Urbanization and Its Impact on Groundwater Resources: A Case Study

Synopsis submitted by

Suddhasil Bose

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Doctor of Philosophy

School of Water Resources and Engineering
Faculty of Interdisciplinary Studies, Law and Management
Jadavpur University
Kolkata, India

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Urbanisation is the inevitable phenomenon for social and economic development. Urbanisation process refers to the demographic process where people migrate to live within an urban environment. It is assumed that, development of a country significantly depends on its magnitude of urbanisation. Presently more than 50% of the world's population are residing in urban areas, whereas in 1950 it was just 30% and it estimated that, it will exceed up to 68% in 2050. Certainly, urbanisation process helps in multi-dimensional development approach but it has definite negative impacts on environment also. Water resource is one of the most important natural resources that is needful to sustain in urban environment. Urban area has definite characteristics about consumption of water where high amount of water is consumed within a comparatively small amount of area. Supply of this water comes from either surface water source or groundwater sources. In most of the urban areas around the World, groundwater resource is the ultimate reliable resource to cater the demand. Groundwater is a fresh water resource and comparatively less contaminated than other sources. It is easily accessible and it holds large amount of reserve below the surface. Groundwater abstraction in urban environment is a common practise for years specifically where groundwater is the only resource. Mostly groundwater is treated as non-renewable resource as it takes thousands of years to replenish itself. Groundwater is often referred to as an invisible resource and estimation of this resource is comparatively a complex process, it is identified as an undervalued resource and awareness about importance of groundwater resource is limited to people. Continuous groundwater abstraction from a location for over years definitely creates an impact upon subsurface environment. Water level declination, contamination of pollutants, land subsidence are the common effects. Important global cities like Mexico City, Tokyo, London, Paris, Delhi, Beijing, Dhaka, Jakarta along with many other important cities has already observed the negative impact of groundwater abstraction. Recently question has been raised about the sustainability of environment in populated urban area. Finding the actual cause and effect of impact of urbanisation on groundwater resources has become one of the most important subjects within the overall context of global change and development of response strategies.

Significance of the Case Study

In light of this above situation, the impact of urbanisation on groundwater resources has been studied in this thesis. It has been observed from previous researchers that urban groundwater scenario is distinct and mostly different from the other city. So, It has been decided that apart from understanding the process of urbanisation and its impact on groundwater resources, an

area has to be chosen where both of these processes create significance and interconnect with each other. For this, Kolkata has been taken as a study area along with findings on the effect of urbanisation on groundwater resources. It is the most important city in the eastern part India and the gateway for other several adjoining countries. It has been observed that Kolkata has a distinct history of urbanisation at least for the last two hundred years. Having a comparatively better situation in surface water sources, Kolkata still depends on groundwater as an water source. Groundwater withdrawal is a common exercise for public water supply and private consumption over years. From the published research and reports it has been observed that recently after the beginning of globalisation in India, significant changes in land use have been observed in Kolkata that directly reflects the urbanisation process with other changes like declining groundwater level, mixing of pollutants as contaminants in groundwater, the possible presence of arsenic in groundwater, seawater intrusion and land subsidence. Limited number of researchers have tried to identify the actual impact of urbanisation on groundwater resources for Kolkata. Already a research gap has been identified in this context. Assuming that Kolkata faces a definite impact of urbanisation on groundwater resources, this study has been processed further with the context of this concept.

Objectives

The study has been proceeded further following these objectives to :

- Overview the process of urbanisation and groundwater resources individually and its contemporary situation globally
- Identify different aspects about the general interaction between urban area and groundwater resource on a global scale
- Review literatures about the impact of urbanisation on groundwater resources and related methodologies
- Analyse the study area Kolkata to understand evolution of this study area with prospect of urbanisation
- Understand about the physical and socio-economic aspect of the study
- Understand the process of urbanisation approaching different aspects of it through spatio temporal analysis
- Understand the condition of groundwater resources through spatio temporal analysis
- Understand the impact of urbanisation on groundwater resource following different aspects which are retrieved from the previous objectives.
- Recognise the impact of urbanisation on groundwater resources and specifically for Kolkata and further identification of solutions and recommendations for betterment

Study Framework

Data Sources

Detailed spatio-temporal datasets are needed to accomplish the process. Worldwide urbanisation related data have been collected from organisations like United Nations and World Bank. For groundwater related study, worldwide data has been collected from various organisation like WHYMAP, UN-IGRAC, IAH and UN-WATER. For the case study, detailed locational data is needed. Primarily thirty years (1990-2020) of timespan has been selected to analyse spatio temporal changes in urbanisation and groundwater resources of Kolkata. Urbanisation has been analysed based on high resolution satellite data that have been collected from USGS to generate accurate and detailed result. For groundwater resource analysis this study mostly relied on chronological secondary data that have been collected from various governmental organisations like CGWB, SWID and WBPCB etc. For overall understanding about the scenario of Kolkata, relevant data have been collected from KMC and previously collected relevant data and literatures of various researchers also incorporated to gather idea about the study area.

Applied Methodologies

Understanding about the impact of urban area on groundwater resources is a really complex task. These two independent major themes must correlate with each other to make it decidable. So this thesis is majorly based on geospatial analysis to achieve the desired result. For this advanced remote sensing technology has been incorporated in this study to capture changes in the urban land for the long period of time and observe chronological evolution in this study area. Groundwater related data has been curated spatially and temporally. Descriptive statistical analysis has been approached throughout the study to calculate the spatio temporal changes over the time frame. Repeated usage of regression analysis and time series analysis have been the major proponents of this study.

Applied Tools

Microsoft Excel and Word used in this study for tabulation of data and writing respectively. For statistical analysis, advanced statistical programming language R (v. 4.0) has been used. For spatial analysis, GIS software like, QGIS (v. 3.16) and ArcMap (v. 10.3) have been used extensively. Figures have been edited in Inkscape software and this thesis has been written and edited in typesetting software system Latex and references relevant to this study was managed in reference managing software Mendeley desktop (v. 1.19.8)

Organisation of the Thesis

This thesis contains altogether 11 chapters. A brief outline of each chapter is as follows:

Chapter 01

In this study, the first chapter beginning with, the pretext behind the study on urban groundwater issues. Significant problems have been identified regarding groundwater issues in the urban area. Major objectives have been incorporated into the study. The study framework has been discussed mentioning needful methodologies. A study area has been identified and justified the reasons behind it in this chapter. Problems related to this kind of research have been identified and brief ideas about each chapter have been enlisted for a better perception from the beginning of the thesis.

Chapter 02

At the beginning of the study, proper definitions have been given about two different concepts of urbanisation and groundwater for a better understanding. Definitions and perceptions about urban and urbanisation have been incorporated separately in this chapter and theories about urban origin have been discussed. Along with historical evidence, the contemporary urban scenario has been described. Temporal change in the worldwide urbanisation process has been speculated in this chapter in detail. Later in this chapter, the importance of groundwater has been mentioned. Details about the available amount of groundwater, groundwater recharge and abstraction scenario have been mentioned in this chapter. Also, a brief idea has been given about the physio-chemical proponents of groundwater.
It is observed that the population is increasing continuously over the world, from the beginning of this century urban population is increasing in the Asian and African continents at a higher pace than in other continents whereas, in Europe and America, the increasing rate of urban population is more or less stagnant. The percentage of urbanisation is higher in South America, North America and Europe than in Asia and Africa. The increasing rate of urbanisation in these two continents is recently higher than in others. The number of smaller cities with fewer populations than 3 lacks is increasing megacities with 10 million people also increasing in number. For groundwater, it is observed that out of 2.5% of freshwater of the total resources groundwater is about 30% from the freshwater source. Asia contains about 7.8 $km^3 \times 10^6$ groundwater in the upper layer of the earth's crust which is higher than other continents. Groundwater recharge rate is very high around rivers and very high in Amazon and Congo Basin Rainforest. Asia abstracts about 69% of groundwater from total abstraction over the world where as Africa abstracts only 4.1%. Most of the abstraction

is utilised for irrigation purposes all over the world. Domestic groundwater usage is high in American continents. India, China and USA are the top three groundwater abstracting countries in the world.

Chapter 03

The interaction between an urban area and groundwater has been specified in this chapter. Briefly historical examples have been tried to recapitulate the usage of groundwater resources ages ago. A basic idea with certain advantages and disadvantages has been given that will be easier to get an idea about the diversified utilisation of groundwater in an urban area. A theoretical perspective has been mentioned that, defines the changing scenario of groundwater usage and its consequences of it with the evolution of an urban area.
It is identified that groundwater creates an advantage in the urban water supply but without proper management and planning condition of groundwater deteriorates in terms of both quality and quantity both. The evolution of a city from a town alters the subsurface environment. Initially, groundwater supply proves to be beneficial but in long run, it reduces the water level, creates the possibility of saline intrusion and subsidence risk, exceeds aquifer assimilation capacity and contaminates with pollutants. Large number of cities with huge populations are either solely or partially dependent upon groundwater and only from China more than 22 cities, in the USA, 19 cities and in India 15 cities are dependent on groundwater resources as urban water supply. Dependence on groundwater resources is an alarming issue for developing areas with densely increasing populations. Major issues have been identified in this chapter for 10 cities around the world with major groundwater related issues.

Chapter 04

In this chapter, an extensive literature survey has been done using bibliometric analysis to understand the previous researchers that discussed the concept of urban groundwater. This chapter covers significant studies on urban groundwater from the period within 1990 to 2020. Researchers broadly divided the investigation into the quantity of groundwater and quality of groundwater. it has been summarised that groundwater abstraction-related issues are the most common in cities along with some anthropogenic factors that pollute the groundwater quality. Characteristics of aquifers play a crucial factor regarding any change due to consumption. Researchers previously investigated general problems related to urban groundwater but recently locational individuality is being identified. Researchers are now applying advanced statistical techniques along with remote sensing and geospatial techniques to analyse this problem in a more advanced way.

Chapter 05

From historical traces, the evolution from old Calcutta to recent Kolkata has been redefined in this chapter in light of the urbanisation process. The importance of Kolkata as an urban area has been analysed from the past to the present. From the inception of this city to its present structure and all the journey in between mentioned in this chapter. Different identical characteristics of Kolkata as a district, as a municipal corporation and as a megacity all have been clarified here. The geographical location of Kolkata has been defined here, which has been used for the case study.

Chapter 06

The physical setup of Kolkata has been mentioned in this chapter. Elevation, slope, geology, geomorphology, and soil type have been mentioned in detail. The subsurface environment of the study area is also discussed in detail through lithostratigraphy, subsoil characteristics, aquifer characteristics and borewell data. thirty years of climate has been analysed to understand the local rainfall and temperature characteristics. The land surface temperature has been analysed to understand the local land characteristics in soil moisture retaining capacity.

From the observation, it has been identified that, the land of Kolkata is extensively plain; situated on a deltaic plain mainly formed upon quaternary alluvium where the soil is mainly clayey in nature which is high runoff potential in nature. The river levee on the western side and wetland on the eastern side created a general slope from west to east. Tropical wet and dry climate can be observed here with an average rainfall of 165 cm annually and a maximum temperature of 35°C to a minimum temporary 17°C with an average temp 26.8°C. Kolkata is having confined aquifer underneath, where groundwater level can be observed below 150 meters to 200 meters and the thick sedimentary aquifer layer can be observed up to 700 meters. Within this boundary, two prominent water tables can be identified. Near about 4.5 million people reside in only 186 sq. km area of the Kolkata Municipal Corporation area. The administrative boundary has been divided into 144 wards. Population density is higher than even 1 lakh population within an sq. km area. In this urban area surface water supply is common but it is not available in every part of Kolkata to meet up the need, use of groundwater abstraction is a common practise. Private groundwater abstraction is practised for years without even noticing the government.

Chapter 07

Socio economic aspects have been highlighted in this chapter through the prospect of urbanisation. Details about landuse, demographic profile, urban amenities, transport network

and water supply system all have been incorporated here.
It has been analysed that, Kolkata is most urbanised district in West Bengal and population density in kolkata is excessively higher than other major cities in India. Kolkata provides almost world class urban facilities in terms of amenities are well distributed over the city. Transport network are well structured and water supply is provided by KMC and this facility incapable to cater the huge demand. Groundwater is commonly used for supply either from public or private source.

Chapter 08

In this chapter, the situation of urbanisation has been analysed spatio temporally that identified using geo-informatics. Different kind of remote sensing techniques have been applied to analyse the process of urbanisation in between 1990 to 2020. Urban area of Kolkata has been assessed with three different correlating factors. First of all, Landuse and Landcover changes have been analysed using supervised machine learning process to identify changes in land class over the time. Next, built-up areas have been identified through web computing to with a gap of two years to analyse the changing pattern of built-up that directly reflects the process of urbanisation. Further changes in impervious surface have been identified for the city within time frame of 1990 to 2020 with maximum likelihood classification algorithm. Different urbanisation indices have been applied to understand the urbanisation scenario quantitatively.
It has been observed that, urbanisation is prominent in Kolkata in between the mentioned time. Urbanisation process is continuous in Kolkata but northern part was already saturated; further prominent process of urbanisation has been identified in the southern part of Kolkata. It has been identified in 1990, 77% of the Kolkata was urbanised whereas in 2020, already 92% of the Kolkata is urbanised out of them 62% land is now covered into impervious whereas, in 1990 it was only 43%. The urbanisation growth rate was the highest in timespan of 1990 to 2000, later it slowed down. Total built-up area is continuously increasing in Kolkata encroaching, water bodies, vegetation covers, and wetlands.

Chapter 09

Details about groundwater resources about Kolkata have been highlighted in this chapter. Alluvium aquifer system resides underneath the Kolkata. It is a major aquifer system where groundwater level is available within 2 to 40 meters and for Kolkata and it is confined in nature. According to literature review, groundwater level is decreasing due to huge groundwater abstraction through private wells. Land subsidence is a serious issue faced recently in Kolkata. Landfill site crated a definite impact upon the groundwater quality of

Kolkata. Groundwater recharge scope is minimum from the land within the boundary of Kolkata and traces of arsenic has been discovered in groundwater of Kolkata. Interpreting satellite images, it has been discovered that, groundwater storage is following a decreasing trend in between 2003 to 2020. Details about groundwater quantity has been analysed using water level data collected from different authenticated reliable sources for the time span of 1990 to 2020.

It has been observed that, groundwater level is comparatively lower in Kolkata than other adjoining districts although having same aquifer characteristics. Observed minimum groundwater level increased over time in Kolkata but maximum depth of groundwater level declined over the years. Usually, groundwater level is available in Kolkata below 10 meters to more than 20 meters from the ground surface. Seasonal groundwater level changes are prominent. Groundwater level rise up after the monsoon on an average 1 to 2 meters near to surface. Analysing long term trend, it has been identified groundwater level pattern has been changed for Kolkata in 30 years. In 1990 a trough zone was formed in Kolkata in the central part of Kolkata with comparatively low groundwater level that changed its position afterwards and recently in 2020, it is found between north to south stretch of Kolkata. Available chemical properties in groundwater are highly fluctuating in nature. Among principal physiochemical components, Bi-carbonate, chloride, sulphate, sodium are the most common and affluently available in groundwater of Kolkata. Here, water is hard in nature. Available iron in groundwater is two to three times higher than permissible limit prescribed by Indian standards. Amount of TDS available in groundwater is also high in nature that reflects through electrical conductivity. Groundwater type of Kolkata majorly are Mg-HCO_3 and Na-K-HCO_3 in nature. Analysing entropy-based water quality index maintaining Indian standards, it has been assessed that, groundwater quality is poor in Kolkata due to iron, and sulphate in high amount. Groundwater quality is poor in western and south eastern part of Kolkata. Central Kolkata and South west Kolkata are better in terms of groundwater quality.

Chapter 10

Impact of urbanisation on groundwater resources have been analysed in this chapter. Different types of attempts have been made to analyse the impact on groundwater resources focusing on Kolkata. First of all, a time series analysis has been initiated to understand continuous change in built-up area and parallel change in groundwater level on whole Kolkata. A long-term time series with 2-year interval identified a strong positive correlation between increase in built-up area and decline in groundwater level. ARIMA model has been applied to understand the future perspective. Locational effectiveness has been been identified applying Geographical weighted regression model. Next ward wise decadal changes have been analysed with LULC and groundwater level has been correlated parallelly. It has

been identified that, in between 1990 to 2020, groundwater decline level was highest in northern part, where high density built-up increased abruptly, groundwater level decline was minimum where, there was domination of vegetation and other natural land. In next decade, between 2000 to 2010, ward wise inequality decreased with further change in LULC. In the last decade, it has been identified that in the saturated built-up area, groundwater level declining trend further slowdown. Clustering pattern of groundwater decline dissolved into every area of Kolkata. It has been observed that, built-up area definitely correlated with decline trend of groundwater in a positive way whereas more land with vegetation cover prevents downdrift of groundwater. Lastly identified impervious surface on each ward for different decade correlated with groundwater level of that year. It has been identified that, impervious surface creates a positive effect on groundwater level decline, and vegetation cover has a negative correlation with groundwater level, it helps to prevent water level decline. A change has been identified in percentage for each ward with impervious surface, vegetation and soil and groundwater level. Further, linear regression model applied for individual land type and combined effect has been identified with multiple linear regression.It is revealed that lack of vegetation in a ward area highly impactful for groundwater level decline. Along with these major observations, some minor steps have been attempted to identify overall impact of urbanisation on groundwater. Groundwater recharge proportion after rainfall declined drastically over the years with exapnsion of impervious surface. Difference between population and household have been calculated and along with difference in groundwater level and correlated ward wise. It has been identified that both the factors also create a definite impact on groundwater to decline its level further down. Above all, groundwater quality of landfill area Dhapa has been analysed to understand impact of urbanisation process on groundwater quality also. It has been found negative. Groundwater quality beneath the landfill is highly degraded and it is not suitable for drinking or bathing, even some hazardous toxic elements also identified in groundwater near to the landfill area.

Chapter 11

Above mentioned chapters, covered almost every aspect that can lead to understand about the impact of urbanisation on groundwater resources. Finally, observing all major aspect, over all situation has been assessed with D-P-S-I-R framework in this chapter. Major findings have been identified for Kolkata and recommendations have been suggested for the beneficial purpose. It has been identified that, continuous population growth, rapid urbanisation, vertical growth of the city and significant amount of floating population are the reasons behind negative change in groundwater resources. Insufficient,unhealthy surface water resource, unplanned land transformation and over exploitation of groundwater are the pressure that have been identified behind the changes in groundwater level as case

for Kolkata. The deteriorated situation has been identified observing dug well condition, deteriorated groundwater level data with time, analysing groundwater quality and scope of reduced recharge using water balance estimation method. Identified impacts are significant depletion in groundwater level, land subsidence in different parts of Kolkata, trace of arsenic in groundwater and contamination of pollutants in subsurface environment. Responses identified for the densely urbanised areas in Kolkata. Groundwater monitoring at frequent intervals of three months is necessary. Groundwater abstraction should checked strictly by abiding strict rules and regulation. Protection of landfill area with proper precautions that can prevent from further percolation. Most important response should be taken with artificial recharge in places where groundwater level declining abruptly. Rainwater harvesting could be another method where runoff water can be used in daily activities. Reuse of water, efficient use of water should be practised in every household. In Kolkata, awareness about the importance of groundwater is most prior thing to be done immediately. Kolkata has been demarcated as double restricted zone for groundwater abstraction but private self-supply is still practised without noticing it to local governing bodies, this malpractice should be taken as serious offence and strict laws should be amended to stop this illegal abstraction.

Limitations and Future Scopes of the Study

The execution of this study is based on detailed spatial and temporal data. Detailed locational data from past to present needs to be available in every phase of this study. Data collection was the most crucial part of this study where authenticated secondary data were more valuable than primary surveys as this study is based on the chronological evolution of urbanisation and its impact on groundwater resources. It has been realised that groundwater-related data is really limited and from that available data either locational details are missing or chronology has not been maintained properly. Individually, all of the authorised departments were visited physically, but in most cases, historical data were found to be either unavailable or missing. Irregularity in chronological datasets and erroneous data has been found as a major limitation of this study. Strangely it has been observed that, for the same place and same period, groundwater data differed with different governmental organisations. Validation and authentication of datasets was the toughest job throughout the study.
Presently, Kolkata is divided into 144 wards. This study remained limited to 141 wards of KMC. Three wards were excluded from the study because previously that part of the land was not an urban area at all and data related to it not goes with the theme of this study. The observation period for this study is mostly limited to thirty years (1990-2020). Retrospection was only limited within the literature review because further detailed analysis could not be possible without sufficient historical data. It is another limitation of this study.

Groundwater consumption data from households are unavailable and if available that lacks in minuteness. This study remained limited within a small sphere due to diverse obstacles but the further scope of this alarming topic does not end here with this study. Further detailed data collection using modern appliances will create immense scope to make this study more accurate and precise.

List of Publications

- Bose, S., Mazumdar, A., & Basu, S. (2023). Evolution of groundwater quality assessment on urban area-a bibliometric analysis. *Groundwater for Sustainable Development, 100894*.
- Bose, S., Mazumdar, A., & Basu, S. (2022, September). Assessment of subsurface water resource in an urban area -a case study on Kolkata. *The Observer (Vol: 56, ISSN: 2230-9535)*. The Students Geographical Association, Kolkata
- Bose, S., Mazumdar, A., & Basu, S. (2020, July). Review on Present Situation of Groundwater Scenario on Kolkata Municipal Area. In *IOP Conference Series: Earth and Environmental Science (Vol. 505, No. 1, p. 012022)*. IOP Publishing. (Conference paper)

Accepted Article in Press

Monitoring Change in Urbanization and Green Space for Eastern Indian Cities in 30 Years-A Comparison between Kolkata and Bhubaneswar in *IOP Conference Series: Earth and Environmental Science*

List of Presentations in National/ International conferences

- E-Conference on Geospatial Science For Digital Earth Observation 2021 (GSDEO2021). Paper title:*Monitoring Change in Urbanization and Green Space for Eastern Indian Cities in 30 Years-A Comparison between Kolkata and Bhubaneswar*, organised by Adamas University, Kolkata
- International conference on Sustainable Water Resources Management under Chnaged Climate.(ICSWRMCC 2020). Paper title: *An overview on urban water supply- a case study on Kolkata*,International Conference on Sustainable Water Resources Management under Changed Climate at Gandhi Bhawan Auditorium, Jadavpur University, Kolkata during March 13 – 15, 2020.
- 6^{th} International Conefernce on Environment and Renewable Energy (ICERE 2020). Paper title: *Review on Present Situation of Groundwater Scenario on Kolkata Municipal Area*,6^{th} International Conference on Environment and Renewable Energy (ICERE 2020) organized by Hong Kong Chemical, Biological Environmental Engineering Society at Hanoi, Vietnam.