detailing the issues faced daily with access to water to reflect interlocking systems of privilege and oppression (i.e., racism, sexism, castes, heterosexism, and classism) at the micro social-structural level, which is of interest to a wide range of academic beneficiaries. This study draws on established understanding with the research which developed through close collaboration between academia and socially excluded communities, activists, and policy makers. The doctoral research is, therefore, relevant to the academic beneficiaries (alongside other direct and indirect beneficiaries) in different ways:

- The research addresses an under-researched phenomenon -inequality- which is on the rise across the global south and across different layers of the society. The study investigates the effects of exclusion in unstable and diverse communities in the form of a detailed case study of sustainability which is currently under constant pressure everywhere in the world during the COVID-19 pandemic.
- The research adopts an innovative methodology, bringing together, mainly, two sources of evidence: 1) the ethnographic generation of knowledge through the researcher's deep understanding of the site, context and of participants' experiences, values, and beliefs; 2) the close analysis of audio and video-recorded inter- professional communication through moment-by-moment transcription of verbal and non-verbal interaction.
- Overall, this PhD research works toward society readiness and human wellbeing in and with the affected communities through co-creation of integrated solutions and instruments that provide support to mitigate the water related threats. The approach is unique in its integration of the communities from the start of the research, employing the inclusionary principles of co-production and involving the stakeholders, that allows the researchers to properly address water issues both in the theoretical and practical dimension – the research process instruments and solutions. The affected communities contributed to the adequate selection of the most pertinent questions regarding the water security. This community-based approach is supported by studies that showed the importance of co-creation of knowledge and solutions in order to achieve sustainable transformation.

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Appendices

Appendix 2.1. Definitions of water security.

1. Water Security is ‘a situation of reliable and secure access to water over time. It does not equate to constant quantity of supply as much as predictability, which enables measures to be taken in times of scarcity to avoid stress’ (Applegren, 1997).

2. A comprehensive definition (of Water Security) goes beyond availability to issues of access. Access involves issues that range from a discussion of fundamental individual rights to national sovereignty rights over water: It also involves equity and affordability, and the role of states and markets in water's allocation, pricing, distribution, and regulation. Water security also implies social and political decision-making on use - the priority to be accorded to competing household, agricultural or industrial demands on the resource (Gutierrez, 1999).

3. Water Security is ‘a condition in which there is a sufficient quantity of water, at a fair price, and at a quality necessary to meet short and long term human needs to protect their health, safety, welfare, and productive capacity at the local, regional, state and national levels’ (Witter and Whiteford, 1999).

4. Water Security ensures ‘every person has access to enough safe water at affordable cost to lead a clean, healthy and productive life, while ensuring that the natural environment is protected and enhanced’ (GWP, 2000).

5. Water security means that every person has access to enough safe water at an affordable cost to lead a healthy and productive life and that the vulnerable are protected from the risks of water related hazards (Ministerial Declaration of The Hague, 2000).

6. Household water security is ‘the reliable availability of safe water in the home for all domestic purposes’ (WHO, 2003).

7. Water security is a situation of reliable and secure access to water over time. It does not equate to constant quantity of supply as much as predictability, which enables measures to be taken in times of scarcity to avoid stress (Abrams, 2003).

8. The water security can be defined as the ability of different section of population to access sufficient quantities of clean water to maintain adequate standards of food, sanitation, health and production of goods (Institute for the Analysis of Global Security, 2004).

9. There are three important elements of "water security": 1) Water security is based on three core freedoms: freedom from want, freedom from fear and freedom to live in human dignity; 2) Ensuring water security may lead to a conflict of interests, which must be capable of being identified and effectively dealt with at the international, national and local levels; 3) Water security, like water, is a dynamic concept, and one that needs clear local champions and sustained stewardship (Wouters, 2005).

10. Water security means the ability to supply water, according to a specified quality, to homes and industry under conditions satisfactory to the environment and at an acceptable price. The definition of water security includes: (a) population-wide security, that is, everyone can obtain secure water for domestic use; (b) economic security, namely water resources can satisfy the normal requirements of economic development; (c) ecological security, namely water resources can meet the lowest water demands of ecosystems without causing damage (Xia et al, 2007).

11. Water security is linked to a safe water supply and sanitation, water for food production, hydro-solidarity between those living upstream and those living downstream in a river basin and water pollution avoidance so that the water in aquifers and rivers remains usable, i.e., not too polluted for use for water supply, industrial production, agricultural use or the protection of biodiversity, wetlands and aquatic ecosystems in rivers and coastal waters (Falkenmark, 2006).

12. Water security is ‘the availability of an acceptable quantity and quality of water for health, livelihoods, ecosystems and production, coupled with an acceptable level of water-related risks to people, environments and economies’ (Grey and Sadoff, 2007).

13. Water security is ‘availability of, and access to, water sufficient in quantity and quality to meet the livelihood needs of all households throughout the year, without prejudicing the needs of other users’ (Calow *et al*, 2010).

14. Water security is just what we choose to eat [and] nothing to do with the environment or science etc.’… ‘Water security is linked with food trade – as “energy security” is (more obviously, perhaps) linked with oil trade.’… ‘Secure use of water is defined by political processes. Water security is achieved outside the watershed (in the “problemshed)’’ (Allan, 2011).

15. Water security is ‘sustainable access, on a watershed basis, to adequate quantities of water, of acceptable quality, to ensure human and ecosystem health’ (Norman *et all*, 2011).

16. Social and physical processes combine to create or deny water security. Sustainable water security is interpreted as a function of the degree of equitability and balance between interdependencies of the related security areas, played out within a web of socioeconomic and political forces at multiple spatial levels... The “web” of water security identifies the “security areas” related to national water security. These include the intimately associated natural “security resources” (water resources, energy, climate, food) as well as the security of the social groups concerned (individual, community, nation). The “web” recognizes the interaction occurring at all spatial scales, from the individual through to river basin and global levels. In this sense, an individual’s water security may coexist with national water insecurity, as in the case of wealthy farmer-sheikhs with the deepest wells (who may be temporarily water secure) in the dry highlands of Yemen (which is not, overall, water secure) (Zeitoun, 2011).

17. Water security is essential for human access for health, wellbeing, economic and political stability. It is essential to limit risks of water- related hazards. A complete and fair valuation of the resource, sustainability of ecosystems at all parts of the hydrologic cycle and an equitable and cooperative sharing of water resources is very necessary (Water Aid, 2012).

18. Societies can enjoy water security when they successfully manage their water resources and services to – 1) satisfy household water and sanitation needs in all communities; 2) support productive economies in agriculture, industry, and energy; 3) develop vibrant, livable cities and towns; 4) restore healthy rivers and ecosystems; and 5) build resilient communities that can adapt to change (ADB, 2013).

19. Water Security is defined as the capacity of a population to safeguard access to adequate quantities of water of acceptable quality for sustaining human and ecosystem health on a watershed basis, and to ensure efficient protection of life and property against water related hazards -- floods, landslides, land subsidence,) and droughts. (UN Water, 2013)

20. Water Security is the 'sustainable use and protection of water resources, safeguarding access to water functions and services for humans and the environment, and protection against water-related hazards (flood and drought)' (Wheater and Gober 2013).

21. The capacity of a population to safeguard access to adequate quantities of water of acceptable quality for sustaining human and ecosystem health on a watershed basis, and to ensure efficient protection of life and property against water related hazards – floods, landslides, land subsidence, and droughts (UNESCO-IHP, 2017).

Appendix 2.2. A summary of key approaches for quantitative assessment of sustainability of urban water systems.

Category	Approach	Objective	Features	References
Urban Water System Modelling	Integrated Urban Water System Modelling (IUWSM)	Quantification of water flows through urban water infrastructure, i.e., water supply, drainage, wastewater etc., to manage supply against demand or plan infrastructure	Bottom-up simulation of the volumes of water managed by the urban water system, to achieve a supply-demand balance of the water system	Behzadian and Kapelan, 2015; Last, 2010; Makropoulos et al., 2008; Mitchell et al., 2001; Rozos and Makropoulos, 2013; Urich et al., 2013; Venkatesh et al., 2014; Willuweit O'Sullivan, 2013
Sustainability frameworks	United Nations Commission on Sustainable Development (UN-CSD)	Assessment of a policy for Reporting, Comparison and Decision-Making towards sustainability	Consideration of 4 dimensions of sustainability, namely Environmental, Social, Economic and Institutional	UNCDS, 2001
Complex systems approach	Ecological Network Analysis (ENA)	Quantifies indicators that represent the relationships between components of the urban water system to characterize how the system functions	Top-down collation of secondary data for anthropogenic water flows between socioeconomic components of the urban water system into input-output tables, from which system-wide performance indicators are generated	Zhang et al., 2010; Bodini et al., 2012; Pizzol et al., 2013
	System Dynamics (SD)	Quantifies trends in anthropogenic urban water flows under varying socioeconomic parameters	Bottom-up dynamic simulation of the anthropogenic water flows under changing variables, based on inter-relationships and feedback loops	Baki et al., 2012; Sahin and Stewart; 2013

Urban Metabolism	Territorial Material Flow Analysis (UM-MFA)	Quantification of city-scale water flows (alongside other resource flows), for monitoring change over time and benchmarking between cities and urban typologies	Top-down collation of secondary data for centralized water flows (total and per capita potable water inflows and wastewater outflows), as part of a wider MFA of all urban resource flows	Ayers and Ayers, 2002; Codoban & Kennedy, 2008 EIU, 2011; Kennedy et al., 2007; Kennedy et al., 2015; Mollay et al., 2011; Newmann et al., 1996; Newton et al., 2001; Pina and Martinez, 2014; Singh et al., 2009; Wernick and Irwin, 2005
	Water Mass Balance (UM-WMB)	Quantification of city-scale water flows and metabolic performance indicators, for visioning and for screening improvement opportunities	Top-down collation of secondary data for all water flows (anthropogenic and natural), and changes in storage, to achieve a water mass balance of the urban entity	Bhaskar and Welty, 2012; Chrysoulakis et al., 2013; Kenway et al., 2011; Marteleira et al., 2014; Thériault & Laroche, 2009
	Life Cycle Assessment (LCA)	Quantification of environmental impact indicators across the life cycle of urban water systems, for understanding their wider environmental implications	Bottom-up estimates of resource inputs to, and waste/pollutant outputs from, all processes in the life cycle of urban water services followed by characterization of their impacts	Fagan et al., 2010; Lane et al., 2015; Lundin, 2003
Consumption approach for Bio-physical Accounting	Water Footprint (WF)	Quantification of indirect water required to produce goods. and services consumed by the city or its inhabitants	Bottom-up estimates of single metric of water extracted from the global hinterland, representing the water required to produce the goods and services consumed by urban dwellers	Hoff et al., 2014; Vanham, 2012
	Environmentally Extended Input-Output Analysis (EIO)	Quantification of economic water flows (and other resources) through economic supply chains	Top-down collation of economic flows from economic input-output tables are multiplied by virtual water use associated with those economic exchanges	Lenzen, 2009 Lenzen and Peters, 2009

Risk based approach	Aqueduct water risk indicators	Quantification of the coincidence of hazards at high resolution	Key Dimensions are Chronic water stress, flood, drought/seasonal variability, environmental degradation, inadequate water supply and sanitation, and the role of institution and infrastructure	Gassert et al, 2013
	Index of water security threats		Key Dimensions are Chronic water stress environmental degradation, and infrastructure	Vorosmarty et al, 2010
System approach	Pressure-State-Response (PSR)	Quantification of environmental progress and performance with international comparison. Monitoring policy integration.	Describes the causal chain of an effect considered as negative for sustainability. Four kinds of descriptive indicators are: 1) Core set, 2) Key Indicators, 3) Sectorial Indicators, and 4) Decoupling set	OECD, 2004; OECD, 2003
	Driver-Pressure-State-Impact-Response (DPSIR)	Assessment of the sustainable development (SD), making science understandable to the public and demand management for SD	Descriptive indicators, showing the state of water resources and its links with diverse water related issues: 1) Basic indicators, 2) Key indicators, 3) Developing Indicators, and 4) Conceptual indicators	Marsili-Libelli *et al*, 2004; Pirrone *et al*, 2005; WWAP, 2006; WWAP, 2002

Appendix 3.1. Details of the spectral and spatial resolutions of the satellite imagery used.

Satellite-Sensor	Bands	Spectral resolution (µm)	Spatial resolution (m)
Landsat-**MSS**	1	0.5 – 0.6	60
	2	0.6 – 0.7	
	3	0.7 – 0.8	
	4	0.8 – 1.1	
Landsat-**TM**	1	0.45 – 0.52	30
	2	0.52 – 0.60	
	3	0.63 – 0.69	
	4	0.76 – 0.90	
	5	1.55 – 1.75	
	7	2.08 – 2.35	
Landsat- **ETM+**	1	0.45 – 0.52	30
	2	0.52 – 0.60	
	3	0.63 – 0.69	
	4	0.76 – 0.90	
	5	1.55 – 1.75	
	7	2.08 – 2.35	
Resourcesat-1	2	0.52 – 0.59	23.5
LISS-III	3	0.62 – 0.68	
	4	0.77 – 0.86	
	5	1.55 – 1.70	

Appendix 5.1A. Castes & sources of drinking water supply (based on survey data).

			Caste				Total
			General	**SC/ST/OBC**	**Tribal**	**NA**	
Source of Water	Direct Piped-water supply by Corporation to the house	Count	535	73	0	2	610
		% within Source of Water	87.7%	12.0%	0.0%	0.3%	100.0%
		% within Caste	82.3%	73.0%	0.0%	50.0%	80.8%
	Standpost outside the houses	Count	53	18	0	2	73
		% within Source of Water	72.6%	24.7%	0.0%	2.7%	100.0%
		% within Caste	8.2%	18.0%	0.0%	50.0%	9.7%
	Dugwell/Tubewell	Count	3	1	0	0	4
		% within Source of Water	75.0%	25.0%	0.0%	0.0%	100.0%
		% within Caste	0.5%	1.0%	0.0%	0.0%	0.5%
	Waterbody nearby	Count	1	1	0	0	2
		% within Source of Water	50.0%	50.0%	0.0%	0.0%	100.0%
		% within Caste	0.2%	1.0%	0.0%	0.0%	0.3%
	Other	Count	48	4	1	0	53
		% within Source of Water	90.6%	7.5%	1.9%	0.0%	100.0%
		% within Caste	7.4%	4.0%	100.0%	0.0%	7.0%
	NA	Count	10	3	0	0	13
		% within Source of Water	76.9%	23.1%	0.0%	0.0%	100.0%
		% within Caste	1.5%	3.0%	0.0%	0.0%	1.7%
Total		Count	650	100	1	4	755
		% within Source of Water	86.1%	13.2%	0.1%	0.5%	100.0%
		% within Caste	100.0%	100.0%	100.0%	100.0%	100.0%

Appendix 5.1B. Ethnic groups & sources of drinking water supply (based on survey data).

			Ethnic group (Based on Main Language Spoken)				Total
			Bengali	Other Indian	non-Indian	NA	
Source of Water	Direct Piped-water supply by Corporation to the house	Count	509	97	1	3	610
		% within Source of Water	83.4%	15.9%	0.2%	0.5%	100.0%
		% within Ethnic group	83.7%	68.8%	50.0%	75.0%	80.8%
	Standpost outside the houses	Count	39	33	0	1	73
		% within Source of Water	53.4%	45.2%	0.0%	1.4%	100.0%
		% within Ethnic group	6.4%	23.4%	0.0%	25.0%	9.7%
	Dugwell/Tubewell	Count	3	0	1	0	4
		% within Source of Water	75.0%	0.0%	25.0%	0.0%	100.0%
		% within Ethnic group	0.5%	0.0%	50.0%	0.0%	0.5%
	Waterbody nearby	Count	1	1	0	0	2
		% within Source of Water	50.0%	50.0%	0.0%	0.0%	100.0%
		% within Ethnic group	0.2%	0.7%	0.0%	0.0%	0.3%
	Other	Count	46	7	0	0	53
		% within Source of Water	86.8%	13.2%	0.0%	0.0%	100.0%
		% within Ethnic group	7.6%	5.0%	0.0%	0.0%	7.0%
	NA	Count	10	3	0	0	13
		% within Source of Water	76.9%	23.1%	0.0%	0.0%	100.0%
		% within Ethnic group	1.6%	2.1%	0.0%	0.0%	1.7%
Total		Count	608	141	2	4	755
		% within Source of Water	80.5%	18.7%	0.3%	0.5%	100.0%
		% within Ethnic group	100.0%	100.0%	100.0%	100.0%	100.0%

Appendix 5.1C. Religion and sources of drinking water supply (based on survey data).

			Religion				Total
			Hindu	**Muslim**	**Other**	**NA**	
Source of Water	Direct Piped-water supply by Corporation to the house	Count	528	56	23	3	610
		% within Source of Water	86.6%	9.2%	3.8%	0.5%	100.0%
		% within Religion	82.4%	70.0%	79.3%	60.0%	80.8%
	Standpost outside the houses	Count	60	7	5	1	73
		% within Source of Water	82.2%	9.6%	6.8%	1.4%	100.0%
		% within Religion	9.4%	8.8%	17.2%	20.0%	9.7%
	Dugwell/Tubewell	Count	3	0	0	1	4
		% within Source of Water	75.0%	0.0%	0.0%	25.0%	100.0%
		% within Religion	0.5%	0.0%	0.0%	20.0%	0.5%
	Waterbody nearby	Count	1	1	0	0	2
		% within Source of Water	50.0%	50.0%	0.0%	0.0%	100.0%
		% within Religion	0.2%	1.3%	0.0%	0.0%	0.3%
	Other	Count	40	12	1	0	53
		% within Source of Water	75.5%	22.6%	1.9%	0.0%	100.0%
		% within Religion	6.2%	15.0%	3.4%	0.0%	7.0%
	NA	Count	9	4	0	0	13
		% within Source of Water	69.2%	30.8%	0.0%	0.0%	100.0%
		% within Religion	1.4%	5.0%	0.0%	0.0%	1.7%
Total		Count	641	80	29	5	755
		% within Source of Water	84.9%	10.6%	3.8%	0.7%	100.0%
		% within Religion	100.0%	100.0%	100.0%	100.0%	100.0%

Appendix 5.1D. Gender and sources of drinking water supply (based on survey data).

			Gender of the Respondent								Total
			Female	Male	Trans	Intersex	Other	5	7	NA	
Source of Water	Direct Piped-water supply by Corporation to the house	Count	153	212	103	70	35	1	1	32	607
		% within Source of Water	25.2%	34.9%	17.0%	11.5%	5.8%	0.2%	0.2%	5.3%	100.0%
		% within Gender of the respondent	74.3%	79.4%	85.1%	87.5%	94.6%	100.0%	100.0%	82.1%	80.7%
	Standpost outside the houses	Count	20	31	13	6	0	0	0	3	73
		% within Source of Water	27.4%	42.5%	17.8%	8.2%	0.0%	0.0%	0.0%	4.1%	100.0%
		% within Gender of the respondent	9.7%	11.6%	10.7%	7.5%	0.0%	0.0%	0.0%	7.7%	9.7%
	Dugwell/Tubewell	Count	0	2	1	1	0	0	0	0	4
		% within Source of Water	0.0%	50.0%	25.0%	25.0%	0.0%	0.0%	0.0%	0.0%	100.0%
		% within Gender of the respondent	0.0%	0.7%	0.8%	1.3%	0.0%	0.0%	0.0%	0.0%	0.5%
	Waterbody nearby	Count	0	0	2	0	0	0	0	0	2
		% within Source of Water	0.0%	0.0%	100.0%	0.0%	0.0%	0.0%	0.0%	0.0%	100.0%
		% within Gender of the respondent	0.0%	0.0%	1.7%	0.0%	0.0%	0.0%	0.0%	0.0%	0.3%
	Other	Count	26	20	1	1	2	0	0	3	53
		% within Source of Water	49.1%	37.7%	1.9%	1.9%	3.8%	0.0%	0.0%	5.7%	100.0%
		% within Gender of the respondent	12.6%	7.5%	0.8%	1.3%	5.4%	0.0%	0.0%	7.7%	7.0%
	NA	Count	7	2	1	2	0	0	0	1	13
		% within Source of Water	53.8%	15.4%	7.7%	15.4%	0.0%	0.0%	0.0%	7.7%	100.0%
		% within Gender of the respondent	3.4%	0.7%	0.8%	2.5%	0.0%	0.0%	0.0%	2.6%	1.7%
Total		Count	206	267	121	80	37	1	1	39	752
		% within Source of Water	27.4%	35.5%	16.1%	10.6%	4.9%	0.1%	0.1%	5.2%	100.0%
		% within Gender of the respondent	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

Appendix 5.1E. Levels of education and sources of drinking water supply (based on survey data).

			Highest Level of Education						Total
			Primary Education	Secondary Education	College	Postgrad	8th	666	
Source of Water	Direct Piped-water supply by Corporation to the house	Count	115	212	212	61	1	8	609
		% within Source of Water	18.9%	34.8%	34.8%	10.0%	0.2%	1.3%	100.0%
		% within highest level of education	72.3%	87.6%	80.6%	83.6%	33.3%	57.1%	80.8%
	Standpost outside the houses	Count	34	16	15	3	0	5	73
		% within Source of Water	46.6%	21.9%	20.5%	4.1%	0.0%	6.8%	100.0%
		% within highest level of education	21.4%	6.6%	5.7%	4.1%	0.0%	35.7%	9.7%
	Dugwell/Tubewell	Count	0	2	0	1	1	0	4
		% within Source of Water	0.0%	50.0%	0.0%	25.0%	25.0%	0.0%	100.0%
		% within highest level of education	0.0%	0.8%	0.0%	1.4%	33.3%	0.0%	0.5%
	Waterbody nearby	Count	0	0	0	2	0	0	2
		% within Source of Water	0.0%	0.0%	0.0%	100.0%	0.0%	0.0%	100.0%
		% within highest level of education	0.0%	0.0%	0.0%	2.7%	0.0%	0.0%	0.3%
	Other	Count	7	9	31	4	1	1	53
		% within Source of Water	13.2%	17.0%	58.5%	7.5%	1.9%	1.9%	100.0%
		% within highest level of education	4.4%	3.7%	11.8%	5.5%	33.3%	7.1%	7.0%
	NA	Count	3	3	5	2	0	0	13
		% within Source of Water	23.1%	23.1%	38.5%	15.4%	0.0%	0.0%	100.0%
		% within highest level of education	1.9%	1.2%	1.9%	2.7%	0.0%	0.0%	1.7%
Total		Count	159	242	263	73	3	14	754
		% within Source of Water	21.1%	32.1%	34.9%	9.7%	0.4%	1.9%	100.0%
		% within highest level of education	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

Appendix 5.1F. Occupation and sources of drinking water supply (based on survey data).

			Occupation														Total
			Job—Undefined	**Job Organised**	**Job Unorganised**	**Business—Undefined**	**Business Organised**	**Business Unorganised**	**Student Undefined**	**School**	**College**	**University**	**Household**	**Household**	**Other**	**NA**	
Source of Water	Direct Piped-water supply by Corporation to the house	Count	8	127	11	2	108	14	1	21	41	11	228	1	25	11	609
		% within Source of Water	1.3%	20.9%	1.8%	0.3%	17.7%	2.3%	0.2%	3.4%	6.7%	1.8%	37.4%	0.2%	4.1%	1.8%	100.0%
		% within Occupation	80.0%	83.0%	84.6%	100.0%	80.0%	53.8%	100.0%	100.0%	85.4%	73.3%	82.3%	100.0%	83.3%	50.0%	80.8%
	Standpost outside the houses	Count	0	8	2	0	9	11	0	0	2	2	28	0	2	9	73
		% within Source of Water	0.0%	11.0%	2.7%	0.0%	12.3%	15.1%	0.0%	0.0%	2.7%	2.7%	38.4%	0.0%	2.7%	12.3%	100.0%
		% within Occupation	0.0%	5.2%	15.4%	0.0%	6.7%	42.3%	0.0%	0.0%	4.2%	13.3%	10.1%	0.0%	6.7%	40.9%	9.7%

	Dugwell/Tube well	Count	0	0	0	0	2	0	0	0	0	0	0	0	1	1	4
		% within Source of Water	0.0%	0.0%	0.0%	0.0%	50.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	25.0%	25.0%	100.0%
		% within Occupation	0.0%	0.0%	0.0%	0.0%	1.5%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	3.3%	4.5%	0.5%
	Waterbody nearby	Count	0	1	0	0	0	0	0	0	0	0	0	0	0	1	2
		% within Source of Water	0.0%	50.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	50.0%	100.0%
		% within Occupation	0.0%	0.7%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	4.5%	0.3%
	Other	Count	1	13	0	0	14	1	0	0	5	2	15	0	2	0	53
		% within Source of Water	1.9%	24.5%	0.0%	0.0%	26.4%	1.9%	0.0%	0.0%	9.4%	3.8%	28.3%	0.0%	3.8%	0.0%	100.0%
		% within	10.0%	8.5%	0.0%	0.0%	10.4%	3.8%	0.0%	0.0%	10.4%	13.3%	5.4%	0.0%	6.7%	0.0%	7.0%

		Occupation															
	NA	Count	1	4	0	0	2	0	0	0	0	0	6	0	0	0	13
		% within Source of Water	7.7%	30.8%	0.0%	0.0%	15.4%	0.0%	0.0%	0.0%	0.0%	0.0%	46.2%	0.0%	0.0%	0.0%	100.0%
		% within Occupation	10.0%	2.6%	0.0%	0.0%	1.5%	0.0%	0.0%	0.0%	0.0%	0.0%	2.2%	0.0%	0.0%	0.0%	1.7%
Total		Count	10	153	13	2	135	26	1	21	48	15	277	1	30	22	754
		% within Source of Water	1.3%	20.3%	1.7%	0.3%	17.9%	3.4%	0.1%	2.8%	6.4%	2.0%	36.7%	0.1%	4.0%	2.9%	100.0%
		% within Occupation	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

Appendix 5.1G. Caste and presence of toilet in the house (based on survey data).

			Caste				Total
			General	**SC/ST/OBC**	**Tribal**	**666**	
Presence of toilet in the house (Y/N)	Yes	Count	455	72	0	2	529
		% within Presence of toilet in the house (Y/N)	86.0%	13.6%	0.0%	0.4%	100.0%
		% within Caste	70.0%	71.3%	0.0%	50.0%	70.0%
	No	Count	136	20	0	0	156
		% within Presence of toilet in the house (Y/N)	87.2%	12.8%	0.0%	0.0%	100.0%
		% within Caste	20.9%	19.8%	0.0%	0.0%	20.6%
	NA	Count	59	9	1	2	71
		% within Presence of toilet in the house (Y/N)	83.1%	12.7%	1.4%	2.8%	100.0%
		% within Caste	9.1%	8.9%	100.0%	50.0%	9.4%
Total		Count	650	101	1	4	756
		% within Presence of toilet in the house (Y/N)	86.0%	13.4%	0.1%	0.5%	100.0%
		% within Caste	100.0%	100.0%	100.0%	100.0%	100.0%

Appendix 5.1H. Ethnic groups and presence of toilet in the house (based on survey data).

			Ethnic Group (Based on Main Language Spoken)				Total
			Bengali	**Other Indian**	**Non-Indian**	**NA**	
Presence of toilet in the house (Y/N)	Yes	Count	438	90	0	1	529
		% within Presence of toilet in the house (Y/N)	82.8%	17.0%	0.0%	0.2%	100.0%
		% within Ethnic group	71.9%	63.8%	0.0%	25.0%	70.0%
	No	Count	116	38	1	1	156
		% within Presence of toilet in the house (Y/N)	74.4%	24.4%	0.6%	0.6%	100.0%
		% within Ethnic group	19.0%	27.0%	50.0%	25.0%	20.6%
	NA	Count	55	13	1	2	71
		% within Presence of toilet in the house (Y/N)	77.5%	18.3%	1.4%	2.8%	100.0%
		% within Ethnic group	9.0%	9.2%	50.0%	50.0%	9.4%
Total		Count	609	141	2	4	756
		% within Presence of toilet in the house (Y/N)	80.6%	18.7%	0.3%	0.5%	100.0%
		% within Ethnic group	100.0%	100.0%	100.0%	100.0%	100.0%

Appendix 5.1I. Religion and presence of toilet in the house (based on survey data).

			Religion				Total
			Hindu	Muslim	Other	NA	
Presence of toilet in the house (Y/N)	Yes	Count	456	57	14	2	529
		% within Presence of toilet in the house (Y/N)	86.2%	10.8%	2.6%	0.4%	100.0%
		% within Religion	71.1%	70.4%	48.3%	40.0%	70.0%
	No	Count	131	12	13	0	156
		% within Presence of toilet in the house (Y/N)	84.0%	7.7%	8.3%	0.0%	100.0%
		% within Religion	20.4%	14.8%	44.8%	0.0%	20.6%
	NA	Count	54	12	2	3	71
		% within Presence of toilet in the house (Y/N)	76.1%	16.9%	2.8%	4.2%	100.0%
		% within Religion	8.4%	14.8%	6.9%	60.0%	9.4%
Total		Count	641	81	29	5	756
		% within Presence of toilet in the house (Y/N)	84.8%	10.7%	3.8%	0.7%	100.0%
		% within Religion	100.0%	100.0%	100.0%	100.0%	100.0%

Appendix 5.1J. Gender and presence of toilet in the house (based on survey data).

			Gender of the Respondent								Total
			Female	Male	Trans	Intersex	Other	5	7	NA	
Presence of toilet in the house (Y/N)	Yes	Count	135	178	84	69	34	1	0	27	528
		% within Presence of toilet in the house (Y/N)	25.6%	33.7%	15.9%	13.1%	6.4%	0.2%	0.0%	5.1%	100.0%
		% within Gender of the respondent	65.5%	66.4%	69.4%	86.3%	91.9%	100.0%	0.0%	69.2%	70.1%
	No	Count	41	68	34	5	3	0	1	3	155
		% within Presence of toilet in the house (Y/N)	26.5%	43.9%	21.9%	3.2%	1.9%	0.0%	0.6%	1.9%	100.0%
		% within Gender of the respondent	19.9%	25.4%	28.1%	6.3%	8.1%	0.0%	100.0%	7.7%	20.6%
	NA	Count	30	22	3	6	0	0	0	9	70
		% within Presence of toilet in the house (Y/N)	42.9%	31.4%	4.3%	8.6%	0.0%	0.0%	0.0%	12.9%	100.0%
		% within Gender of the respondent	14.6%	8.2%	2.5%	7.5%	0.0%	0.0%	0.0%	23.1%	9.3%
Total		Count	206	268	121	80	37	1	1	39	753
		% within Presence of toilet in the house (Y/N)	27.4%	35.6%	16.1%	10.6%	4.9%	0.1%	0.1%	5.2%	100.0%
		% within Gender of the respondent	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

Appendix 5.1K. Occupation and presence of toilet in the house (Based on Survey Data).

			Occupation														Total
			Job—Undefined	**Job Organised**	**Job Unorganised**	**Business—Undefined**	**Business Organised**	**Business Unorganised**	**Student—Undefined**	**School**	**College**	**University**	**Household**	**Household**	**Other**	**NA**	
Presence of toilet in the house (Y/N)	Yes	Count	7	122	4	0	106	14	1	15	41	11	174	1	22	11	529
		% within Presence of toilet in the house (Y/N)	1.3%	23.1%	0.8%	0.0%	20.0%	2.6%	0.2%	2.8%	7.8%	2.1%	32.9%	0.2%	4.2%	2.1%	100.0%
		% within Occupation	70.0%	79.7%	30.8%	0.0%	77.9%	53.8%	100.0%	71.4%	85.4%	73.3%	62.8%	100.0%	73.3%	50.0%	70.1%
	No	Count	1	20	9	2	20	10	0	3	3	2	74	0	7	4	155
		% within Presence of toilet in the house (Y/N)	0.6%	12.9%	5.8%	1.3%	12.9%	6.5%	0.0%	1.9%	1.9%	1.3%	47.7%	0.0%	4.5%	2.6%	100.0%
		% within Occupation	10.0%	13.1%	69.2%	100.0%	14.7%	38.5%	0.0%	14.3%	6.3%	13.3%	26.7%	0.0%	23.3%	18.2%	20.5%
	NA	Count	2	11	0	0	10	2	0	3	4	2	29	0	1	7	71
		% within Presence of toilet in the house (Y/N)	2.8%	15.5%	0.0%	0.0%	14.1%	2.8%	0.0%	4.2%	5.6%	2.8%	40.8%	0.0%	1.4%	9.9%	100.0%

		% within Occupation	20.0%	7.2%	0.0%	0.0%	7.4%	7.7%	0.0%	14.3%	8.3%	13.3%	10.5%	0.0%	3.3%	31.8%	9.4%
Total		Count	10	153	13	2	136	26	1	21	48	15	277	1	30	22	755
		% within Presence of toilet in the house (Y/N)	1.3%	20.3%	1.7%	0.3%	18.0%	3.4%	0.1%	2.8%	6.4%	2.0%	36.7%	0.1%	4.0%	2.9%	100.0%
		% within Occupation	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

Appendix 5.2. Borough wise distribution of vales of individual ecosystem services in US$ in 2009, 2014 and 2019 during pre-monsoon and post-monsoon seasons in Kolkata Municipal Corporation (KMC) and East Kolkata Wetlands areas (outside Kolkata Municipal Corporation) (based on Mamat et al., 2018) and satellite image interpretation from Landsat series-USGS).

Regulating Services						
KMC Boroughs	**2009 Pre-Monsoon**	**2009 Post-Monsoon**	**2014 Pre-Monsoon**	**2014 Post-Monsoon**	**2019 Pre-Monsoon**	**2019 Post-Monsoon**
I	99,431.73	99,990.86	138,984.00	151,208.22	230,251.36	122,000.63
II	5,490.15	7,449.94	11,969.40	10,127.26	29,168.95	8,065.79
III	167,464.02	238,272.56	183,697.81	207,909.72	275,495.65	195,437.21
IV	4,340.05	22,755.64	6,184.97	3,570.43	27,249.10	3,435.17
V	42,357.87	167,867.77	80,167.55	57,253.65	114,997.15	69,671.16
VI	38,291.65	122,797.85	50,782.01	33,106.15	68,518.17	31,922.11
VII	1,417,760.61	2,137,953.19	1,362,726.47	1,895,272.45	1,304,985.30	1,656,932.42
VIII	174,360.36	132,062.87	181,176.71	139,686.90	250,386.65	148,535.09
IX	711,705.64	674,576.64	825,809.00	712,884.10	1,027,374.07	633,618.84
X	276,304.99	198,558.04	243,333.92	245,655.13	277,712.65	166,966.46
XI	775,106.78	507,736.07	560,032.03	659,682.03	548,044.99	392,925.18
XII	3,210,648.17	3,925,048.79	3,139,736.03	4,207,568.60	2,747,856.27	3,691,303.21
XIII	364,787.83	300,709.95	339,783.60	336,811.33	270,466.57	267,503.77
XIV	344,749.52	225,608.04	269,225.10	246,773.25	339,071.06	205,644.54
XV	356,448.52	239,957.43	328,980.70	350,837.49	372,305.31	335,477.94
XVI	647,262.68	406,969.68	553,077.76	536,104.84	458,700.52	425,713.39
East Kolkata Wetlands Outside KMC	17,814,006.62	24,319,990.26	17,514,583.70	23,798,959.78	21,545,085.84	23,056,171.22
Supporting Services						
KMC Boroughs	**2009 Pre-Monsoon**	**2009 Post-Monsoon**	**2014 Pre-Monsoon**	**2014 Post-Monsoon**	**2019 Pre-Monsoon**	**2019 Post-Monsoon**
I	71,701.63	70,989.98	91,027.82	67,343.61	164,199.51	73,403.93

II	4,632.19	4,377.51	9,006.79	4,086.58	22,248.64	5,439.02
III	131,238.26	130,526.24	125,858.50	120,119.78	207,911.88	124,937.18
IV	3,661.82	5,424.79	5,218.43	1,963.28	22,012.81	2,898.35
V	27,395.50	140,143.96	56,289.27	18,926.21	80,982.43	43,413.57
VI	29,284.92	110,170.89	38,723.61	17,349.63	52,357.39	20,978.83
VII	551,633.94	890,885.83	538,415.64	592,099.96	378,444.34	544,360.98
VIII	148,515.09	137,546.42	153,689.10	112,477.36	211,970.55	122,490.52
IX	287,482.77	377,721.93	353,502.09	178,853.08	445,662.89	177,397.17
X	216,638.87	224,033.16	185,716.34	159,083.09	203,547.56	113,964.91
XI	623,721.65	630,101.49	434,027.64	475,888.73	414,144.54	280,423.54
XII	1,338,474.97	1,315,357.23	1,039,970.78	1,222,176.91	650,022.78	1,149,337.25
XIII	281,521.52	295,001.12	243,690.75	222,606.49	149,581.04	154,411.81
XIV	269,712.42	281,164.13	210,948.51	174,703.43	259,210.56	150,499.48
XV	272,928.40	288,794.69	259,639.27	249,520.46	293,866.77	257,607.89
XVI	535,430.33	547,977.86	454,053.79	417,793.12	369,681.49	339,154.74
East Kolkata Wetlands Outside KMC	4,645,182.97	4,739,474.13	4,820,301.15	4,322,623.06	4,646,136.96	4,166,283.29

Provisioning Services						
KMC Boroughs	**2009 Pre-Monsoon**	**2009 Post-Monsoon**	**2014 Pre-Monsoon**	**2014 Post-Monsoon**	**2019 Pre-Monsoon**	**2019 Post-Monsoon**
I	67,706.60	79,397.53	90,810.85	85,604.57	156,021.12	77,007.72
II	4,018.69	5,356.06	8,306.71	5,556.98	20,367.80	5,335.19
III	91,167.42	131,771.04	96,000.56	98,914.33	163,117.60	96,359.12
IV	3,176.84	11,482.89	4,527.29	2,176.69	19,538.69	2,514.49
V	26,677.43	47,166.78	53,548.80	28,891.63	77,494.79	44,599.21
VI	26,309.63	36,318.60	35,151.07	19,492.87	47,413.24	20,693.36
VII	766,420.92	1,117,285.31	740,759.72	965,359.21	649,030.56	851,956.53
VIII	79,305.28	79,499.95	92,245.97	49,596.12	137,695.66	58,568.07
IX	390,645.71	473,531.55	461,572.40	345,869.37	576,680.76	315,085.43

X	195,386.33	208,645.74	169,959.85	159,755.56	190,472.04	111,013.54
XI	554,767.60	568,652.30	393,910.57	449,276.97	381,069.09	266,340.89
XII	1,776,626.68	2,199,891.19	1,615,226.29	2,102,231.70	1,308,699.39	1,873,300.36
XIII	256,085.57	288,804.06	230,816.17	220,906.72	165,245.83	166,129.00
XIV	243,540.20	253,402.38	190,321.85	166,684.35	237,006.15	140,949.20
XV	249,333.12	263,227.10	233,343.03	237,451.64	264,087.23	234,970.94
XVI	469,337.20	482,143.54	399,600.28	378,042.23	328,542.94	303,275.13
East Kolkata Wetlands Outside KMC	8,469,807.08	11,166,822.41	8,523,688.98	10,640,453.10	9,995,419.23	10,326,581.89
Cultural Services						
KMC Boroughs	**2009 Pre-Monsoon**	**2009 Post-Monsoon**	**2014 Pre-Monsoon**	**2014 Post-Monsoon**	**2019 Pre-Monsoon**	**2019 Post-Monsoon**
I	31,867.29	36,235.15	38,515.34	38,934.15	55,432.00	29,153.01
II	5,434.72	5,952.82	6,590.44	6,059.06	9,748.22	5,565.43
III	43,834.57	58,912.09	45,807.73	49,001.14	53,944.66	39,104.73
IV	5,374.61	8,275.67	5,720.85	5,172.30	9,620.00	5,204.79
V	15,443.98	43,358.76	22,436.63	17,093.61	28,769.74	17,181.54
VI	14,265.43	33,960.20	16,570.56	12,892.80	19,802.60	11,710.02
VII	261,036.75	418,375.80	253,307.41	331,161.54	231,761.64	117,084.76
VIII	46,058.39	44,518.62	47,111.36	39,212.83	45,005.14	39,935.91
IX	142,861.18	164,512.24	162,606.18	137,035.58	196,136.61	53,274.52
X	71,333.62	75,519.19	64,974.75	63,833.27	70,810.18	44,778.05
XI	163,367.57	167,813.66	122,550.67	138,923.32	119,762.21	80,123.87
XII	564,007.00	717,874.54	519,907.04	688,673.66	451,816.72	211,716.82
XIII	78,793.05	89,586.28	73,177.48	71,595.02	58,203.75	43,584.19
XIV	76,408.25	78,864.23	62,484.23	57,316.35	75,003.70	45,507.24
XV	79,141.08	82,642.62	74,498.20	77,024.70	82,500.57	70,139.26
XVI	135,948.27	139,415.79	118,167.28	113,771.78	100,193.90	89,789.25
East Kolkata Wetlands Outside KMC	2,478,936.15	3,495,493.16	2,611,617.19	3,351,653.75	3,187,801.21	235,730.66

Appendix 5.3A. Compilation of approaches, dimensions, and issues of urban water security (modified from Mukherjee et al., 2021).

Approach	*Dimensions							**Issues									
	Env.	**Soc.**	**Cult**	**Pol.**	**Econ.**	**Gov.**	**Tech.**	**Av**	**Ac**	**HR**	**WQ**	**WM**	**NH**	**WD**	**Mg**	**Tech**	**UES**
Integrated Urban Water System Modelling (IUWSM) (Behzadian and Kapelan, 2015; Last, 2010; Makropoulos et al., 2008; Mitchell et al., 2001; Rozos and Makropoulos, 2013; Urich et al., 2013; Venkatesh et al., 2014; Willuweit O'Sullivan, 2013)	X				X	X	X	X			X	X				X	
United Nations Commission on Sustainable Development (UN-CSD) (UNCDS, 2001)	X	X			X	X		X	X		X		X	X	X		X
Ecological Network Analysis (ENA) (Zhang et al., 2010; Bodini et al., 2012; Pizzol et al., 2013)	X				X			X	X							X	X
System Dynamics (SD)	X	X	X		X	X	X	X							X	X	

(Baki et al., 2012; Sahin and Stewart; 2013)																	
Territorial Material Flow Analysis (UM-MFA) (Ayers and Ayers, 2002; Codoban & Kennedy, 2008; EIU, 2011; Kennedy et al., 2007; Kennedy et al., 2015; Mollay et al., 2011; Newmann et al., 1996; Newton et al., 2001; Pina and Martinez, 2014; Singh et al., 2009; Wernick and Irwin, 2005)	X				X	X	X	X	X		X	X				X	
Water Mass Balance (UM-WMB) (Bhaskar and Welty, 2012; Chrysoulakis et al., 2013; Kenway et al., 2011; Marteleira et al., 2014; Thériault & Laroche, 2009)	X					X	X	X	X			X			X	X	
Life Cycle Assessment (LCA)	X				X	X	X	X	X		X	X	X	X	X	X	X

(Fagan et al., 2010; Lane et al., 2015; Lundin, 2003)																	
Water Footprint (WF) (Hoff et al., 2014; Vanham, 2012)	X	X			X			X	X	X	X					X	X
Environmentally Extended Input-Output Analysis (EIO) (Lenzen, 2009; Lenzen and Peters, 2009)	X	X			X												
Aqueduct water risk indicators (Gassert et al, 2013)	X	X			X	X	X	X	X				X		X	X	X
Index of water security (Vorosmarty et al, 2010; Aihara et al., 2015; Shrestha et al., 2018; van Ginkel et al., 2018; Aboelnga et al., 2019; Aboelnga et al., 2020)	X	X			X	X	X	X	X							X	X
Pressure-State-Response (PSR) (OECD, 2004; OECD, 2003)	X	X			X	X	X	X	X		X	X	X	X	X	X	X

Driver-Pressure-State-Impact-Response (DPSIR) (Marsili-Libelli *et al*, 2004; Pirrone *et al*, 2005; WWAP, 2006; WWAP, 2002)	X	X			X	X	X	X	X		X	X	X	X	X	X	X

*Dimensions: Env: Environmental; Soc: Social; Cult: Cultural; Pol: Political; Econ: Economics; Gov: Governance: Tech: Technology

**Issues: Av: Availability; Ac: Accessibility; HR: Human Rights; WQ: Water Quality; WM: Waste Management; NH: Natural Hazards; WD: Waterborne Diseases; Mg: Management; Tech: Technology; UES: Urban Ecosystem Services

Appendix 5.3B. Borough wise population data based on Census of India-2011.

Borough	Associated wards	Number of Households	Total Population	No. of Males	No. of Females	No. of Public Toilets	TG included Public Toilets
I	1, 2, 3, 4, 5, 6, 7, 8 & 9	69903	310059	160598	149461	38	-
II	10, 11, 12, 15, 16, 17, 18, 19 & 20	43668	202195	107100	95095	23	-
III	13, 14, 29, 30, 31, 32, 33, 34 & 35	82211	365618	188310	177308	33	-
IV	21, 22, 23, 24, 25, 26, 27, 28, 38 & 39	47656	235399	134243	101156	21	-
V	36, 37, 40, 41, 42, 43, 44, 45, 48, 49 & 50	43221	226274	138113	88161	29	-
VI	46, 47, 51, 52, 53, 54, 55, 60, 61 & 62	49582	252287	137383	114904	32	-
VII	56, 57, 58, 59, 63, 64, 65, 66 & 67	114778	534606	281017	253589	44	-
VIII	68, 69, 70, 72, 83, 84, 85, 86, 87, 88 & 90	46343	202143	103356	98787	30	6
IX	71, 73, 74, 75, 76, 77, 78, 79, 80 & 82	88849	404625	216087	188538	27	2
X	81, 89, 91, 92, 93, 94, 95, 96, 97, 98, 99 & 100	105355	389461	193731	195730	31	-
XI	103, 104, 110, 111, 112, 113 & 114	61952	232522	116344	116178	19	6
XII	101, 102, 105, 106, 107, 108 & 109	78608	307200	155395	151805	9	-
XIII	115, 116, 117, 118, 119, 120 & 122	45324	179290	90401	88889	13	-
XIV	121, 127, 128, 129, 130, 131 & 132	58700	225948	112804	113144	12	-
XV	133, 134, 135, 136, 137, 138, 139, 140 & 141	49681	278021	146438	131583	8	-
XVI*	123, 124, 125, 126, 142, 143 & 144	39097	151046	75446	75600	6	-

*Wards No. 142, 143 and 144 were added in 2012 from rural constituencies (Gram Panchayet) to Kolkata Municipal Corporation areas. Therefore, no census data are available so far.

Appendix 5.3C. Borough wise Basti (socially deprived area) data with WaSH provision, based on Census of India-2011.

Borough	No. of Basti	Dweller/Latrine	Male/Latrine	Female/Latrine	Hindu/Latrine	Muslim/Latrine	Other Religion/Latrine	Bengali/Latrine	Hindi/Latrine	Urdu/Latrine	Other Language/Latrine
I	104	15.66	7.15	6.32	13.40	2.25	0.00	10.23	5.24	0.18	0.00
II	82	32.09	15.83	12.35	30.80	1.29	0.00	24.55	6.43	1.10	0.00
III	93	35.53	17.28	10.19	32.81	2.72	0.00	12.04	21.05	2.09	0.35
IV	82	19.65	8.75	7.09	15.82	3.83	0.00	14.37	4.23	0.92	0.13
V	66	30.78	12.85	11.39	21.22	9.56	0.00	19.44	11.30	0.04	0.00
VI	100	21.73	11.88	6.40	14.50	7.21	0.03	9.76	6.55	5.30	0.12
VII	172	35.30	14.21	11.08	14.25	20.40	0.65	9.17	7.74	17.31	1.08
VIII	100	27.56	10.39	9.75	18.08	9.31	0.16	15.85	4.97	6.58	0.16
IX	186	30.53	13.19	11.13	21.67	8.71	0.14	20.44	7.92	2.05	0.11
X	84	16.71	7.26	6.78	13.44	3.27	0.00	14.77	1.91	0.02	0.01
XI	52	11.09	4.03	3.52	10.32	0.74	0.04	10.48	0.52	0.06	0.04
XII	85	7.58	3.00	2.71	7.57	0.00	0.00	7.23	0.35	0.00	0.00
XIII	72	100.85	39.86	39.71	96.25	4.60	0.00	96.11	2.27	2.47	0.00
XIV	66	13.06	4.00	4.30	12.98	0.08	0.00	12.60	0.43	0.04	0.00
XV	91	24.22	8.33	7.56	3.41	20.81	0.00	6.70	9.55	7.96	0.00
XVI*	25	15.64	5.04	4.99	5.11	10.53	0.00	11.60	3.76	0.27	0.00

*Wards No. 142, 143 and 144 were added in 2012 from rural constituencies (Gram Panchayet) to Kolkata Municipal Corporation areas. Therefore, no census data are available so far.

Appendix 5.3D. Detailed list of variables for data collection through household survey during the research visit in Kolkata, India (November-December 2018).

- **Physical-Infrastructural dimensions of Urban Water Security**

1. Availability

Question No.	**Question**	**Answer Options**
AvlQ1	The main source of all waters used at the house	Corporation direct supply
		Local tap
		Bore well
		Waterbody nearby
		Other
AvlQ2	Frequency to get supplied water at house(s)	Once a day
		Twice a day
		Other
AvlQ3	No. of Toilets at the work/study place	0
		1
		2
		3
		5
		>5
AvlQ4	Number of users	<5
		5-20
		21-40
		41-60
		61-80
		80-100
		>100
AvlQ5	Source of drinking water	Piped supply
		Treated water from tap outside the house
		Tube well
		Well
		Bottled water to buy

		Pond
		Other
AvlQ6	Source of water for other household purposes except drinking	Piped supply
		Local tap outside the house
		Tube well
		Well
		Pond
		Other
AvlQ7	Means of waste management	Household bin collected by the corporation
		Roadside bin
		No available service
AvlQ8	Presence of toilet in the house	Yes
		No
AvlQ9	Presence of water for flushing in the toilet	Yes
		No
AvlQ10	Source of water for flushing in the toilet	Piped supply
		Collected from outside
		Other
AvlQ11	Presence of direct water supply in Kitchen	Yes
		No

2. Accessibility

Question No.	Question	Answer Options
AcsQ1	Gender character of the (personal) toilet(s) in the house	Male only
		Female only
		Disabled inclusive
		Trans inclusive
AcsQ2	Presence of WaSH provisions in the toilet(s)	Yes
		No
AcsQ3	Gender character of the toilet(s) at the work	Male only
		Male & Female
		Trans inclusive
		Disabled inclusive
AcsQ4	Gender character of the public toilet(s) used?	Male only
		Male & Female
		Trans inclusive
		Disabled inclusive
AcsQ5	In absence of both the personal/public toilet, other option	Nearby waterbody
		Other
AcsQ6	Monthly cost of water (in INR), if any	<100
		100-500
		500-1000
		>1000
AcsQ7	Time needed for collecting drinking water – from start to finish – i.e., if one must leave the house, from leaving the house to coming back?	<10 minutes
		10-15 minutes
		15-20 minutes
		>20 minutes
AcsQ8	The distance (in metres) from the house to the place to collect drinking water	<100 metres
		100-200 metres
		201-400 metres
		401-500 metres
		501-1000 metres
		>1000 meters

3. Quality

Question No.	Question	Answer Options
WqtQ1	Different sources of water for drinking and other household purposes	Yes
		No
WqtQ2	If yes, water quality is the reason for using different sources of water for drinking and other household purposes	Yes
		No

4. Risks

Question No.	Question	Answer Options
WrhQ1	Incident of Waterborne diseases in the house in the last 5 years	Yes
		No
WrhQ2	Number of Incident of Waterborne diseases in the house in the last 5 years (No./Year)	0
		1-2
		3-4
		5 or more
WrhQ3	Type of Disease(s)	Malaria
		Dengue
		Other
WrhQ4	No. of Casualty (s)	0
		1-2
		3-4
		5 or more
WrhQ5	Occurrence of flooding in the last 5 years	Yes
		No
WrhQ6	Type of flood related problem	Inundation
		Loss of wealth
		Death in family
		Diseases

		Loss of workdays
		Other
WrhQ7	Occurrence of flooding in the last 5 years (No./Year)	1-2
		3-4
		5 or more
WrhQ8	Occurrence of water scarcity	Yes
		No
WrhQ9	Type of Water Scarcity	Disrupted water supply at house
		No or less water at the tap outside
		Other
WrhQ10	Frequency in the last 5 years (No./Year)	1-2
		3-4
		5 or more
WrhQ11	Social/criminal threat when using public toilet. If yes, type of threat (Verbal/Physical assault)	No
		Verbal
		Physical
		Verbal + Physical

Socio-economic dimension of Urban Water Security

Question No.	Question	Answer Options
DemQ1	No. of Members in the house of the respondent	<5
		5-7
		7-10
		10-12
		12-15
		>15
DemQ2	Type of Household of the respondent	Own house
		Rented
		Apartment/Block
		Semi-permanent/Slums
DemQ3	Monthly household income (INR) of the respondent	<10,000
		10,000-25,000
		>25,000
DemQ4	Caste of the respondent	General
		SC-ST-OBC
		Tribal
		Other
DemQ5	Ethnic group of the respondent	Bengali
		Other Indian
		Non-Indian
DemQ6	Religion of the respondent	Hindu
		Muslim
		Other
DemQ7	Employment status of the respondent	Yes
		No
DemQ8	Occupation of the respondent	Job
		Business
		Student
		Household
		Other
DemQ9	If Job	Organised sector

		Unorganised sector
DemQ10	if Business	Organised sector
		Unorganised sector
DemQ11	Employment status of the other member(s) of the household	Job
		Business
		Student
		Household
		Other
DemQ12	If Job	Organised sector
		Unorganised sector
DemQ13	if Business	Organised sector
		Unorganised sector
DemQ14	Highest level of education of the respondent	Primary School
		Secondary School
		College or bachelor’s degree
		Postgraduate degree
DemQ15	Education level of other family member (s)	Primary School
		Secondary School
		College or bachelor’s degree
		Postgraduate degree
DemQ16	Gender of the respondent	Female
		Male
		Trans
		Intersex
		Other

For reasons of data protection, the curriculum vitae is not published in the electronic version

Eidesstattliche Erklärung

Hiermit erkläre ich, dass ich die vorliegende Arbeit selbständig angefertigt und keine anderen als die von mir angegebenen Quellen und Hilfsmittel verwendet habe.

Ich erkläre weiterhin, dass die Dissertation bisher nicht in dieser oder in anderer Form in einem anderen Prüfungsverfahren vorgelegen hat.

Subham Mukherjee

Berlin, 29.04.2021