An Integrated Quantitative Assessment of Urban Water Security of a Megacity in the Global South

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Keywords

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Abstract

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Water security, the access to adequate amounts of water of adequate quality, is and will remain a hugely important issue over the next decades as climate change and related hazards, food insecurity and social instability will exacerbate insecurities. Despite attempts made by researchers and water professionals to study different dimensions of water security in urban areas, there is still an absence of comprehensive water security measurement tools. This study aims to untangle the interrelationship between biophysical and socio-economic dimensions that shape water security in a megacity in the Global South - Kolkata, India. It provides an interdisciplinary understanding of urban water security by extracting and integrating relevant empirical knowledge on urban water issues in the city from physical, environmental, and social sciences approaches. To do so we use intersectional perspectives to analyze urban water security at a micro (respondent) level and associated challenges across and between areas within the city. The study concludes with the recommendation that future studies should make use of comprehensive and inclusive approaches so we can ensure that we leave no one behind.

Contribution to the field

This study aims to assess UWS from a quantitative bottom-up approach. We will include the factors behind the multiple intersections in Kolkata, India, covering one of the world's most densely populated areas, characterized by complex inherited social structures characterized by diverging communities and religious groups (Mukherjee et al, 2018; Mukherjee et al, 2020;). The approach sheds lights on the complexity and interconnectedness of water security issues. For example, we want to carve out, how water access issues for multiple social identities at the micro level (i.e., intersections of caste, gender, and socio-economic status) correspond with macrolevel structural factors (i.e., poverty, racism, and sexism) to produce unequal accessibility to water in Kolkata. Therefore, the objective of this study is to develop a quantitative assessment index within the framework of water (in)security in urban areas that can capture the complex interrelationships present between bio-physical and social dimensions within water security.

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Abstract

Water security, the access to adequate amounts of water of adequate quality, is and will remain a hugely important issue over the next decades as climate change and related hazards, food insecurity and social instability will exacerbate insecurities. Despite attempts made by researchers and water professionals to study different dimensions of water security in urban areas, there is still an absence of comprehensive water security measurement tools. This study aims to untangle the interrelationship between biophysical and socio-economic dimensions that shape water security in a megacity in the Global South - Kolkata, India. It provides an interdisciplinary understanding of urban water security by extracting and integrating relevant empirical knowledge on urban water issues in the city from physical, environmental, and social sciences approaches. To do so we use intersectional perspectives to analyze urban water security at a micro (respondent) level and associated challenges across and between areas within the city. The study concludes with the recommendation that future studies should make use of comprehensive and inclusive approaches so we can ensure that we leave no one behind.

Keywords

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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 represents multiple challenges to 21st century water management and crucial to achieve Sustainable Development (Cook and Bakker, 2012; UN, 2015). As a Sustainable Development Goal, water security has three primary dimensions: environmental, economic, and social (Giddings *et al*., 2002). To achieve "sustainability and security" within water security, each of these three dimensions should be addressed. While water scarcity has historically been more severe in rural areas, emerging research has shown a worsening availability and quality of water in urban areas and thus, urban areas are the focus of this study (Maiti and Agrawal, 2011; Mohan *et al*., 2011; Cook and Bakker, 2012; Mukherjee *et al*., 2020; Mukherjee *et al*., 2021a ;). From the rapidly changing urban perspective, the dimension of water security includes a focus on the need for organizational and institutional flexibility and capabilities 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). To address and better capture the multidimensional issues related to and driving water security, this study creates a quantitative index based on social, economic, cultural, and bio-physical dimensions of water security, specifically focusing on water availability, water accessibility, water quality and risks associated with water.

UWS issues are particularly pertinent and show insufficient conditions in megacities in the developing world due to rapid and unplanned demographic and economic growth. India is one of the emerging economies where UWS issues are non-satisfying (Shaban and Sattar, 2011; Shaban *et al*., 2020; Chatterjee and Roy, 2021). In urban India, the rapid population growth combined with increasing levels of consumption and pollution has increased water insecurities (Shaban and Sattar, 2011; Mukherjee *et al*, 2018). 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). Among the megacities in India, we chose Kolkata (under jurisdiction of Kolkata Municipal Corporation or KMC) as our study area. Kolkata is a growing megacity that faces rising pressures on water-environmental provision due to the rapid population growth coupled with sporadic urbanization and resultant governance and infrastructural issues despite of having enough water resources (Mukherjee *et al*., 2018; Mukherjee *et al*., 2020; Mukherjee *et al*., 2021b).

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 in Kolkata (Mukherjee *et al*., 2018). 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, within the city or in fringe areas (Kundu, 2003; Mukherjee *et al*., 2020). Despite of the fact that the right to water and sanitation was recognized as a human right by the United Nations General Assembly on 28 July 2010 (UN, 2010) and recognized by UN’s sustainable development goal 6 (SDG) (Mukherjee *et al*., 2020), social inequities in (mega)cities like Kolkata play an important role in water and sanitation-related risks. With informal settlements and socially deprived areas generally having lower levels of UWS 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 as an explanatory factor to analyze how access, needs, and use of water are shaped in every society (Wallace and Coles, 2005; Ray, 2007). Risks associated with water are higher among women and transgender people in comparison to their male counterpart (Denton, 2002; MacGregor, 2009; Demetriades and Esplen, 2010). Insecurity related to water 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). The transgender and other gendered communities, 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).

1.1. Urban Water Security assessment so far

Previous studies in different disciplines have highlighted that vulnerabilities and experiences of UWS vary according to a range of bio-physical and socio-economic factors (Mukherjee *et al*., 2021a). UWS 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). Most recent studies have demonstrated the development of numerous definitions and assessment frameworks for UWS 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 complex dynamics of UWS particularly at the urban level (Mukherjee *et al*., 2021a). This research tries to fill this gap.

The existing measurement frameworks of UWS have been conceptualized in various ways; some focus on risks, while others have adopted broader aspects 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, such as lack of updated legal tenures, socio-cultural exclusion, and inadequate survey reports, associated with accurately measuring the proportion of the population without access to clean and safe water, it is probable that the proportion thought to have access is grossly overestimated (Adams, 2017; Nganyanyuka *et al*., 2014; Satterthwaite, 2016). This lack of accurate data on access to clean and safe water 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 improve 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 index-based assessment and the corresponding dimensions and issues of urban water mentioned in the previous studies are summarized in Appendix A of the electronic supplementary material. This list shows that any attempt to assess UWS needs to consider the intersecting characteristics of bio-physical environment, society, and communities together along with 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).

1.2. Aims and objectives of the study

This study aims to assess UWS from a quantitative bottom-up approach. We will include the factors behind the multiple intersections in Kolkata, India, covering one of the world's most densely populated areas, characterized by complex inherited social structures characterized by diverging communities and religious groups (Mukherjee *et al*, 2018; Mukherjee *et al*, 2020;). The approach sheds lights on the complexity and interconnectedness of water security issues. For example, we want to carve out, how water access issues for multiple social identities at the micro level (i.e., intersections of caste, gender, and socio-economic status) correspond with macrolevel structural factors (i.e., poverty, racism, and sexism) to produce unequal accessibility to water in Kolkata. Therefore, the objective of this study is to develop a quantitative assessment index within the framework of water (in)security in urban areas that can capture the complex interrelationships present between bio-physical and social dimensions (for details see Mukherjee *et al.*, 2021a) within water security.

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) situated on the east bank of River Hugli in the deltaic Bengal Basin developed by the action of the Ganga-Brahmaputra River system and nearly 120 km away from the Bay of Bengal. The city area as governed under Kolkata Municipal Corporation (KMC) covers about 205 km^2 and is divided into 16 boroughs or administrative blocks, having 21 assemblies and 3 parliamentary constituencies and 144 wards. Population counts 4,496,694 inhabitants and a population density of 24,760 km^{-2}. The ratio of the population is 956 females for every thousand males; 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 the 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 often referred to as slums (officially known as ‘basti’) comprising a total area of 25.95 km^2 (Mukherjee *et al.*, 2020). We have carried out in depth analysis focusing socially excluded areas, often defined as ‘slums’, elsewhere (see Mukherjee, et al., 2020). Hence, we exclude the repetition in this research article. In this paper, we aim to have an inclusive approach for which we took the entire survey sample across various socio-economic (i.e., gender, religion, caste etc.) and spatial demographic variations within the study area (i.e., KMC area) as representative population, where ‘slums’ and other ‘non-slums’ households were given equal priorities for analyses. 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 totals 375 of which. The statistics of boroughs of KMC are given in appendices B and C. Mukherjee *et al*. (2018) documented detailed bio-physical and social characteristics of Kolkata city and its water security issues. Figure 2 emphasizes the importance of looking at intra city variations when it comes to analyzing water security issues, exemplified by variations of gender inclusive public toilets and the number of basti in the different wards of the city. These maps outline the background and a starting point for our analysis as we see how social issues, like population density and the existence of WaSH facilities, for example, are related.

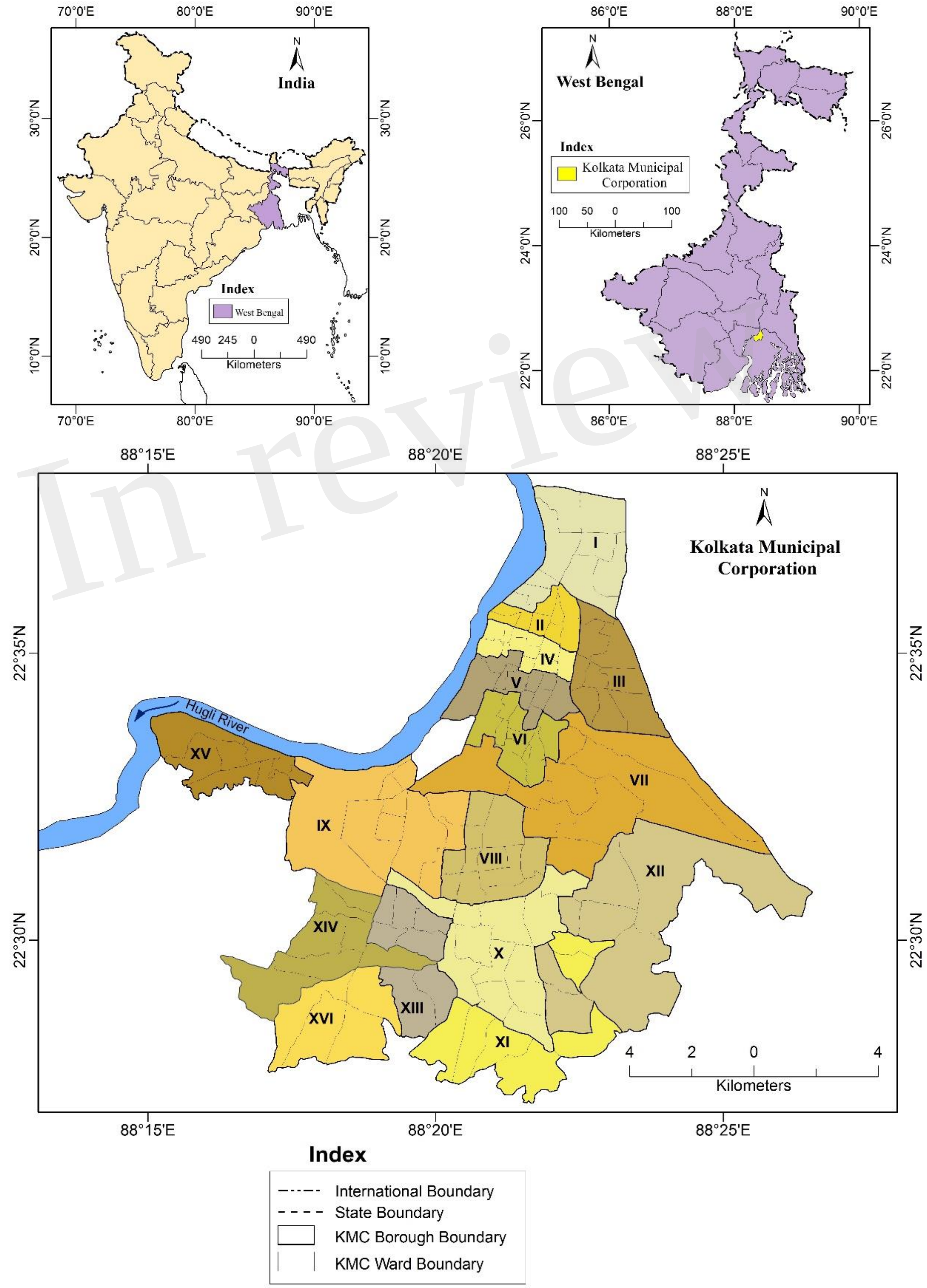

Figure 1: Location of Kolkata Municipal Corporation (KMC) boroughs (featuring the wards associated in a borough) within West Bengal, India. Roman numbers mark the borough numbers and darker tones represent higher values (Source: Mukherjee *et al*., 2018).

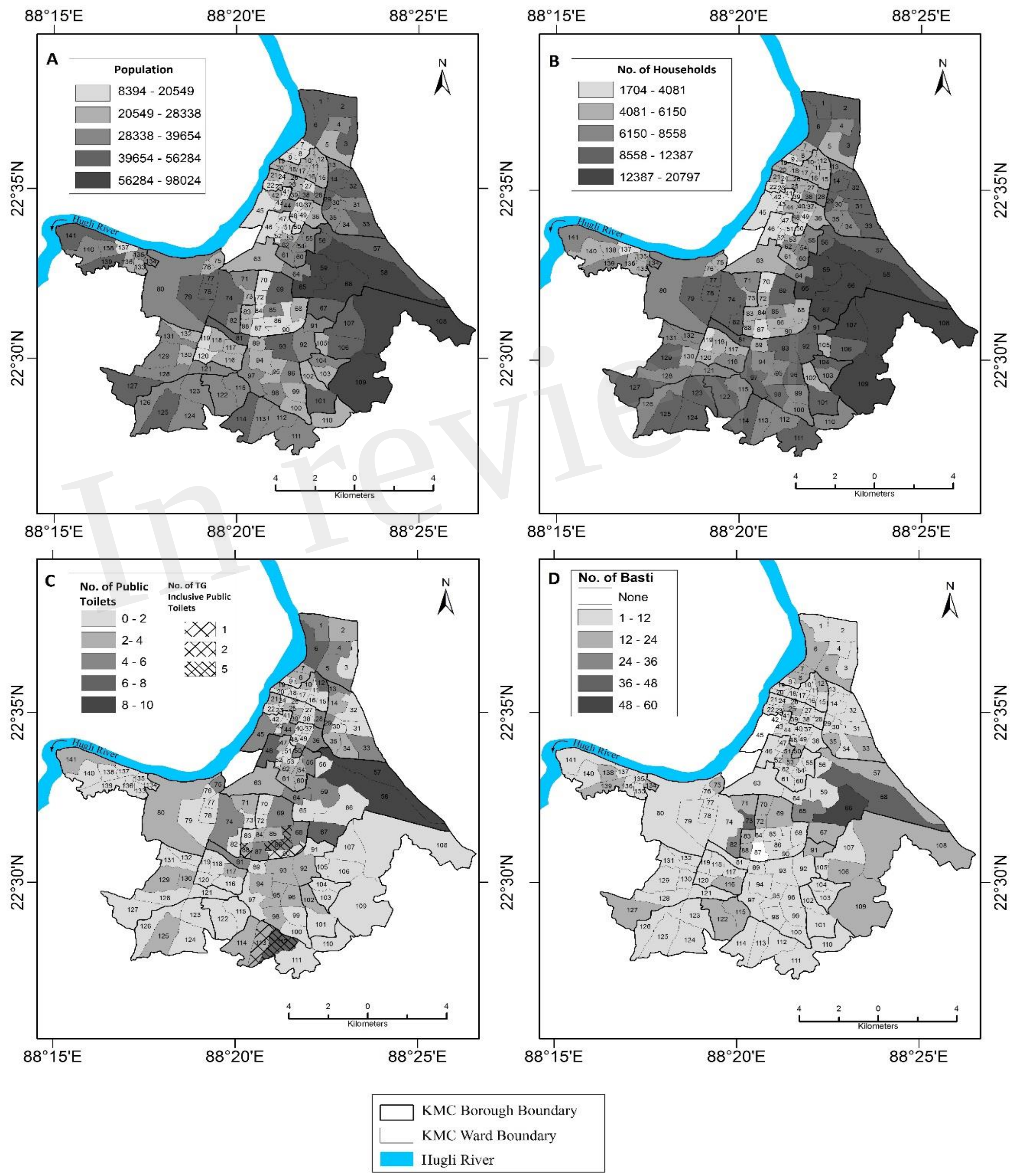

Figure 2: Demographic features of the Kolkata Municipal Corporation (KMC) area (Wardwise). A) Population, B) Number of Households, C) Number of Public Toilets along with number of

Transgender (TG) inclusive Public Toilets, and D) Number of basti. (Sources: Census of India, 2011; Department of Slum Development and Department of Water Engineering, Kolkata Municipal Corporation, India)

3. Methods

3.1. Data

3.1.1. 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 D.

The Survey questionnaire (Appendix D) forming the basis of the household survey consists of 47 questions divided into 5 segments. The first four segments cover different 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 cover all relevant aspects of the integrated urban water security index (Grey and Sadoff, 2007; Mukherjee *et al.*, 2021b) as well as, together with socio-demographic indicators form the assessment framework of urban water security within Kolkata Municipal Corporation area. 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, they were trained how to avoid biased language as well as ethical issues that may arise during an interview. Survey training activities were 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.

3.1.2. Secondary Data

Secondary data were collected from the Department of Water Investigation and Department of Urban Development of Government of West Bengal (data on amount of treated water, urban water supply, distribution, and infrastructures). Additionally, the data from the Kolkata Municipal Corporation (KMC) (Department of Slum Development, Department of Water Engineering) (data on 'Slum' population, housing and public toilets), West Bengal Pollution Control Board (WBPCB) (data on surface water quality) and Kolkata Municipal Development Authority (KMDA) were also collected (data on groundwater quality, urban water supply and distribution network at the boundary areas of Kolkata Municipal Corporation). These data contained information on the components of water security within Kolkata Municipal Corporation (KMC) area.

3.2. Data Processing

3.2.1. Initial Data Processing

We assigned variables' scores on a 0 to10-point scale of water security, 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). These categories and cut off values for *security status* were based on the 'urban water security dashboard' proposed by Ginkel *et al*. (2018). Here, 5 (median value between 0-10) is considered as the 'threshold' point. Therefore, score higher than 5 denotes *secure* status of UWS and lower than 5 indicates *insecure* status of UWS. Aggregation from each level to the next was done by calculating the arithmetic mean. Finally, the borough level scores of the four components of water security were further combined into one water security index (borough level), which determined the final ranking of the KMC boroughs.

3.2.2. Principal Component Analysis (PCA)

Principal Component Analysis (PCA) allows us to identify patterns and components that enhance our understanding of water security (Raschka, 2015). In this case, it helps us to identify which factors come together to create the crucial components of water security, and then allowing us to create an index to measure it (Aihara *et al*, 2015; Shrestha *et al*., 2018). 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).

3.3. Calculation of Urban Water Security Index

Urban Water Security Index (UWSI) scores have 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 analyse 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:

$$UWSI=(Avl*w1) + (Acs*w2) + (Wqt*w3) + (Wrh*w4) \quad \text{(eq1)}$$

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 0–10-point scale (Status of security status as discussed earlier) classifying the status of urban water security

3.4. Interrelationships between UWSI and Socio-demographic variables

Indicator scores were aggregated to an Urban Water Security Index (UWSI) at the borough level, (we preferred borough level index to be able to access to government data at the borough level than that of 144 wards). We then studied the coherence between UWSI's scores and the sociodemographic characteristics of the Kolkata Municipal Corporation area, through statistical analyses (Pearson's correlation and crosstabs-contingency tables) using SPSS.

4. Results

4.1. Principal Component Analysis

The aggregated values of the four water security components were analyzed using Principal Component Analysis (PCA), and four principal components (PCs) were identified. The choice of 4 components was based on each of the PCs explaining data variation between 13.02 to 36.23% and accounting for 100% of the total variance (Table 1). In the analysis of the variables studied, the resulting first principal component PC1 explained 36.23% of the data variability, while PC2 explained 27.58% of the variance. The remaining principal components PC3 and PC4 accounted for 10-20% of the variance. Communalities statistics revealed that >70% of the variance can be explained by the factor *Water Availability* and *Water Accessibility*, >60% of the variance by the factor *Water Quality* and >45% of the variance can be explained by the factor *Water Risk and Hazards* (Table 2). This analysis confirms the assumptions of our study that these dimensions are the crucial dimensions of water security, and we go on to look at what social and bio-physical dimensions are associated with higher or lower levels of security along these dimensions.

Table 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 2. Communalities

	Initial	Extraction
Water Availability	1.000	0.742
Water Accessibility	1.000	0.738
Water Quality	1.000	0.614
Water Risk and Hazards	1.000	0.458

Extraction Method: Principal Component Analysis.

Table 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 represents the set of information collected through survey, and we argue, that this index improves assessment of the multidimensional issues affecting water security. The factors loadings (Table 3) associated with the variables indicate which are the most important of the different water security components 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). These factor loadings are the weights assigned to each variable in Equation 1 to calculate UWSI values. *Water Availability* (0.837) and *Water Risk and Hazards* (0.667) show the highest factor loadings and are the highly correlated with the first principal component PC1; correspondingly, they are the best single-dimensional descriptors of the dataset. As the data have been scaled and centred, the resulting principal components and index of values based on this component are all relative values enabling comparisons, however their absolute values without validity (Tables 1-3). In contrast, the variables which were less important in the index still contributed to the distinction, including *Water Accessibility* (0.332) and *Water Quality* (-0.416), which is why we still include them.

4.2. Spatial distribution of UWSI values

After calculating UWSI values using the weights of PC1, 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 3) shows the scores of UWSI (mean=7.33; median=7.33; Interquartile Range IQR=8.56-6.20); data are normally distributed without skew and fall into the range of status of water security within Kolkata Municipal Corporation area. Skewed data distribution occurs for the UWS components: 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 (mean=6.72, median=7.37; IQR=5.65 – 7.70). *Water Accessibility* (mean=4.88; median=4.91; IQR=5.34 – 4.50) has a low variability and falls into 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. From this we can see the importance of disaggregating the index to understand which component is driving and influencing the overall averages, here we see the overall higher mean of *Water Risk and Hazard*, compared to lower overall ‘security’ along *Water Accessibility and Water availability.*

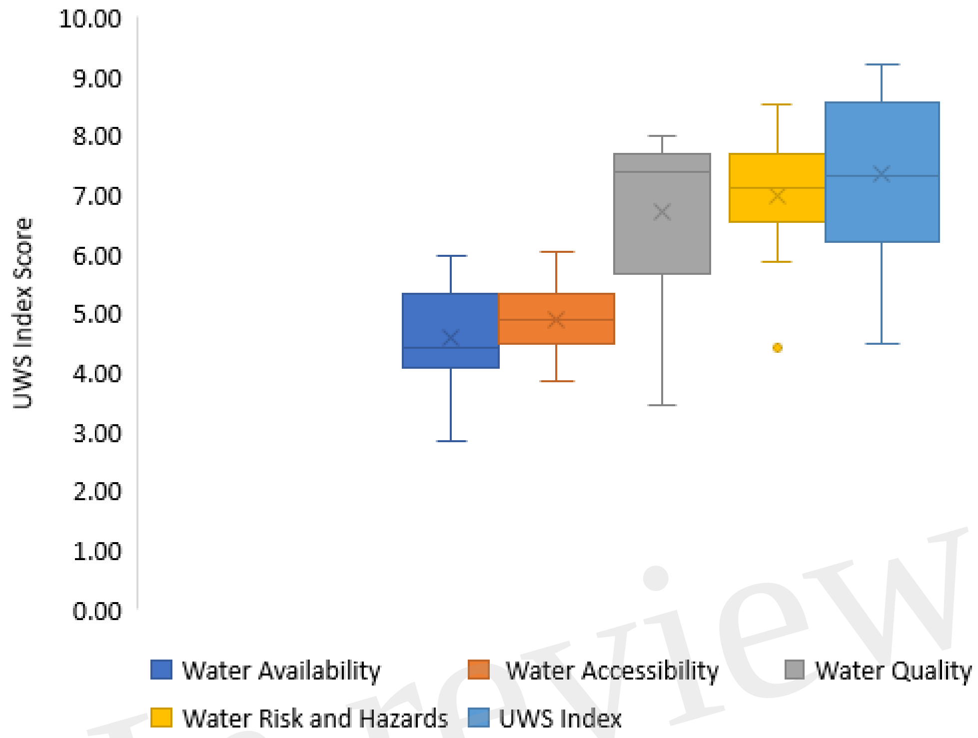

Figure 3: Distribution of scores of Urban Water Security (UWS) Index (along the Y axis) and Components of Urban Water Security (*Water Availability*, *Water Accessibility*, *Water Quality* and *Water Risks and Hazards*) (along the X axis) within Kolkata Municipal Corporation (KMC) area at the respondent level. Data source: Survey data.

Further delving into the components of the UWSI index, we find that (*Water Availability, Water Accessibility, Water Quality* and *Water Risks and Hazards*) (Figure 4) the scores for *Water Availability* and *Water Risks and Hazards* played a major role in the overall status of the UWS of the boroughs, thus explaining the overall high mean and median for the UWSI. High values of *Water Risks and Hazards* component dominate the final index scores for all the boroughs. Figure 4 highlights the intra city variations across the components and underlines the need for researchers to take intra city variation into account when studying water security. For the *Water Risks and Hazards* component, boroughs VIII and XV show highest UWSI scores within Kolkata Municipal Corporation (KMC) area (borough VIII=9.21, borough XV=9.05). For borough VIII, both *Water Risks and Hazards* and UWSI score are greater than 8. For borough XV, UWSI score is higher than 9 despites of the score for *Water Quality* amounts 3.44 which means 'Insecure'. Scores of Water *Quality* component have no impact on the total UWSI scores for boroughs IX and X. These boroughs show the lowest scores in *Water Quality* within Kolkata Municipal Corporation (KMC) area (boroughs IX=5.11 boroughs X=3.66), but the urban water security status for borough IX and X are still 'Very secured' because of the higher scores in *Water Risks and Hazards*. In borough VI the value for the *Water Quality* component totals 7.89, however, due to its low score in *Water Availability* (3.65), it only receives an 'Around acceptable threshold' status of UWS. For borough XIII UWSI score (4.48) is ranked as the lowest within Kolkata Municipal Corporation (KMC) area, coinciding with the lowest score in *Water Availability* (2.85).

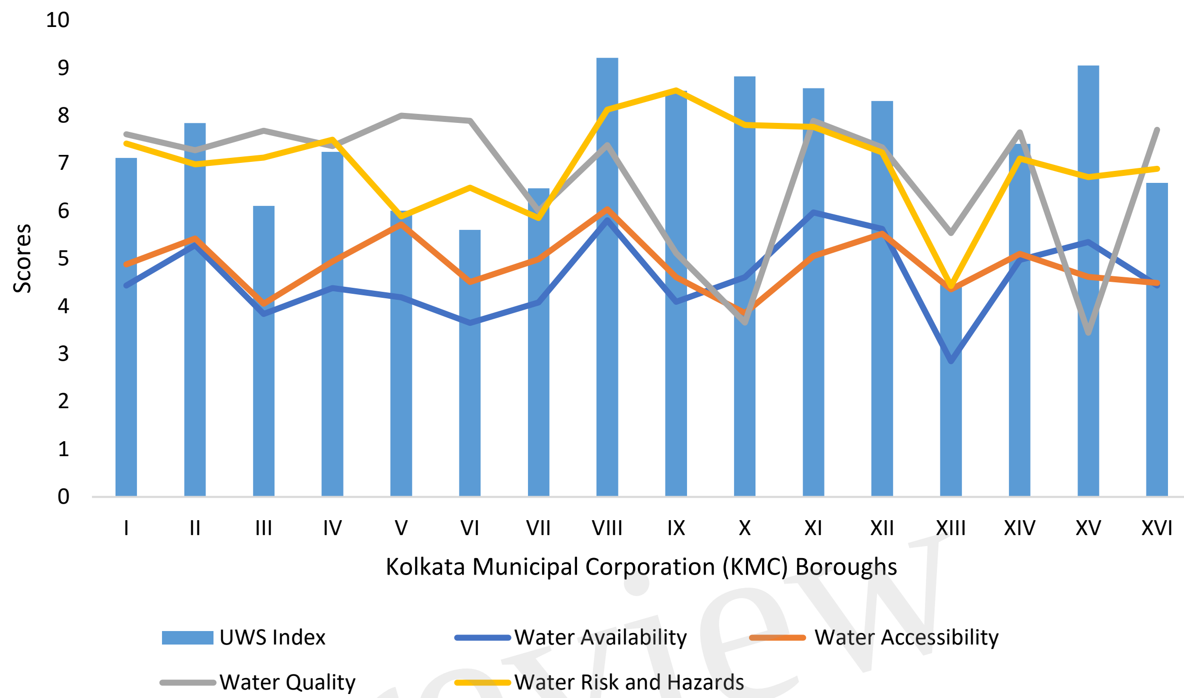

Figure 4: Borough wise distribution of average scores of Urban Water Security (UWS) Index and Components of Urban Water Security (*Water Availability, Water Accessibility, Water Quality and Water Risks and Hazards*) within Kolkata Municipal Corporation (KMC) area. Roman numbers mark the borough numbers. Data source: Survey data.

Figure 5 shows borough wise distribution of % of respondents with different status of Urban Water Security (UWS) across the Kolkata Municipal Corporation (KMC) area. The highest percentage of respondents projected as 'Very Secured' status of UWS are in borough VIII (>86%). Borough I has the maximum respondents with 'Secured' status. No respondent in borough VI and XIII is falling within 'Very Secured' status of UWS. More than 2% of respondents within borough XIII are falling into 'Very Insecure' status of UWS and this is the only borough which has respondents with 'Very Insecure' status of UWS. Most respondents (39.16%) within the whole survey dataset are falling within 'Very Secured' status of UWS. Boroughs I, IV, VIII, IX, XI, XII and XV-XVI have no respondent with either 'Very Insecure' or 'Insecure' status of UWS.

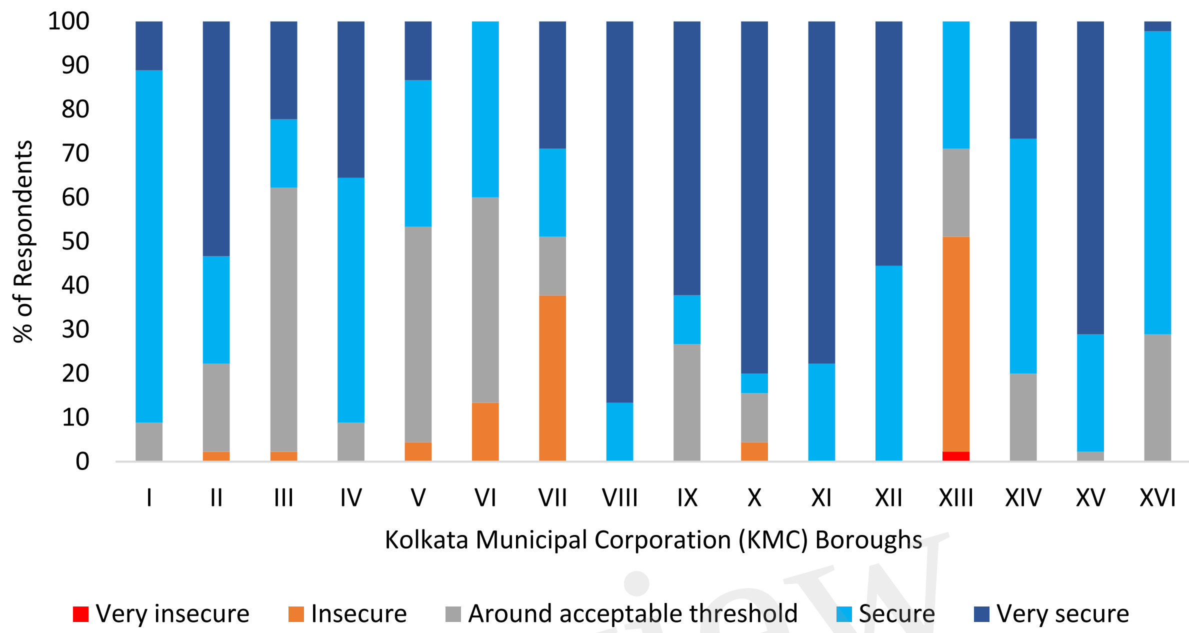

Figure 5: Borough wise distribution of % of respondents with different status of Urban Water Security (UWS) across Kolkata Municipal Corporation (KMC) area. Roman numbers mark the borough numbers. Data source: Survey data.

As seen in Figure 5, another crucial factor to take into account is highlighted when we look at intra borough variation of the UWS components.

Looking at the geographical distribution of the components of UWS (*Water Availability, Water Accessibility*, *Water Quality* and *Water Risks and Hazards*) we can better appreciate how they vary across boroughs in the KMC area (Figure 6). For *Water Availability*, no borough has entirely either ‘Very Secure’ or ‘Very Insecure’ status of UWS. Most boroughs have ‘Secure’ status, except boroughs IX, XIV and XV where the UWS status is limited to ‘Around acceptable 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*. 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’ status and broughs I, II, and III are in ‘Very Secure’’ status of UWS, where rest of the boroughs are having ‘’Secure’’ status for *Water Risks and Hazards*. Borough wise scores for *Water Quality* vary more than other components of UWS across the entire KMC area. Boroughs IV and XIII are within ‘’Very Secure’’ status, boroughs II, III and VII are within ‘’Around accepted threshold’’ status and the rest are in ‘Secure’ status of UWS.

By using borough wise UWS index scores we can observe the combined effect all component of UWS across the KMC area (Figure 7). The UWS index scores appear to be within ‘Secure’ status for the boroughs I-V and VII in the north-central part of KMC area and boroughs XIV and XVI in the southern part of KMC area. For boroughs VI and XIII, the UWS index scores fall within the ‘Around accepted threshold’ status. However, boroughs VIII-XII and XV in the southern part of KMC fall within ‘’Very Secure’’ status of UWS.

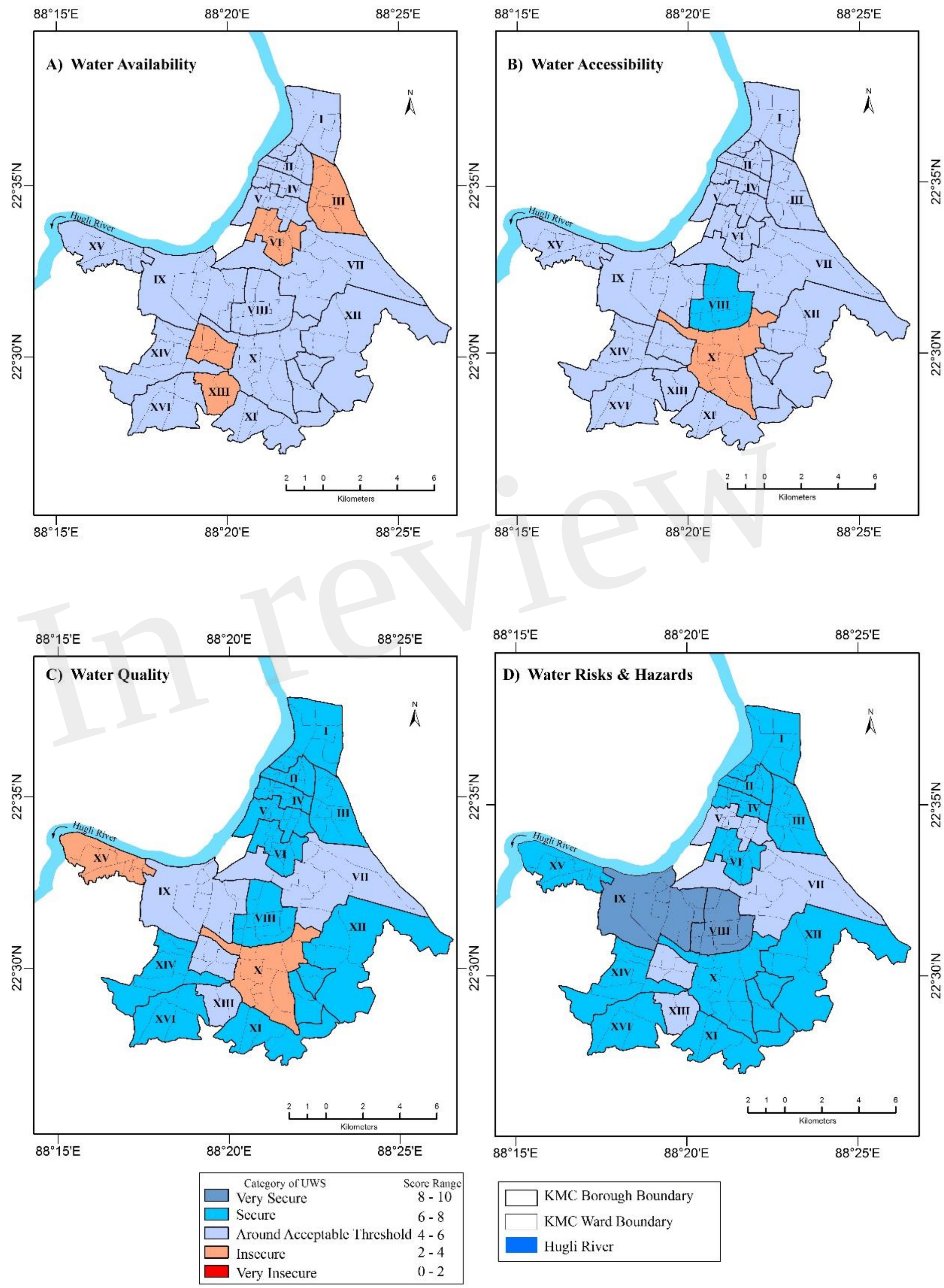

Figure 6: Urban Water Security (UWS) status associated with each component (*Water Availability, Water Accessibility, Water Quality and Water Risks and Hazards*) of UWS within each borough of Kolkata Municipal Corporation (KMC) area. Roman numbers mark the borough numbers. Data source: Survey data.

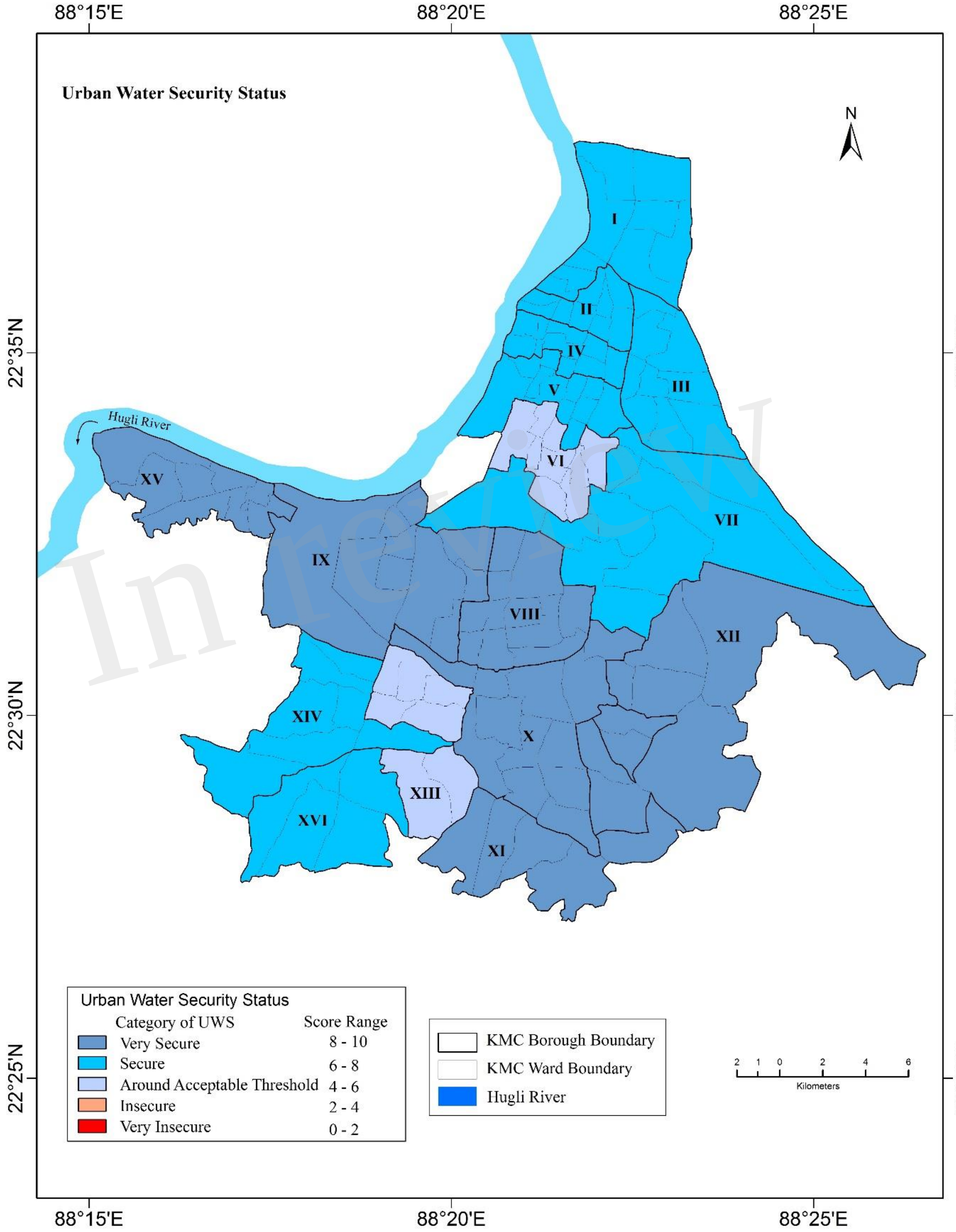

Figure 7: Borough wise distribution of UWS Index status within Kolkata Municipal Corporation (KMC) area. Roman numbers mark the borough numbers. Data source: Survey data.

4.3. Interrelationships between Index values and Socio-demographic variables

4.3.1. Pearson's r

We calculated Pearson correlation coefficients to assess the strength and direction of correlations between socio-demographic variables (Independent variables), urban water security (UWS) components (*Water Availability, Water Accessibility, Water Quality and Water Risks and Hazards*) and the UWS Index (Dependent variables) (Table 2) within the Kolkata Municipal Corporation (KMC) area. There are statistically significant correlations 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 ($\alpha<0.01$) (Table 4). UWSI values also correlate with *Ethnicity* ($\alpha<0.05$). *Water Availability* component of UWS shows statistically significant correlations with other UWS components and types of households, 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 households, 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 ($\alpha>0.05$). High income, caste, education, and occupational level correlate with higher levels of UWS. Furthermore, religion, ethnicity and gender also matter as being a Hindu, Bengali speaker and cis-man is associated with higher UWS.

Table 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 (2018-19). * marking 95% confidence level, ** marking 99% confidence level.

		Availability	Accessibility	WaterQuality	WaterRisksandHazards	TypeofHousehold	Numberofmembersinthehouse	MonthlyHouseholdIncome	Caste	Ethnicity	Religion	EmploymentStatus	Occupation	EmploymentStatusoftheFamilyMembers	HighestLevelofEducationinthefamily	EducationLevelofthe respondent	Gender
ComponentsofUrbanWaterS	WaterAvailability	1	.271**	-.128**	.303**	.384**	-	.269**	.148**	.125**	-	.205**	.162**	-	.346**	.107**	-.114**
	WaterAccessibility	.271**	1	.290**	-	.261**	-	.221**	-.086*	-	.180**	.220**	-	.093**	.136**	.074*	-

ecurity	Water Quality Factor	-.128**	.290**	1	-	-.084*		.105**	-.074*	-.130**	-	-	-.128**	-	-.090*	.082*	-.145**
	Water Risks and Hazards	.303**	-	-	1	.169**	-.104**	.195**	.128**	-	-	-	.134**	-	.194**	.100**	.124**
UWS Index Scores		.801**	.722**	-515**	.642**	-.074**	-.110**	-	-.098**	-.088*	-	-.123**	-	-	-	-	-

4.3.2. Cross tabulation

The Cross tabulation of survey data (Appendix E) 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*) as shown by the bivariate analysis in the previous section (chapter 4.3.1(). The main findings from the ´cross-tabulation analysis are as follows:

Household types: Respondents having their own house constitute the majority in the *Very Secure* status of UWS. In contrast, respondents dwelling in semipermanent houses in deprived areas are found in the *Very Insecure* status of UWS.

Monthly household income: 47% of the respondents from the higher income group (monthly income >25,000 INR), 33.3% of the respondents from the middle income (monthly income 10,000 - 25,000 INR) and 16.7% of the respondents from the lower income group are within the *Very Secure* status of UWS. However, the remaining respondents from the lower income group are within the *Very Insecure* status of UWS.

Caste: 86.2% of the respondents from general (upper) caste and 13.8% of the respondents from scheduled caste/scheduled tribes/other backward castes (SC/ST/OBC) are within the *Very Secure* status of UWS. Respondents from general caste are the majority (86.2%) in the *Secure* status of UWS than the SC/ST/OBC (12.9%) respondents.

Ethnicity based on languages spoken: 81.9% of Bengali speaking respondents and 17.4% of Other Indian languages speakers are in the *Very Secured* status of UWS. Conversely, 0.3% of Bengali speakers and 0.8% of total *Other Indian language* speakers are within the *Very Insecure* status of UWS.

Religion: 83.3% of Hindu respondents and 11.6% Muslim respondents are having *Very Secure* status of UWS. In contrast, *Insecure* status of UWS is higher among Muslim respondents (40%) than Hindu respondents (10%).

Occupation: Respondents who do household works are the most water secured ones, while students and those working in unorganized business/jobs are the least water secured respondents.

Level of education: 34.7% of the respondents with a college/bachelor's degree have the *Very Secure* status of UWS, while only 2.9% of the Postgraduate degree holders are the least water secured.

Gender: Within the *Very Secure* status of UWS, 37.7% of cis-males build the majority. Simultaneously, 9.6% of cis-female, 5% of intersex, 13.2% of cis-male and 13.7% of trans(gender) respondents are within the *Insecure* status of UWS, while 0.8% of the cis-male respondents and 0.9% of the trans(gender) respondents are within the *Very Insecure* status *of UWS*.

5. Discussion

This research quantifies the spatial distribution of urban water security (UWS) of Kolkata city through a novel index-based assessment framework that encapsulates both bio-physical and social dimensions. In this discussion section, we discuss the explanations 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 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.

5.1. 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). Based on our findings *Water* Availability varies across boroughs and wards in KMC and is varying around what has been set as an 'acceptable' threshold. The lower range of *Water Availability* indicates that there is a demand for supply of potable water, in particular in some areas of KMC, namely the southern peripheral boroughs such as boroughs XIII-XIV (Figure 1 and 2; Appendix B and C).

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 are connected with 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.

The resultant effect of urbanization within and around KMC area 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 level 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).

Other 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 *et al*., 2000; Moss, 2008; Feng *et al*., 2010; Veldkamp *et al*., 2017; Chen *et al*., 2020). Mukherjee *et al*, (2018 and 2020) showed that borough wise declining rate of wetlands 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).

Furthermore, our survey data show that only 67% households (n=720) within KMC have a toilet inside. 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).

5.2. 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. 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 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 considered.

5.3. 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, the 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 $\mu g\ L^{-1}$ to a factory site producing Paris Green, an arsenical pesticide manufactured between 1965 and 1985, sporadic lead>10 $\mu g\ L^{-1}$ from well-fittings, many samples contaminated by Cl from wastewater (sewage and septage) and natural Mn >0.3 $mg\ L^{-1}$.

5.4. 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 the 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. This result establishes the links between deteriorated water quality of Adi Ganga canal and poor and inadequate living conditions, sanitation issues and lack of municipal services in the canal side temporary/semi-permanent settlements where morbidity and mortality rates are high (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 people living in these areas have been a key focus for urban planning work in respect to accessibility of safe drinking water and availability of adequate sanitation facilities (Sau, 2017).

The importance of deprivation in the area of water security cannot be underestimated. During severe flooding, such as in September 1999, the deprived areas of the city 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 (Mukherjee *et al*., 2018). 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 (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).

5.5. Urban Water Security

The urban water security index (UWSI) reveals the intrinsic spatial disparity of water security within the city as a combined result of physical setup of the cityscape including subsurface structures, over-ground infrastructure as well as social inequality and exclusions (Sultana, 2020). 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 must be analysed and considered to fully understand water security. Here we have shown intersecting points between water insecurity and societal disadvantages related to gender, deprivation, social class, caste, ethnicity, and religion (Simpson 2009; Thompson, 2016). These intersectional disparities are *particularly critical for cis- women, other gendered people and for making progress towards* both SDG 5 (gender equality and empower all women and girls). To achieve SDG 6 (clean water and sanitation for all) we need to ensure we take into account these groups of people so we can ensure 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 that the (cis)male-female gender gap has slowly decreased, 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 as a whole and 18.08% against the 57.07% 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. This is important in our analysis as we can better understand the particular water security issues related to where different groups experience what water security issues, i.e. cis-men in Kolkata are 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). This type of focus can also bring us to look at conditions in schools, where (in India), 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).

Water security issues experienced by trans, and other gendered people are even worse. 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 of UWSI also depicts that the portion of the respondents who are regarded as working in ''household'' are the most water-secure and most of them are cis- women. However, as we have shown, this does not mean that cis- women overall are more water secure than men. What this does point to is a need to understand the complex set of factors differentiating and influencing people's water security when it comes to looking at water security by gender. The next section of this paragraph will speak about cis-women and as there is no national level statistics on trans-women's data as of now. Chances are high that a major portion of cis-women having higher education are not engaged in active workforce. This non-engagement of cis- women in active workforce doesn't only reduces their role as decision-maker about WaSH expenditures at home, but also for their workplaces lessening cis-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 cis-women's work force participation is low. Recent studies have observed that cis-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 cis-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 UWSI 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 aspects related to religion is found to shape 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. This links to Schenk's work (2010), where they found that Muslim women are more water insecure in the deprived areas as they are not allowed to go outside to take bath) which made it difficult to maintain hygiene 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).

6. Conclusions

The inclusive framework for urban water security assessment presented in this article highlights the challenges of urban water security (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 by drawing on bio-physical and social indicators to answer the key questions of UWS: *how, for whom 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, inequalities 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. Declining inland surface waterbodies and their littoral zones due to the changes in urban land use, increasing water demand owing to population growth, poor sanitation and lack of enough water treatment facilities coupled with mismanagement, issues associated with unplanned, excessive, and 'unaccountable' groundwater extractions such as depletion of groundwater level, land subsidence and aquifer contamination 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.

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.

Overall, this study provides a unique quantitative index-based 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.

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Appendices

Appendix A: 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	X				X			X	X							X	X

Analysis (ENA) (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 & 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	X					X	X	X	X			X			X	X	

(UM-WMB) (Bhaskar and Welty, 2012; Chrysoulakis *et al*., 2013; Kenway *et al*., 2011; Marteleira *et al*., 2014; Thériault & Laroche, 2009)																	
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 (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 B: 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 C: 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 D: Detailed list of variables for data collection through Household Survey during the research visit in Kolkata, India (November-December 2018)

- **<u>Physical-Infrastructural dimensions of Urban Water Security</u>**

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

- **<u>Socio-economic dimension of Urban Water Security</u>**

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
DemQ16	Education level of other family member (s)	Primary School
		Secondary School
		College or bachelor's degree
		Postgraduate degree
DemQ17	Gender of the respondent	Female
		Male
		Trans
		Intersex
		Other