Evaluating Water Resource Potential of Asansol Municipal Corporation in West Bengal towards its Sustainable Management

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Under the supervision of

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Certificate from the Supervisor

This is to certify that the thesis entitled "**Evaluating Water Resource Potential of Asansol Municipal Corporation in West Bengal towards its Sustainable Management**" submitted by Mr. Sarbeswar Haldar who got his name registered on 21.09.2020 for the award of Ph.D (Science) degree of Jadavpur University, is an original piece of work and absolutely based upon his own contribution under my supervision and that neither this thesis nor any part of it has been submitted for either any degree/diploma or any other academic award anywhere before.

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Dedicated to my Daughter

Srinita Haldar

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Evaluating Water Resource Potential of Asansol Municipal Corporation in West Bengal towards its Sustainable Management

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Abstract

Water is essential for all forms of development, yet it faces growing global challenges, making sustainable management practices increasingly critical. Effective water resource management hinges on a deep understanding of the unique availability and demand patterns within each region. The Asansol Municipal Corporation (AMC), the second-largest urban centre in West Bengal, has a long history of water shortages, particularly during the summer months. This study aims to assess the water resource potential of AMC by thoroughly evaluating current demand and supply patterns, groundwater conditions, surface water resources and the potential for rainwater harvesting, including through the utilisation of opencast mining pits and rooftop rainwater harvesting systems. The research is structured around five primary objectives: **Firstly, the present water supply patterns are analysed to estimate the demand-supply gap**. This involves assessing the existing water availability pattern and forecasting domestic water needs to better understand the balance between supply and consumption in AMC. **Secondly, the study investigates the dynamics and sustainability of surface water resources**. It focuses on their availability and the changing landscape of surface water bodies, vegetation, built-up areas and land surface temperature providing an in-depth analysis of whether these water bodies can continue to meet the growing demands of the region. Thirdly, **the groundwater potential zones within AMC are examined to delineate areas where groundwater can be sustainably extracted** by using two popular methods (AHP and FR) in a GIS environment, offering a detailed assessment of groundwater availability and its capacity to support the region's water supply. **Fourthly, the study identifies suitable locations for surface rainwater harvesting structures and estimates the potentiality of** surface rainwater harvesting in opencast mining pits and pit channels. **Finally, the potential for rooftop rainwater harvesting has been assessed** involving the feasibility of such systems in both residential and commercial settings for non-potable uses. The study reveals a growing demand-supply gap in the area, exacerbated by rapid urbanisation, which is leading to the decline of surface water bodies, rendering them insufficient to meet current water needs. Furthermore, the area's hard rock formations result in limited groundwater potential. However, there is significant potential for surface rainwater harvesting, particularly through the use of opencast mining pits and rooftop rainwater harvesting presents a viable solution for addressing non-potable water demands.

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ABBREVIATIONS

AHP: Analytical Hierarchy Process

AMC: Asansol Municipal Corporation

AUA: Asansol Urban Agglomeration

AUC: Area Under Curve

CGWB: Central Ground Water Board

FAHP: Fuzzy Analytical Hierarchy Process

FR: Frequency Ratio

GPM: Global Precipitation Measurement

GPZ: Groundwater Potential Zone

GPZM: Groundwater Potential Zone Map

IDW: Inverse Distance Weighted

LPCD: Litre Per Capita Per Day

LST: Land Surface Temperature

MCDM: Multi Criteria Decision Making

MG: Million Gallon

MNDWI: Modified Normalized Differential Water Index

NBSS: National Bureau of Soil Survey

NDBI: Normalized Differential Built-up Index

NDVI: Normalized Differential Vegetation Index

NWP: National Water Policy

ROC: Receiver Operating Characteristics Curve

RRWH: Rooftop Rainwater Harvesting

RWH: Rainwater Harvesting

SRTM: Shuttle Radar Topography Mission

TOA: Top of Atmospheric Radiance

TRMM: Tropical Rainfall Measuring Mission

USGS: United States Geological Survey

CONTENTS

CHAPTER-1

PRELUDE TO THE STUDY

1.1 Introduction

Water is the key prerequisite for the survival of life. For this reason, from the beginning of society, utilization of water resources has been a human kind's endeavour. History has examples of societies that flourished with the accessibility of steady water supplies and then due to intermittent water supply. Water crisis is the prime concern of present day researchers as water is the fundamental issue of all kinds of developing actions. All kinds of societal development and ecological balance in the world depend on the Water. Presently many countries and governments throughout the world try to find a suitable way to reduce the water crisis. Gap between existing water availability and demand creates water scarcity in any region. If the present available water resources fail to fulfil the demand then water scarcity arises. Nearly 2.8 billion people around the world are affected by the water crisis at least one month each year and more than 1.2 billion people covering almost all countries do not have access to clean drinking water (WHO, 2005). Water stress can be observed at any time due to various social constructs as well as inherent shortage of water supply such as climate change, population growth and urbanisation. Human beings can use only 1% of the total available water (Anon, 2006). Two types of water scarcity are observed in the environment which are either physical or economic in nature (Jenkins et al., 2006). Physical water scarcity is related to insufficient water resources in any area whereas economic water scarcity is related to faulty management systems. As per the population of 2011, per capita water availability in India was 1567 m^3 per head annually. As per this standard, India is already a water stress nation. Per capita water availability is the key indicator to explain water security of any country. Based on per capita water availability, a region is defined as water stress region (per capita water availability 1000 to 1700 m^3) and if the per capita water availability is less than 1000m^3 then the region is termed as water scarcity region following International Standards. By 2025, the United Nations estimates that 1.8 billion people will experience severe water shortages, with two-thirds of the global population potentially living under conditions of water stress. India is already a water stress country as per capita water availability of India was 1567m^3 as per census, 2011. Under these circumstances, management of water resources must be prior to the formulation of developmental plans for every country in the World.

1.2 Conceptual Framework

Water is one of the most significant resources on earth. Any plants and animals cannot survive without water. Existence of life on earth depends on water. It is a transparent fluid and as a chemical compound , a water molecule contains one oxygen and two hydrogen atoms. Water is a liquid at standard ambient temperature and pressure but it often co-exists on earth with its solid and gaseous state as ice and water vapour. The world's total water resources are estimated at 1.37 x 10^8 ha-m. Of these global water resources 97.2% is salt water mainly found in oceans and only 2.8% is fresh water. Out of these 2.8% available fresh water about 2.2% is available as surface water and 0.6% as ground water (Raghunath, 2014). The main source of freshwater is the groundwater and surface water. At present urban water management is one of the most challenging tasks of all the urban development authorities throughout the world due to excessive population growth accompanied with increasing demand for water.

For sustainable water resource management especially in urban context priority should be given to the collective use of surface and ground water. Surface water are the bodies of stationary or moving water found on the earth surface as river, lakes, pond, ocean etc. On the other hand, groundwater refers to the water occupying all the void space within the geological stratum (Todd, 2006). Numerous references exist in Vedic literature to groundwater availability and its utility. During 3000BC, groundwater development through wells was known to people of the Indus Valley civilization as revealed by archaeological excavations at Mohenjodaro (Subramanya, 2015).

India has more than 18% of the world's population, but has only 4% of the world's renewable water resources and 2.4% of the world's land area (Pandit et al., 2012). The availability of utilizable water is not universal throughout the country due to uneven distribution over time and space, frequent floods and droughts and impact of climate change. National Water Policy (2012) highlights that low consciousness about the life sustaining value of water, mismanagement, wastage, inefficient use, pollution, reduction of flow below minimum ecological needs may be the vital factors for future water crisis in the country. A significant portion of India has already become water stressed due to high rising demand coupled with rapid growth of population, and urbanization, which ultimately creates serious challenges to water security (Pandit et al., 2012).

Given the critical importance of water, this study has been designed to assess the current water availability situation within the Asansol Municipal Corporation (AMC) and to thoroughly examine the actual conditions faced by its residents. Asansol has a long history of water shortages, a fact confirmed by a recent pilot survey conducted in the area. Currently, the primary source of water for the city's growing population is the purified water supplied from the Damodar River by the AMC. However, this source is insufficient to meet the increasing demand due to the city's rapid population growth. Moreover, the region's geological characteristics, dominated by hard rock formations and coalfields, make groundwater an unreliable and inadequate alternative to supplement regular water supplies. The poor quality and limited quantity of groundwater further exacerbate the water crisis, making it imperative for AMC to explore alternative, sustainable sources of water.

In light of this situation, it has become urgent for the AMC to identify a permanent alternative water supply source, which can only be achieved through scientific research and accurate prediction of available water resources. Immediate investigation into the city's water resources is necessary to ensure an uninterrupted and reliable water supply in the future.

A promising approach to addressing water scarcity in the Asansol Municipal Corporation (AMC) may be the implementation of rainwater harvesting technology. This solution has the potential to significantly enhance the local water supply while alleviating pressure on existing primary sources. By capturing and storing rainwater, this technology can contribute to narrowing the gap between current water demand and available supply, offering a sustainable and eco-friendly alternative.

The main objective of this study is to tackle the ongoing imbalance between water demand and supply within AMC. This will be achieved through a comprehensive assessment of the region's existing water resources, as well as an exploration of viable alternatives, such as rainwater harvesting systems. In addition, the study will account for the socio-economic and environmental conditions unique to the AMC area, ensuring that proposed solutions are tailored to local needs. Ultimately, the goal is to establish a long-term, reliable water supply system that can better support both community and industrial activities, promoting sustainability for future generations.

1.3 Area Under Study

Asansol is one of the biggest cities of West Bengal in Paschim Burdwan outside Kolkata Metropolitan Area which covers the latitudinal and longitudinal extension 23°35′12″N to 23°46′37″N and 87°09′35″E to 86°47′40″E(Fig.1.1). It appeared as a Municipal Corporation in the year 1994 by the way of merging the Burnpur Notified Area, some rural parts of Asansol Block and some colliery areas with erstwhile Asansol Municipality and the formation of present Assansol Urban Agglomeration was ended with the integration of Raniganj, Jamuria and Kulti municipalities with the jurisdiction of Asansol Municipal Corporation in June, 2015 (AMC, 2020). The second leading Urban Agglomeration of Eastern India is geographically located at the confluence of the Chottanagpur plateau and the Ganga plain, southern and western sides of which are bounded by the Damodar and Ajay rivers. The total aerial extension of AMC is 326.48km^2 having a total population of nearly 1.243million (Census 2011). North-west to south-east slope is observed having an average height of 122metre above mean sea level in the urban area (AMC, 2020).

It is a cosmopolitan city and famous for coal mining and industrial activities. Eastern Coalfields Limited (ECL), a subsidiary of Coal India Limited (CIL), manages the coal mining activities under the Asansol Mining Complex (AMC). This region is rich in coal reserves and has been a hub for mining operations for several decades. The mining process includes both underground and opencast methods, contributing significantly to India's coal production, which supports the country's energy sector. ECL ensures the implementation of safety measures and sustainable practices in mining to minimize environmental impact. Modern technology and mechanization have been introduced to increase efficiency and reduce hazards. Furthermore, AMC plays a key role in providing employment opportunities and supporting local economies. As part of its social responsibility, the company undertakes community development initiatives, including healthcare, education, and infrastructure development for the surrounding regions. Overall, AMC's coal mining operations form an integral part of India's industrial and energy landscape.

The entire AMC is dominated by five geomorphological features consisting of pediment pediplain complex, flood plain, quarry and mining landfill and inland aquatic forms including river (Haldar & Majumder, 2022). A major portion of AMC is shielded by complex landforms of pediment pediplain. Quarry and mine dump is observed randomly in the entire AMC. Asansol has hot and dry summers and mild winters. This area basically falls under “Aw”(Tropical Savana) climate under Koppen Classification. The average height of the area is 122metre and direction of general slope is north-west to south-east (AMC, 2020).

Demographically, Asansol Municipal Corporation is a diverse and cosmopolitan urban centre characterized by a heterogeneous population. The city's population has witnessed substantial growth over the years, fuelled by factors such as rural-to-urban migration, industrialization, and commercial activities. As a result, Asansol is home to a vibrant community comprising individuals from various cultural, linguistic, and socioeconomic backgrounds, contributing to its dynamic social fabric. The AMC had experienced a rapid population growth along with rising water demand. Being a cosmopolitan urban-industrial area, a diverse kind of water demand is observed throughout the year. The present sources of water for the area are not sufficient to fulfil the demand of water for the entire population. The inhabitants of AMC are used to facing summer water crises. The main source of water for the region is river Damodar, the flow of which is tremendously affected by the too much sand quarry. Under these circumstances only proper management of water resources including groundwater may protect the area from an absolute water crisis in near future. Economically, Asansol Municipal Corporation serves as a vital economic hub within the region, propelled by its robust industrial base and commercial activities. The city's economy revolves around key sectors such as coal mining, steel manufacturing, railways, and trade, with a significant presence of small and medium enterprises (SMEs) and commercial establishments. The industrial prowess of Asansol not only drives local employment generation but also fuels regional economic growth and contributes to the state's revenue. The number of large and medium scale industries are located in areas including Burn Standard, Gajanan Iron Private Limited, Asansol Steel Casting Private Limited, Lofty Paints & Chemical Works, Sarkar Cement etc., which have a huge water demand. Being a part of the coal mining area there are observed so many difficulties in ground water management, The traditional ways of managing water resources in urban areas are hampered in this region because of illegal mining activities. Aside from this industrial demand, AMC also has a high rising domestic demand along with agricultural demand as the population of this area has almost doubled in recent decades.

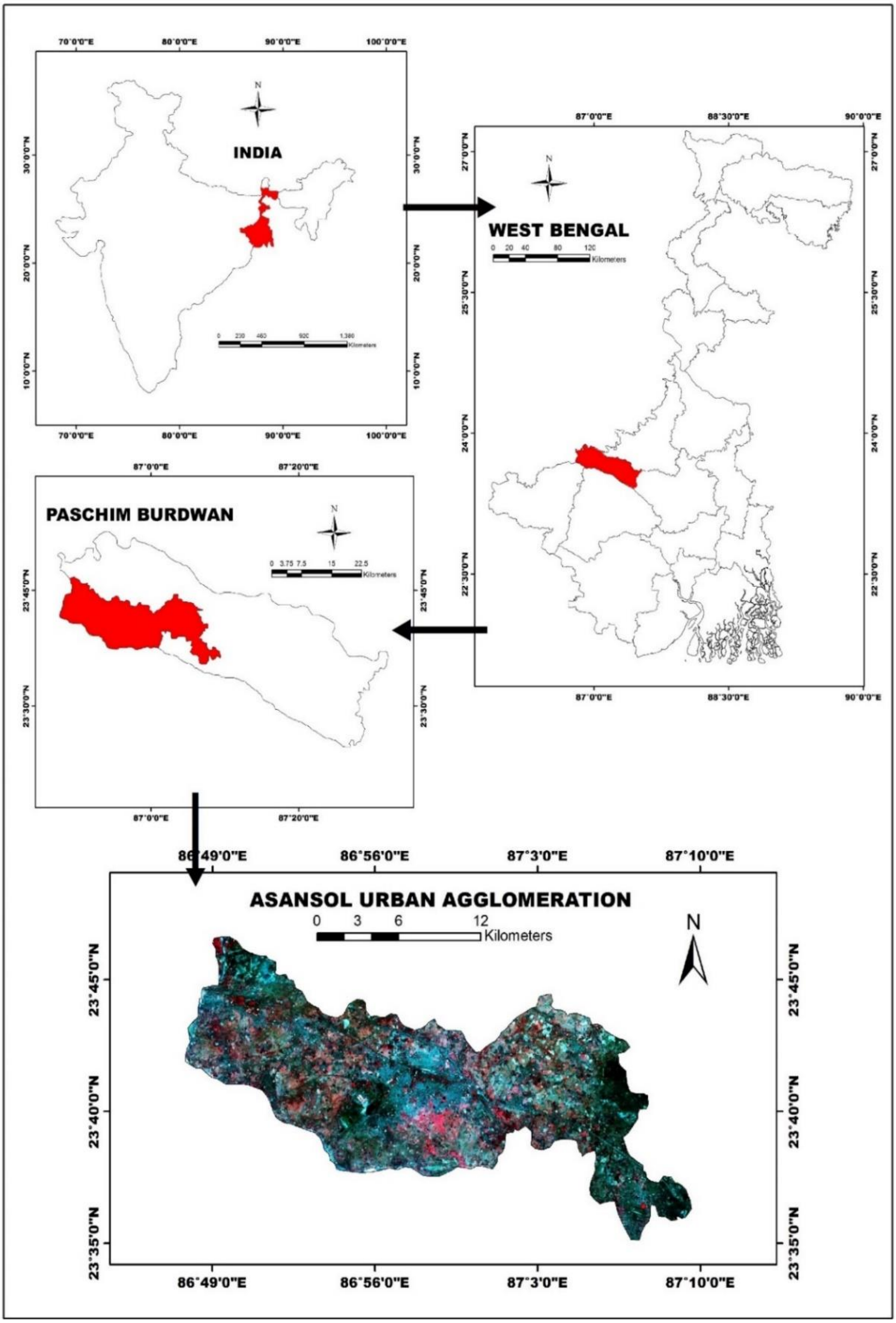

Fig.1.1: Location of Asansol Municipal Corporation

1.4 Rationality behind the Selection of Study Area

Asansol Municipal Corporation, the second largest city in West Bengal, has been selected as the focus area for this study due to several critical factors:

- AMC is the second-largest city, and its rapid population growth rate reflects its increasing prominence and urban expansion.
- The city has a long-standing history of water stress, particularly during the summer months.
- According to the report of pilot study over 70% of AMC's population is dissatisfied with the current water supply system, with 25% partially satisfied and only 5% fully satisfied.
- The water availability situation is especially dire in the extended areas of AMC, including Jamuria and Kulti, where conditions are more severe compared to the older parts of the city.
- Significant disparities exist in water supply across different wards within AMC, ranging from once to three times a day.
- The Damodar River, the primary source of water for AMC, is experiencing a steady decline in its water levels.
- Seasonal fluctuations in water supply present further challenges for the residents of the Asansol urban area.
- The region's hard rock geological formation and coal mining activities have resulted in poor groundwater quality, which is insufficient to meet the growing population's demands.

1.5 Physical Aspects of the Study Area

1.5.1 Geology

Geology has a significant role on availability of surface and groundwater resources for any region as it controls the rate of infiltration and formulates aquifer structure. There are observed six lithological units in Asansol Municipal Corporation. A major portion of AMC is occupied by rocks of raniganj formation which is followed by the structure of panchet formation. Another two important formations are kulti and barakar formation. Raniganj, kulti and barakar formation belong to Damuda group and mainly consist of sandstone, shale and coal originated in Permian age. Panchet formation is mainly consists of sandstone and shale and belongs to gondwana super group. A minor part of AMC is composed by pink granite and alluvium formation. Pink granite is a part of chotonagpur granite genesis complex and biotite and quartz biotite granite gneiss are main elements. Alluvium formation is a part of recent formation consists of sedimentary deposition.

1.5.2 Geomorphology

Understanding the Geomorphology is very crucial for the water resource management as geomorphology influences groundwater availability of any region by controlling the surface runoff and infiltration rate. Geomorphology regulates the direction of surface runoff and determines the amount and infiltration rate (Alsharhan & Rizk, 2020). Mainly five distinct categories of geomorphological features are observed including pediment pediplain complex, quarry and mine dump, flood plain, surface water bodies and river (Haldar & Majumder, 2022). The maximum part of AMC is covered by a complex landform of pediment-pediplain. Quarry and mine dump is another significant feature of AMC which is observed randomly in the entire study area. Some portion is covered by flood plain associated with river Damodar. Finally, the entire region has inland water bodies like canals, ponds, rivers etc.

1.5.3 Climate

The Asansol Municipal Corporation (AMC) region predominantly experiences a humid tropical climate, characterized by three distinct seasons: summer, monsoon, and dry winter. This climate falls under the Aw subtype (Tropical Savanna) according to the Köppen Climate Classification. During the summer months, temperatures can soar to nearly 45°C, often accompanied by hot, dry winds known as “loo.” In contrast, winter temperatures can drop below 10°C, creating a significant seasonal variation. Rainfall plays a crucial role in regulating the hydrological cycle of the region, directly influencing groundwater recharge. The primary source of groundwater replenishment in AMC is precipitation. While the average annual rainfall exceeds 1200 mm, there are notable variations in rainfall distribution across the region. The south-western part of AMC generally receives higher levels of rainfall, whereas the north-eastern part tends to experience comparatively lower precipitation. These differences in rainfall patterns have a direct impact on the region’s water availability and groundwater recharge, highlighting the importance of understanding localized climatic conditions for water resource management.

1.5.4 Soil

The Asansol Municipal Corporation (AMC) region is predominantly characterized by three types of soil: fine loamy, loamy, and coarse loamy. These soil textures play a significant role in determining the surface water retention capacity, which is crucial for managing water resources. The physical properties of soil, such as porosity, permeability, structure, adhesion, and consistency, are directly influenced by its texture. These factors collectively impact the ability of the soil to support groundwater recharge (McGarry, 2006). In the case of AMC, the prevalence of fine loamy, loamy, and coarse loamy soils highlights the importance of soil composition in influencing hydrological processes and water retention in the region.

1.5.5 Land use/ Land Cover

LULC study is very crucial for water resource management as it has a direct effect on overland flow, evapotranspiration and infiltration. Five major categories of LULC have been observed in the study area. Around 24% of AMC is occupied by urban settlement which is entirely incompatible for groundwater recharge. Around 60% of the area of AMC is covered by Agricultural land. Some portion of study area is shielded by quarry and mining areas. Others two significant units are water bodies (2%) and vegetation (7%). Water bodies, water logged areas, agrarian lands are considered as decent for groundwater recharge whereas absolute urban areas are treated as insignificant for groundwater recharge due to less infiltration (Agarwal & Garg, 2016). Agricultural land is considered as a high groundwater recharge area due to its high permeability and low compactness. Expansion of urban areas ultimately converts the natural surface into paved surface by constructing building, industry and transport networks along with other commercial activities, which ultimately hinders the natural infiltration process.

1.6 Review of Literature

1.6.1 Literature on Urban Water Resource Management

Sustainable water resource management has become a challenging issue for the development of cities suffering from scarcity of water. It is necessary for effective urban water resource management to implement system approach based on cooperative regional measures with participation of number of provinces and municipalities sharing water resource from same river basin (Bai & Imura, 2001). Edge or boundary problems are always encountered when applying a holistic or ecosystem approach of water resource management and design of institutional arrangement cannot eliminate these problems but can minimize them (Mitchell, 2005). A residential water demand model incorporating dynamic panel data technique has been applied for estimating residential water demand of

Zaragona, Spain where three water demand have been proposed and results indicate that domestic demands are inelastic with respect to price (Arbués & Villanúa, 2006). A comprehensive urban water management system including water resource allocation planning, urban development planning and environmental planning is vital for ensuring access of safe and reliable supply of water for urban communities in China (Cosier & Shen, 2009). For understanding the complex nature of urban water system and its management inclusion of social learning and engagement are necessary in sustainable decision support framework incorporating adaptive management and integrated urban water management strengths at the strategic and operational level (Pearson et al., 2010). The traditional linear approach that is take, make, waste approach of water resource management is failed to fulfill the high rising demand of modern society in sustainable manner, and this is the time to adopt techniques like storm water management, rainwater harvesting, water conservation, water reclamation and water reuse in water short locations (Daigger, 2012). Governance reforms in Australian cities are essential to establish adaptive and resilient urban water resource management that takes into account complexity, uncertainty and immediate and long term change (Rijke et al., 2013). A new ' Safe & Sure' approach of urban water resource management has been suggested (Butler et al., 2014) to cope up with the problems of 21st century associated with climate change and variability, rapid urbanization and population growth, energy constraint, tight environmental regulation. A flexible bottom up framework of urban water management incorporating various locally driven factors like water use efficiency, stress on existing supplies, adaption capacity has been suggested for San Francisco bay area (Gonzales & Ajami, 2017). Managed aquifer recharge approach suggested various methods of aquifer recharge such as infiltration techniques for unconfined aquifer, injection well for deep confined aquifer in diversifying urban water sources for sustainable urban water resource management (Page et al., 2018). Indian states need to shape up a water policy to provide an integrated direction for the development of water sector which should include urban local bodies in planning process of the water supply system (Nag & Garg, 2013). The lack of piped water availability in Kolkata is mainly due to issues of governance and politics rather physical and financial shortage (Kapuria, 2018). Unprecedented population growth, rapid urbanization, climate change , land conversion , migration, infrastructure development has created associated problems of water fluxes, water pathways and storage in Kolkata (Mukherjee et al., 2018). For protecting aquifer in Saltlake city, Kolkata rainwater harvesting techniques has been suggested by comparing with others techniques like grey and waste water recycling

(Banerji & Mitra, 2017). Quality assessment of water resource in Asansol suggested that there is a need of detailed hydro geochemical investigation and water management plan along with installation of rainwater harvesting techniques (Singh & Singh, 2018).

1.6.2 Literature on Application of RS and GIS in water resource management

Remote sensing technique is one of the promising techniques for hydrological observation as most hydrological processes are dynamic in nature and require frequent observation (Bhatta, 2017). Earth observation and remote sensing techniques have become appreciated tools in supplying data required for water resource management and are gaining impetus due to their capability of providing better spatial and temporal information (Makapela et al., 2015). Application of remote sensing in hydrological analysis includes wetland mapping and monitoring, water quality monitoring, soil moisture estimation, snow pack monitoring, measuring snow thickness, river and lake ice monitoring, river and delta change detection, drainage basin mapping and watershed modeling and irrigation canal leakage detection etc.(Bhatta, 2017). Spatial spectral classification where use of spectral signature and spatial descriptors are mandatory for image classification using high resolution satellite imagery along with machine learning techniques has been used in urban water consumption studies in Western Costa del Sol, Spain (Wolf & Hof, 2012). Satellite multi- sensor data has been used to investigate the evolution of Lake Trasimeno , Italy over time and space where MERIS and MODIS sensors have been suggested to monitor large scale water quality in regular basis (Giardino et al., 2010). In various water resource management project GIS and remote sensing techniques are used to replace, supplement and complement data collection and the maps produced by GIS are efficiently used by the employees of water department for identification of every detailed in water management system quickly (Guo et al., 2010). Remote sensing techniques have been widely used to estimate meteorological and hydrological variables (such as temperature, precipitation and soil moisture / soil water), to estimate fluxes such as total evaporation, and to delineate water bodies (Makapela et al., 2015). Remote sensing offers acute data for mapping water resources, measuring hydrological fluxes, monitoring drought and flooding inundation, while geographic information systems (GIS) arrange for the best tools for water resources, drought and flood risk management (Wang & Xie, 2018).

High spatial resolution remote sensing image (HSRRSI) data provide rich texture, geometric structure, and spatial distribution information for surface water bodies detail information of which offers better representation of the internal components of each object category and better reveals the relationships between adjacent objects (Song et al., 2020).

The recent technologies applied for water resource management includes ground penetration radar for soil moisture estimation, the Tropical Rainfall Measuring Mission(TRMM), 3D surface model analysis, storm hyetography analysis, rainfall runoff and urban flooding simulation, optical image classification and the Global Precipitation Measurement(GPM) (Wang & Xie, 2018). The weighted overlay analysis method using the fuzzy-analytical hierarchy process (FAHP) multi-criteria decision making (MCDM) techniques combined with geoinformatics technology has been used to explore the groundwater potential zones in the Itwad-Khamis watershed of Saudi Arabia where twelve thematic layers have been prepared and processed in a GIS setting to produce the groundwater potential zone map (GPZM) (Mallick et al., 2019). The application of geospatial technology, remote sensing, and the AHP technique has been validated as the best tools for the identification of groundwater potential zones in the Comoro watershed (Pinto et al., 2017).

Over the last decades remote sensing data plays an important role in research of various disciplines. Land surface temperature is one of the vital factors that control the physical, chemical and biological processes on the earth (Pu et al., 2006). The LSTs extracted from satellite borne sensors have been used in several, heat-balance, climate modeling and global change observing studies (Bhattacharya et al., 2010; Fall et al., 2010). The limited scope of globally in-situ observations of surface temperature, satellite derived LST provides comparatively large spatial variability, high resolution, consistent and repetitive coverage of measurements of earth surface conditions on a regional or global scale (Malik & Shukla, 2018; Yan et al., 2020). Despite LST estimation, the TIR region of the electromagnetic spectrum has enormous potential to estimate land surface related changes in any region, and is widely applied in every sector in Earth science (Alexander, 2020; Khan et al., 2020).

Ground water potential zone has been identified using remote sensing, geographical information system(GIS), and multi criteria decision making(MCDM) techniques in different parts of India such as Unnao district, Uttar Pradesh, Palamu district in Jharkhand, Kancheepuram district in Tamilnadu, Southern western Ghats (Agarwal et al., 2013; Arulbalaji et al., 2019; Saranya & Saravanan, 2020; Shekhar & Pandey, 2015).

Analytical Hierarchy Process(AHP) and geospatial techniques have been used for delineating ground water potential zone in various districts of West Bengal such as Puruliya,part of purba Burdwan, Raniganj in Paschim Burdwan district and alluvial tract of Hooghly district (Chakrabortty et al., 2018; Das et al., 2019; Pal et al., 2020; Patra et al., 2018).

1.6.3 Literature on Rainwater Harvesting

Simply rainwater harvesting is the technology of conserving rainwater by collecting and storing of rainwater from naturally or man-made catchment areas like the rooftop, compounds, impervious or semi-pervious land surface with the help of artificially designed system. It has been used from the very beginning of the society before the introduction of large scale public water system. A system of new rainwater harvesting technique in Lebanon have been discussed in the paper entitled "Rooftop level Rainwater Harvesting System" which can be easily used in both rural and urban areas. It collects and stores rainwater directly in tanks already installed on the building roofs not necessarily in special ground or underground ones (Traboulsi & Traboulsi, 2017). It has been proved that the rainwater harvesting can fulfill the demand of monthly WC flushing and laundry for the people of Abeokuta except the month of November, December, January and February (Aladenola & Adeboye, 2010). They calculated the amount of harvested rainfall using the 26th year average rainfall and roof area with suitable runoff coefficient value.

The amount of harvested rainwater in case of rooftop rainwater harvesting depends on roof area, depth of precipitation, storage and finally roof design and materials based runoff coefficient value (Thomas & Martinson, 2007). A simple and low cost technology rainwater harvesting system installation and its benefits has been discussed in the paper ' Feasibility study of rainwater harvesting system in Sylhet City' where it can be found that suitable rooftop rainwater harvesting system using low cost technology is also suitable for meeting the all kinds domestic water demand also for the people of rural area (Alam et al., 2012). By analyzing the cost-benefit they concluded that rainwater harvesting system is three to five times cheaper than the conventional and private water supply system. They also recognized that using local material and skill should be most profitable. Tank location (underground or rooftop) and materials based environmental performance has been analyzed in the paper 'Environmental performance of rainwater harvesting strategies in Mediterranean buildings' for the optimization of rainwater harvesting. A comparative discussion of rooftop tank and underground tank has been made for the environmental performance analysis (Angrill et al., 2011).

The efficiency of smart RWH for the improvement of integrated urban water system has been analyzed in the paper 'Can smart rainwater harvesting schemes result in the improved performance of integrated urban water systems?'(Behzadian et al., 2018). They explained that smart RWH scheme has the capacity of pro- actively controlling the tank water level to ensure sufficient spare storage throughout the year to maintain the runoff from storm events. The smart RWH also have the capacity to control local floods during heavy storm and supply of non-potable water. Optimal design parameter of the smart RWH scheme has been identified to achieve the best operational performance of the UWS. The rainwater harvesting techniques can be used in communal way for meeting the demand of potable water also in a small city, the main advantage of which is the flexibility of matching supply and demand for different households where additional energy penalty is required for collection and distribution of water (Cook et al., 2013). In the paper 'Rainwater Harvesting System for Continuous Water Supply to the Regions with High Seasonal Rainfall Variations' it has been discussed that RWH system is also useful in region of high seasonal rainfall variation like South Korea by setting appropriate tank size based on simulation of utilizing daily rainfall data of last 10 years (Jung et al., 2015). Method of solving urban waterlogging with the help of rainwater harvesting at Nanjing in China has been discussed in the paper 'Urban Rainwater Utilization and its Role in Mitigating Urban Waterlogging Problems—A Case Study in Nanjing, China' (Zhang et al., 2012). Methodologically they differently calculated the underlying surface areas, potential of collectable rainfall, cistern capacity and finally runoff volume reduction by utilizing long term rainfall data. A probabilistic and stochastic based modeling to gauge the adequacy of the supply demand relation of rainwater tank harvesting in suburban Melbourne, Australia has been analyzed in the paper 'Supply–Demand Risk and Resilience Assessment for Household Rainwater Harvesting in Melbourne, Australia (Wang & Blackmore, 2012). A GIS based methods of finding appropriate location for the installation of rainwater harvesting structure utilizing freely available imageries and remote sensing data has been analyzed in the paper 'GIS-based Methodology for Identification of Suitable Locations for Rainwater Harvesting Structures' (Tiwari et al., 2018). They used the layer of surface elevation map (ASTER-DEM), land use/land cover, soil map, drainage map and availability of surface runoff using SCS-CN for identifying the suitable location for rainwater harvesting structures. Different kinds of problems and probable solutions for promoting RWH in Ethiopia have been highlighted in the paper 'Policies and Strategies to Overcome Barriers to Rainwater Harvesting for Urban Use in Ethiopia' (Temesgen et al., 2016). They identified that lack of clear policy definition, lack of sustainable project implementation, poor societal perceptions of RWH and initial investment cost are the main barriers of promoting of RWH in Ethiopia. They suggested that various management strategies such as policy-oriented promotion, formulation of design guidelines, proactive planning, collaborative research, and integration of RWH with cost covering practices may be helpful for promoting RWH.

Ground water recharge in Allahabad city by rainwater harvesting has been analyzed in the paper ' Ground Water Recharge in Urban Areas – Experience of Rain Water Harvesting' where rainfall recharge was computed by using Rainfall Infiltration Factor Method and Water Table Fluctuation Method (Singh et al., 2014).

1.6.4 Literature on Ground Water

Ground water is an economic resource and more than 85% of the public water supplies are obtained from wells (Raghunath, 2007). Ground water hydrology is the science of the occurrence, distribution and movement of water below the surface of the earth and geohydrology has an identical connotation which differs it from hydrology by its greater emphasis on geology (Todd, 1959). He also defined ground water as the water occupying all the voids within a geologic stratum. In his book he presented many aspects of ground water in briefly which include ground water flow , recharge and discharge, properties of ground water, measurement of ground water, trends in ground water use , ground water storage etc. In general ground water or subsurface water refers to the water that occurs below the surface of the earth (Reddy, 2011). The problems are generally faced during ground water investigation are the zones of occurrence and recharge (Raghunath, 2007). Dowling et al. studied the arsenic contamination in the Bengal basin ground water with the help of samples wells and sediments collected from Bengal basin. They found a positive correlation among high levels of dissolved arsenic and iron, ammonia, and methane, especially in samples from a single site (Laxmipur) (Dowling et al., 2002). Hussein analyzed the importance of ground water rights and legislation for the water resources management in Soudi Arabia. He concluded that preparing and maintaining a true ground water rights and legislation in any area may be an important tools for water resource management (Hussein, 2001). A study has been made by Alfy about the numerical ground water modeling for the water resources management in arid areas. For numerical modeling of ground water they used the MODFLOW software with 20 bore holes data and others spatial information. They found that numerical ground water model may be a fruitful solutions for water resource management in arid areas all over the world (Alfy, 2014). Sreetly et al. studied the impacts of excessive ground water abstraction on river flow alteration consequences an ecological disturbance in Midland River in England. They concluded that methods for managing water resources that are based on quantitative relationships between degrees of river flow alteration and ecological impact are scarce and, as a result, most environmental flow management relies on expert opinion and is characterized by high uncertainty (Streetly et al., 2014). Various aspect of ground water in

India specially aquifer system, hydrological setup, ground water estimation methods etc. discussed in the report of ground water resources estimation committee (MWR, 2017).

Raghunath in his book "Ground Water" explained the various matters of ground water. In his first chapter he discussed about some important aspects of ground water in India which include ground water potentiality in India, ground water development India etc. In addition he explained many important things like aquifer properties, well hydraulics, concept of hydrometeorology, water well design, water well drilling, water quality, ground water basin management etc. (Raghunath, 2007). CGWB reported that there has been significant decline of ground water level in some of the blocks in West Bengal and out of 341 blocks 38 blocks are categorized as critical or semi-critical (Ray & Shekher,2009). The stage of ground water development is defined as the ratio between the existing gross groundwater draft for all uses to the net annual groundwater availability in a particular area expressed as percentage (Kumar, 2009).

Nine districts in West Bengal, India, and 42 districts in Bangladesh have arsenic levels in ground water above die World Health Organization maximum permissible limit of 50 pg/L (Chowdhury et al,2000). Bhattachariya and Chakrobarty found that many parts of Purulia District have rising trend of fluoride in ground water. They suggested some alternatives for decreasing the fluoride contamination in ground water in Purulia (Bhattachariya & Chakrobarty, 2002). A study has been conducted by Mitra and Acharya for identifying the ground water potential zones in Purulia by overlaying the lineament density map, lineament length density map and lithological map of the study area using weighted overlay index method. On the basis of the analysis they categorized the Purulia district consisting of metamorphic rocks in three ground water prospect zones(high, moderate and low) (Mitra & Acharya, 2014).

1.7 Identification of Research Gaps

After going through the numerous literatures of international, national and regional standard it has been observed that a great number of works related to water resource management in urban area have been done by different authors with temporal and spatial variation. Most of the international and national works have emphasized on a particular aspects like designing urban water distribution system, artificial ground water recharge, identifying ground water potential zone and improving policy regarding urban water management etc. This trend of research has also found among the notable regional works related to the present study. It has also been observed that a negligible number of works of Asansol Urban Area have been made mainly focusing on surface and ground water quality. It has been established that no prior work has addressed the potential of water resources in the Asansol Urban Area, encompassing various aspects of integrated urban water resource management. This includes the current status of surface and groundwater resources, identifying the demand-supply gap, observing changes in surface water bodies and groundwater over time, and exploring alternatives such as the potential for rainwater harvesting (both surface and rooftop). Consequently, a comprehensive study is necessary to evaluate the potential of water resources and ensure their sustainable management in Asansol Urban Area, balancing the increasing demand for water with the decreasing supply.

1.8 Objectives and Research Questions

The following five objectives and related research questions have been set forth for the present work and all the objectives have been fixed based on the research gap.

Objectives-1

- Evaluating the present scenario of water supply pattern and estimating the demand supply gap.

Research Questions

- Is the current water supply facility adequate to meet the demand?
- What is the nature of water demand across different sectors, and which sector is the largest consumer of water?
- Is there any water demand and supply gap? How might population growth trends affect future water demand and supply dynamics?

Objectives-2

- Identifying the dynamics of surface water resources and its sustainability.

Research Questions

- What is the status of surface water bodies?
- What are the primary drivers of reducing surface water over last few decades?
- How does land use change impact the spatial distribution and connectivity of surface water bodies?

Objectives-3

- Investigating the groundwater potential zones of AMC.

Research Questions

- ➢ What is the current state of groundwater availability, and does it exhibit spatial variation?
- ➢ Does groundwater have the potentiality to fulfil the present water demand?
- ➢ Is it feasible to expand groundwater utilization to meet the growing demand?

Objectives-4

- Identifying the suitable location for surface rainwater harvesting and assessing its potentiality.

Research Questions

- ➢ Is it possible to introduce surface rainwater harvesting?
- ➢ Is there any suitable places for surface rainwater harvesting?
- ➢ Is it possible to use open cast mining pits for surface rainwater harvesting?
- ➢ What are the hydrological characteristics and potential storage capacities of open cast mining pits for surface rainwater harvesting?
- ➢ How do interconnected mining pit channels contribute to the augmentation of surface water storage capacities?

Objectives-5

- Assessing the potentiality of roof top rainwater harvesting for non-potable uses.

Research Questions

- ➢ Is the rainfall pattern of AMC conducive to rooftop rainwater harvesting?
- ➢ What quantity of water can be harvested through rooftop rainwater harvesting? Can this harvested water fulfill the demand for non-potable water uses?

1.9 Materials and Methods

1.9.1 Database

Various primary and secondary datasets have been utilized in this study, sourced from specific origins. Detailed information on the nature and sources of these datasets is provided in the relevant chapters. For a clear understanding of the basic nature and types of data used throughout the study, all information is summarized in the table below (Table 1.1).

Table 1.1: Type and Sources of Data

Sl. No	Name of the Information	Source	Used For
1	Satellite Images(Landsat 8)	September,2021 & May and October 2020.https://earthexplorer.usgs.gov/	Extraction of LST and LULC and Preparation of MNDWI, NDVI, NDBI
2	Satellite Images(Landsat 5)	May & October, 1990, 2000, 2010https://earthexplorer.usgs.gov/	Extraction of LST and LULC and Preparation of MNDWI, NDVI, NDBI
3	Geological Unit	The geological quadrangle sheets (73M & 73I). Collected from the GSI. Scale: 1:250000	AHP & FR Models
4	Geomorphological Map	Bhukosh Geospatial data 250k.shp. Bhukosh Geospatial/Maps Data Download Package. Job ID: 4a8bf608-00b0-40ac-83a3-8f1b1d390d9d. gsi.gov.in	AHP & FR Models
5	SRTM Data	SRTM(30m)https://earthexplorer.usgs.gov/	Preparation of Slope, Drainage Density, Lineament Density, Depression Map
6	Soil Texture	West Bengal Soil sheet (NBSS LUP). Acquired from NBSS, Kolkata. Scale:1:500000	AHP & FR Models
7	Rainfall	Irrigation & Waterways Department, Durgapur Division, West Bengal	AHP & FR Models and for calculating RWH
8	Population	Census of India	Calculating water demand and predicting future water demand
9	Groundwater level data	Last fifteen years CGWB groundwater level data collected from the website of India Water Resource Information System	Preparation of Base map in FR Models
10	Groundwater level data from Observation wells.	Primarily measured from 50 observations wells covering entire study area	ROC Curve operation

1.9.2 Methods

Different methods have been employed in this study, in consideration of the available data and the study's objectives. Each method is discussed in detail in a specific chapter prior to its application. A summary of the different methods used in this study is provided below for a quick understanding of their basic nature (Table 1.2).

Table 1.2: Different methods used for this work

Sl. No.	Name of the Methods	Applied for
1	Normalized Differential Vegetation Index(NDVI)	Finding the Status of vegetation and nature of vegetation change over time
2	Modified Normalized Differential Water Index(MNDWI)	Finding the Status of Surface Water bodies and nature of surface water change over time
3	Normalized Differential Built up Index(NDBI)	Finding the Status of built up area and nature of built up area change over time
4	Feature space Image Classification	For understanding the last thirty years chage of Surface water bodies, vegetation cover and built up area
5	Analytical Hierarchy Processes(AHP)	Predicting ground water potential zone and identifying suitable location for surface rainwater harvesting
6	Frequency Ratio Models(FR)	Predicting Groundwater potential zones
7	Regression Analysis	Understanding the relationship between LST and other spatial indices such as NDVI, MNDWI and NDBI
8	Kappa Co-efficient	Accuracy assessment of the classified images
9	Receiving Operating Characteristics Curve(ROC)	Understanding the accuracy of AHP and FR models
10	Arithmetic Average Method	Predicting future population
11	Geometrical Mean Method	Predicting future population
12	Incremental Growth Method	Predicting future population
13	Mann-Kendall Test	Rainfall trend analysis

1.10 Relevance of the Present Study

This study aims to evaluate the current water resource potential of the Asansol Municipal Corporation (AMC) and predict future water demand in alignment with the UN Sustainable Development Goals (SDGs), particularly Goal 6, which emphasizes ensuring safe and affordable drinking water for all. Sustainable water resource management requires a comprehensive understanding of the current water availability and demand patterns in any region. As the second-largest urban agglomeration in West Bengal, AMC has a history of summer water crises. This research seeks to analyse the present surface and groundwater scenarios in AMC and project future water demands. The findings of this study will provide valuable insights into AMC's water resource potential and the anticipated increase in future water demand. Consequently, the government can implement appropriate measures for sustainable water resource management in AMC, in accordance with the UN Sustainable Development Goals.

1.11 Limitations of the Study

The present work on the "Water Resource Potential of Asansol Municipal Corporation in West Bengal towards its sustainable Management" faces limitations such as the availability of high-resolution and up-to-date data, particularly groundwater information. Technical challenges with GIS tools, including data integration and modelling assumptions, may affect accuracy. Additionally, limited consideration of socio-economic, institutional factors and water quality aspects can reduce the comprehensiveness of the analysis. Short-term study periods may overlook long-term trends, and the rapidly changing land use and water demand in the region may not be fully captured, affecting sustainable management recommendations.

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EVALUATING THE WATER AVAILABILITY AND ESTIMATING THE DEMAND-SUPPLY GAP

Abstract

Water security is one of the prime concern of UN Sustainable Goals as water plays a pivotal role for any kind of developmental activities along with the existence of living world. One of the important task of urban water resource management is the prediction of present and future water demand. The urban water use depends on the existing characteristics of the urban area mainly the type of activities and the nature of demand. The present chapter has been designed to predict the future domestic water demand for the people of Asansol Municipal Corporation by characterizing the different wards of Asansol Municipal Corporation along with the calculation of agricultural and industrial water demand. The characterization of wards has been done based on dominant activities reflected from land-use pattern. The areas under various land-use pattern have been calculated using the high resolution map in Google Earth Pro. The population forecasting has been made using three methods- arithmetic average method, geometric mean method and incremental growth method. The Indian Standard Code of basic requirements for water supply (IS 1172: 1993) has been followed for the prediction of domestic water demand. Agricultural water demand has been estimated using the CROPWAT-8.0 and CLIMWAT-2.0 Software developed by FAO. On the other hand, for understanding the present water supply pattern information provided by AMC has been utilized. The result of the present study reflects that there is a huge gap between demand and supply of water in the Asansol Municipal Corporation, which is increasing day by day. Based on dominant land-use pattern, four distinct categories wards are noticed in the study area. Industrial sector is the largest water consuming sector of AMC followed by agricultural and domestic sectors. The study area has experienced a steady population growth, which will remain same in near future. There is an urgent need of finding alternative sources of water or increasing efficiency of water use for future water security.

2.1 Introduction

Water is one of the most essential elements on Earth, vital for the survival of all living organisms. Both plants and animals rely on water for their existence, as it sustains life and supports countless biological processes. Existence of life on earth depends on water. Water crisis is the prime concern of present day researchers as water is the fundamental issue of all kinds of developing actions. Presently many countries and governments throughout the world try to find a suitable way to reduce the water crisis. Gap between existing water availability and demand creates water scarcity in any region. If the present available water resources fail to fulfil the demand then water scarcity arises. Sustainable water resource management has become a challenging issue for the development of cities suffering from scarcity of water. It is necessary for effective urban water resource management to implement system approach based on cooperative regional measures with participation of number of provinces and municipalities sharing water resource from same river basin (Bai & Imura, 2001). A residential water demand model incorporating dynamic panel data technique has been applied for estimating residential water demand of Zaragona, Spain, the result indicates that residential demands are rigid with respect to price (Arbués & Villanúa, 2006). A comprehensive urban water management system including water resource allocation planning, urban development planning and environmental planning is vital for ensuring access of safe and reliable supply of water for urban communities in China (Cosier & Shen, 2009). For understanding the complex nature of urban water system and its management inclusion of social learning and engagement are necessary in sustainable decision support framework for strengthening the integrated urban water management system at grass root level (Pearson et al., 2010). The traditional linear approach that is take, make, waste approach of water resource management is failed to fulfill the high rising demand of modern society in sustainable manner, and this is the time to adopt techniques like storm water management, rainwater harvesting, water conservation, water reclamation and water reuse in water short locations (Daigger, 2012). Governance reforms in Australian cities are suggested to be essential to establish adaptive and integrated urban water resource management considering variability of demand, complexity and uncertainty (Rijke et al., 2013). A new ' Safe & Sure' approach of urban water resource management has been suggested (Butler et al., 2014) to cope up with the problems of 21st century associated with climate change, urbanization, growth of population, energy shortage and tight environmental regulation. A flexible bottom up framework of urban water management incorporating various local factors like water use efficacy, strain on existing supplies, adaption capacity has been suggested for San Francisco bay area (Gonzales & Ajami, 2017). Managed aquifer recharge approach suggested various methods of aquifer recharge such as infiltration techniques for unconfined aquifer, injection well for deep confined aquifer in diversifying urban water sources for sustainable urban water resource management (Page et al., 2018). Remote sensing technique is one of the promising techniques for hydrological observation as most hydrological processes are dynamic in nature and require frequent observation (Bhatta, 2017). Earth observation and remote sensing techniques have become esteemed tools for water resource management by supplying real time spatial data (Makapela et al., 2015). Remote sensing offers acute data for demarcating water resources, estimating hydrological fluxes, observing drought and flood situation, while GIS arranges best tools for water resources management and drought and flood risk management (Wang & Xie, 2018).

Urban water security is defined by the per capita availability of water which is controlled by the accessibility of water for the city dwellers, water storage, distribution and treatment pattern, financial support system for establishing and maintaining infrastructure and regulating and operating system (Krueger et al., 2019). Different methods for predicting urban water demand have been used by the researchers covering entire world. Meta regression analysis has been applied for forecasting the urban water demand which indicates that the accuracy is controlled by several factors such as sample size, model specification, variability of water demand etc.(Sebri, 2016). Artificial Neural Network along with time series models have been applied for predicting the urban water demand in Soudi Arabia which produces a better result compared to other method (Al-Zahrani & Abo-Monasar, 2015). A comparative study for predicting urban water demand using modern computing methods including ANN, SVM and traditional methods including time series analysis, regression models reveals that using ANN is better than the traditional method (Oyebode & Ighravwe, 2019). The study of urban water supply in Africa reveals that partnership based models involving communities can reduce the urban water demand and supply gap (Adams et al., 2019).

Indian states need to shape up a water policy to provide an integrated direction for the development of water sector which should include urban local bodies in planning process of the water supply system (Nag & Garg, 2013). The lack of piped water availability in Kolkata is mainly due to issues of governance and politics rather physical and financial shortage (Kapuria, 2018). Unprecedented population growth, rapid urbanization, climate change , land conversion , migration, infrastructure development has created associated problems of water fluxes, water pathways and storage in Kolkata (Mukherjee et al., 2018). For protecting aquifer in Saltlake city, Kolkata, rainwater harvesting techniques has been suggested by comparing with others techniques like grey and waste water recycling (Banerji & Mitra, 2017). Quality assessment of water resource in Asansol suggested that there is a need of detailed hydro-geochemical investigation and water management plan along with installation of rainwater harvesting structures (Singh & Singh, 2018).

It is very important to know the demand of water properly for the sustainable water resource management following the UN Sustainable goals. The demand of water in any urban area depends on the major activities of that area which are reflected from the dominant land-use/land-cover pattern. The present chapter has been designed for understanding actual water demand of AMC controlling by major land-use pattern and finding the demand supply gap of water. This study will provide the answer of the following research questions -Is the current water supply facility adequate to meet the demand? What is the pattern of water demand across different sectors, and which sector is the largest consumer of water? Is there any water demand and supply gap? Whether the population growth trend is going to affect future water demand and supply dynamics?

Asansol Municipal Corporation has been selected as study area because AMC has a great history of water crisis mainly in summer season. Most of the people of AMC are not happy with the existing water supply pattern. The present study has four aspects interconnected to water resource management. The first aspect of this study is to categorize all wards under AMC on the basis major land-use pattern for understanding the actual demand of water. Secondly, understanding the population growth pattern as it determined the actual demand of water. Thirdly, to estimate the domestic, industrial and agricultural water demand and predict the future domestic water demand. Finally, to understand the present supply condition and water demand for finding the demand and supply gap which is necessary for the future water security of the city.

The present work will help the reader to understand the real water demand supply scenario of AMC at present and also its future demand. It will help the Government as well as authority of AMC to take appropriate action related to water resource management in sustainable way. At the same time, it will help to understand the spatial distribution of major activities in the city and also the population trend of the city.

2.2 Database and Methodology

The present study is based on both primary and secondary data. The population information has been collected from the Census of India(2011). On the other hand, the pattern of present water supply in quantity has been collected from engineering section of Asansol Municipal Corporation. The land-use and land-cover information have been extracted from high resolution google earth image in Google Earth Pro environment and field survey.

2.2.1 Population Prediction

The population forecasting is a technique to predict future population based on available past and present information. Three methods of population forecasting have been used in this study based on the census population from 1951 to 2011. In this study population for the year 2021, 2031, 2041 and 2051have been predicted.

Arithmetic Increase Method: This method is used for old city where increase rate of population is considered as constant. The average increase rate per decade is calculated from the previous population records to calculate the population of next decade by adding this increase to the present population. The following formula is used for this method-

$$P_n = P_o + n\bar{x},$$

where,

P_o – Known population of base year, P_n – Predicted population after 'n' number of decades, n – Decadal gap, $\bar{x}$ - Average increase rate

Geometrical Increased Method: In this method, it is assumed that the growth of population is proportional to the existing population. This method is suitable for developing cities. In this method the percentage increase in population among decades is assumed to remain constant. The following mathematical formula is used for this technique-

$$P_n = P\,(1 + IG/100)^n$$

where, IG = geometric mean (%), P = Present population, n = Number of decades.

Incremental Growth Method: This is a modified form of arithmetical increase method and suitable for the average size city in normal conditions. The incremental growth rate is calculated for predicting future population. The following formula is used for this method-

$$P_n = P + n.X + \{n\,(n+1)/2\}.Y$$

where,

P_n = Predicted population after 'n' number of decades; X = Mean increase,

Y = Incremental increase

As the various methods of population forecasting have its own inherent merits and demerits, the mean value of these three methods have been considered to find out the final predicted population for each decades. The present study area does not have any specific criteria suitable for applying any specific method of population forecasting.

2.2.2 Categorization of Wards

The categorization of wards has been based on dominant landuse/landcover pattern observed in AMC as major activities and associated water demand are reflected from LULC of any region. Four major types of LULC including area under industry, area under agriculture, built up area and areas under mining specially coal mining have been considered for the categorization of ward considering the existing LULC pattern of AMC. Measurement of areas under these four categories have been calculated using the high resolution images from Google Earth in Google Earth Pro platform (Fig 2.1). Finally, based on the areas under major LULC and field validation four categories of Wards (A,B,C & D) have been identified.

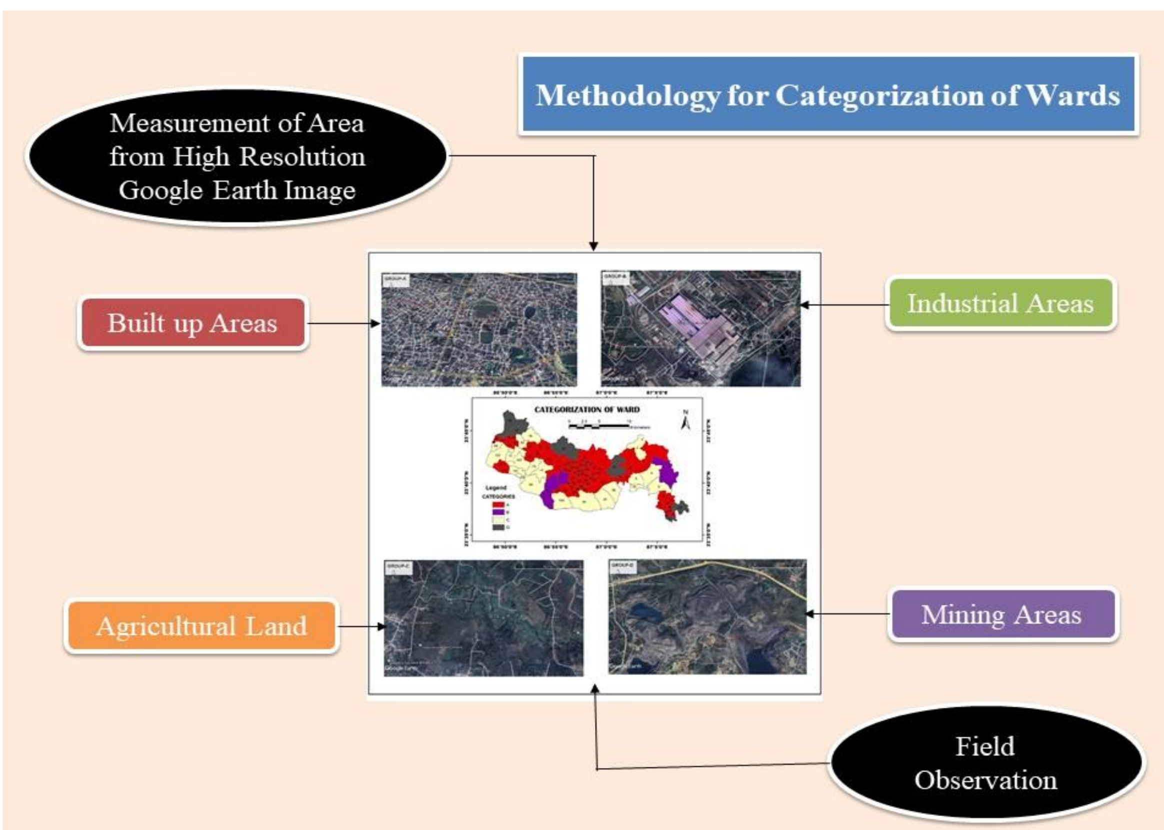

Fig. 2.1: Methodology for Categorization of Wards

2.2.3 Calculation of Domestic Water Demand

Indian Standard Code of basic requirements for water supply, drainage and sanitation (IS 1172: 1993) has been followed for predicting the domestic water demand in Asansol Municipal Corporation (Fig 2.2). This standards explains in details the basic requirements of water in urban area for residential, commercial, industrial and any others including bus stands, railway platforms etc. The details procedure is available in the website: http://dasta.in/wp-content/uploads/2015/04/CB_Code_2002.pdf.

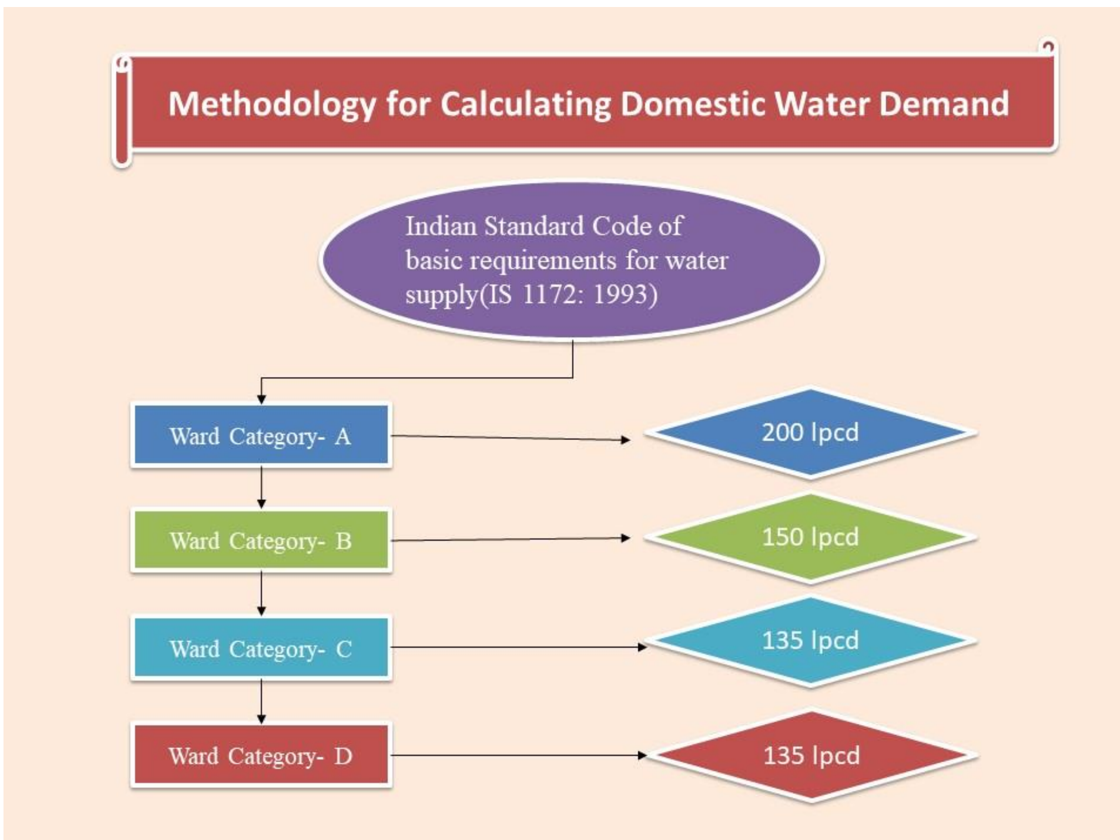

Fig. 2.2: Methodology for Calculating Domestic water demand

2.2.4 Agricultural Water Demand

Agricultural water demand has been calculated using CROPWAT-8.0 and CLIMWAT-2.0 software developed by FAO (Fig 2.3&2.4). For calculating the agricultural water demand of AMC only Aman rice has been considered as other crops are very insignificant in this area. Climatic information, rainfall information and soil parameters have been utilized in software environment for calculating the actual agricultural water demand of AMC.

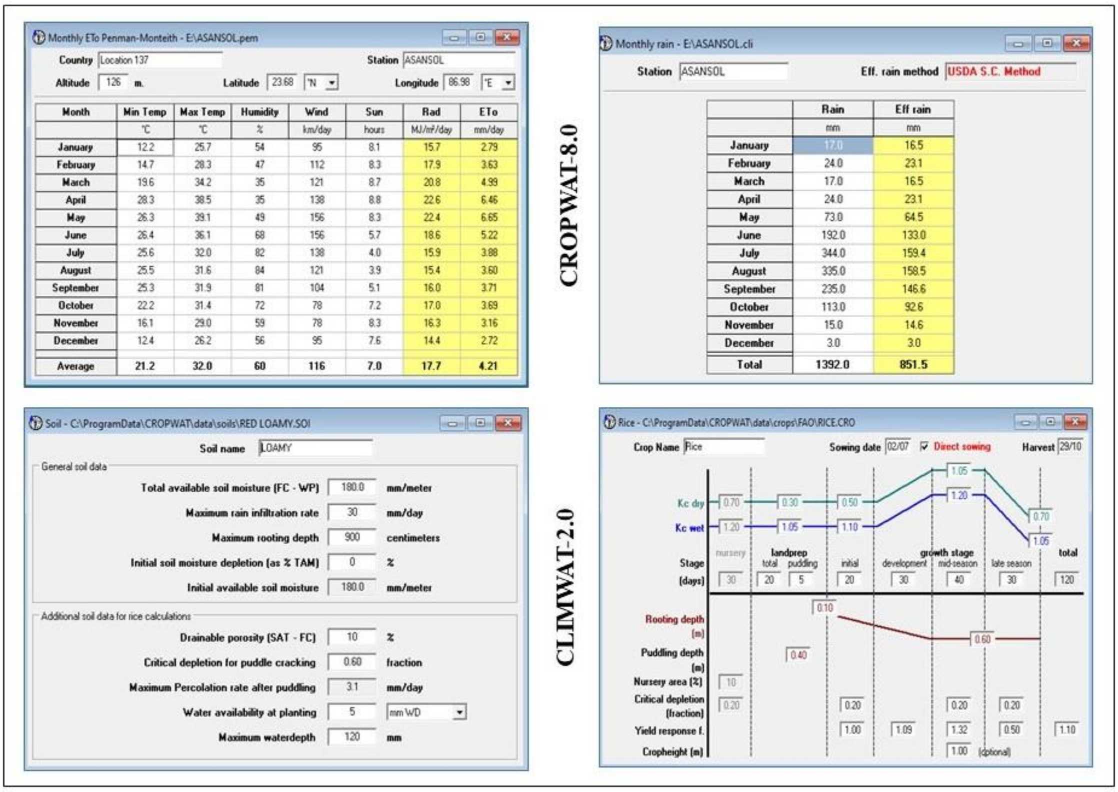

Fig.2.3: Methodology for Calculating Agricultural water demand

Crop Water Requirements

ETo station: ASANSOL — Crop: Rice
Rain station: ASANSOL — Planting date: 02/07

Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req.
			coeff	mm/day	mm/dec	mm/dec	mm/dec
Jun	2	LandPrep	1.05	5.48	49.3	41.7	45.0
Jun	3	LandPrep	1.05	5.01	50.1	48.6	137.6
Jul	1	Init	1.09	4.66	46.6	51.0	0.0
Jul	2	Init	1.10	4.16	41.6	54.4	0.0
Jul	3	Deve	1.10	4.10	45.1	53.9	0.0
Aug	1	Deve	1.11	4.08	40.8	53.3	0.0
Aug	2	Deve	1.11	3.99	39.9	53.3	0.0
Aug	3	Mid	1.11	4.03	44.4	51.8	0.0
Sep	1	Mid	1.11	4.08	40.8	51.5	0.0
Sep	2	Mid	1.11	4.12	41.2	50.8	0.0
Sep	3	Late	1.11	4.11	41.1	44.2	0.0
Oct	1	Late	1.08	4.00	40.0	37.6	2.4
Oct	2	Late	1.04	3.83	38.3	32.0	6.3
Oct	3	Late	1.00	3.50	31.5	18.8	8.6
					590.6	642.8	199.9

Fig.2.4: Irrigation Water requirement

Table 2.1: Agricultural Water Demand

Net Cropped Area=	$125km^2$
Water requirement =	199.9mm/dec
Total Water requirement =	10 x 199.9mm=1999mm=1.999m
Total water requirement for Asansol(Yearly) =	125000000 x 1.999m=249875000m=56726.81MG

Source: Computed by the Author

2.2.5 Industrial Water Demand

Industrial water demand has been calculated using both primary and secondary information. For large scale industries average production and per unit water requirement have been utilized whereas for small and medium scale industries secondary information from West Burdwan Industrial report, 2018 has been considered (Table 2.2).

Table 2.2: Industrial Water Demand

Sl. No.	Name	Type of Industries	Average Production(Yearly)	Average water requirement per tonne	Total Water requirement in MG
1	Indian Iron and Steel Company (IISCO)	Steel Manufacturing	2.5 Million tonnes	150	99064.52
2	Burnpur Cement	Cement Manufacturing	0.3 Million metric tonnes	0.2	17.47
3	Eastern Coalfields Limited	Coal Mining	40 Million tonnes	3.25	34342.37
4	Phillips Carbon Black Limited	Carbon Black Manufacturing	1.25 Million tonnes	7.5	2476.61
5	Bharat Aluminum Company (BALCO)	Aluminum Manufacturing	0.6 Million tonnes	2.5	396.26
6	Jai Balaji Industries	Iron and Steel Manufacturing	0.15 Million tonnes	150	5943.87
7	Hindustan Zinc Limited	Zinc Manufacturing	4.5 Million tonnes	3	3566.32
8	Gajanan Iron Private Limited	Iron and Steel Manufacturing	1.45 Million tonnes	150	57457.42
9	Asansol Alloy Castings	Alloy Casting	0.012 Million tonnes	12	38.23
10	Asansol Cement	Cement Manufacturing	0.010 Million tonnes	0.2	0.58
11	Graphite India Limited	Graphite Product Manufacturing	0.08 Million tonnes	30	544.84
12	Raniganj Castings	Metal Casting	0.009 Million tonnes	12	24.52
13	Ganesh Foundry	Foundry	0.02 Million tonnes	1.5	6.81
14	Jamuria Refractories	Refractory Manufacturing	0.0052 Million tonnes	7.5	8.85
Total water requirement for large scale industries					**203888.67**
Additional requirement for medium and small scale industries					**30000**
Total water requirement(Yearly)					**233888.67**

Source: Computed by the Author

2.3 Results and Discussions

2.3.1 Categorization of Wards

Presently Asansol Municipal Corporation has 106 wards after merging the surrounding three municipalities including Raniganj, Jamuria and Kulti with Asansol in 2015. In this study all the 106 wards have been characterized on the basis of major landuse and associated activities as the prime objective is to find out the water demand accurately. As Asansol Municipal Corporation has been declared after merging the surrounding municipalities, there is observed many wards under AMC where actual urban landuse pattern is not found although by designation these are urban areas. On the basis of existing landuse pattern in AMC, four features including percentage of built up area, percentage of areas under industry, percentage of areas under agriculture and percentage of areas under coal mining have been considered for characterization of various wards. Finally on the basis of major landuse pattern along with ground truth verification four different types of wards have been identified in AMC. The four categories of wards are- Group A, Group B, Group C and Group D.

Group A: Maximum part of these wards are covered by Built-up area. Commercial, residential and administrative are the dominant activities of these wards. Medical and Educational institutions are also observed. Among the 106 wards of AMC, 77 wards have been identified as Group A. During the calculation of water demand maximum celling limit (200 lpcd) has been considered for these wards following Indian Standard Code of basic requirements for water supply in urban areas (IS 1172:1993). The major land-use patterns are given in table below (Table 2.3).

Table 2.3: Land-use Characteristics of 'A' Category Wards

Ward No.	Area in Km	% of Built up areas	% of Industrial Areas	% of Agricultural Lands	% of Coal Mining Areas	% of Others	Category
1	9.09	73.50	3.21	16.50	0.00	6.79	A
3	1.37	78.25	4.75	4.50	0.00	12.50	A
4	4.50	82.25	2.50	3.75	0.00	11.50	A
5	8.17	68.92	3.10	10.25	1.25	16.48	A
10	1.28	58.95	0.00	15.75	2.50	22.80	A

11	3.25	65.75	0.00	13.50	1.35	19.40	A
12	8.10	76.50	0.00	5.63	3.20	14.67	A
14	6.36	56.50	1.35	14.25	2.50	25.40	A
15	5.68	57.78	1.75	16.85	3.20	20.42	A
18	3.48	63.50	3.20	6.95	4.50	21.85	A
19	11.80	68.65	1.20	8.95	3.20	18.00	A
21	2.19	76.95	0.65	1.25	0.00	21.15	A
22	0.54	82.30	0.00	0.75	1.23	15.72	A
23	0.57	84.32	0.39	2.30	0.00	12.99	A
24	0.59	81.25	0.20	3.12	0.59	14.84	A
25	0.54	79.40	3.10	4.10	0.00	13.40	A
26	0.33	83.25	1.25	2.50	1.23	88.23	A
27	0.30	80.25	2.32	2.75	0.00	14.68	A
28	0.30	86.20	1.65	1.58	0.30	10.27	A
29	1.09	85.32	1.76	1.79	0.45	10.68	A
30	1.83	84.53	0.00	2.10	2.75	10.62	A
31	2.43	86.20	1.23	1.65	2.30	8.62	A
33	2.59	72.30	7.15	1.25	0.00	19.30	A
34	4.40	69.35	3.40	3.20	0.00	24.05	A
36	1.96	83.50	3.20	1.25	1.65	10.40	A
37	6.39	85.12	2.35	0.75	0.00	11.78	A
39	1.65	79.25	2.35	2.55	1.20	14.65	A
40	1.80	77.86	3.59	4.50	0.75	13.30	A
41	0.84	80.27	3.45	3.54	0.00	12.74	A
42	0.46	83.50	1.23	3.75	0.00	11.52	A
43	0.32	84.25	1.35	4.65	0.00	9.75	A
44	0.85	77.12	4.70	7.13	1.56	9.49	A
45	0.51	69.35	5.35	10.25	0.00	15.05	A
46	0.43	75.68	4.95	6.95	0.00	12.42	A
47	0.46	77.26	3.65	7.23	0.00	11.86	A
48	0.78	80.25	2.50	5.65	3.20	8.40	A
49	0.44	69.75	7.50	7.95	0.00	14.80	A
50	0.47	72.37	5.30	8.35	0.00	13.98	A
51	0.48	76.55	4.69	9.50	0.00	9.26	A
52	0.95	75.74	3.56	3.57	0.00	17.13	A
53	0.34	79.35	5.39	4.35	1.54	9.37	A
54	0.70	81.20	2.45	5.25	0.00	11.10	A
55	1.71	71.25	7.35	6.95	0.00	14.15	A
56	6.04	69.30	6.95	7.75	0.85	15.15	A

57	3.86	73.58	5.87	6.85	0.00	13.70	A
58	2.38	74.23	6.20	8.25	0.00	11.32	A
59	2.47	78.36	4.20	4.50	2.30	10.64	A
60	3.08	77.10	2.13	6.95	0.00	13.82	A
61	3.15	72.35	4.90	5.36	0.00	17.39	A
63	1.99	76.95	2.35	7.95	3.25	9.50	A
64	0.26	74.25	0.00	8.95	4.50	12.30	A
65	9.99	72.35	0.00	10.65	2.35	14.65	A
67	0.58	55.20	0.00	13.65	3.95	27.20	A
68	2.20	55.24	0.00	17.25	1.23	26.28	A
70	1.25	59.54	0.00	16.50	0.00	23.96	A
71	4.72	62.50	0.00	14.25	0.00	23.25	A
76	1.43	76.65	2.50	8.50	0.00	12.35	A
77	0.63	72.85	3.20	7.25	2.10	14.60	A
78	0.91	82.45	1.25	6.95	1.75	7.60	A
79	1.09	80.20	3.15	4.65	0.00	12.00	A
80	0.67	85.26	2.10	6.32	0.00	6.32	A
81	0.47	78.25	1.75	7.15	2.35	10.50	A
82	0.54	73.52	1.35	9.53	0.00	15.60	A
83	1.44	74.36	0.00	10.26	0.00	15.38	A
84	0.51	79.65	2.50	6.75	3.52	7.58	A
85	2.12	81.25	0.00	4.35	0.00	14.40	A
86	8.13	69.75	3.85	6.55	0.00	19.85	A
88	0.36	74.50	3.20	6.50	0.00	15.80	A
89	0.81	76.25	2.40	8.35	3.45	9.55	A
90	1.33	78.35	1.35	3.95	0.00	16.35	A
92	0.55	78.65	2.50	3.25	1.75	13.85	A
93	13.28	81.75	1.30	1.20	2.35	13.40	A
95	2.51	69.35	4.65	6.85	3.25	15.90	A
96	10.75	73.56	3.25	5.75	1.20	16.24	A
98	11.13	74.55	1.25	6.53	2.14	15.53	A
104	2.43	65.45	0.00	18.25	0.00	16.30	A
105	7.92	62.35	0.00	20.20	0.00	17.45	A

Source: Computed by the Author

Group B: All the wards under these categories are mainly covered by heavy and small industries (>50% areas). Except industrial activities residential and commercial activities are also observed. Three wards have been identified as Group B among 106 wards in AMC. For calculating the domestic water demand of the people residing in these wards 150 lpcd has been considered following the guideline of Indian Standard Code. Percentage details of land-use in these wards are provided in tabulated form (Table 2.4).

Table 2.4: Land-use Characteristics of 'B' Category Wards

Ward No.	Area in km^2	% of Built up areas	% of Industrial Areas	% of Agricultural Lands	% of Coal Mining Areas	% of Others	Category
7	6.97	35.75	61.50	1.75	0.00	1.00	B
75	0.32	28.10	65.85	0.85	0.00	52.00	B
97	1.43	33.25	51.25	3.50	0.00	12.00	B

Source: Computed by the Author

Group C: The all wards under this category are primarily dominated by agricultural activities. More than 50% is covered by Agricultural land and agriculture is the prime activities along with residential unit. Considering the nature of water use lower limit of IS Standard Code (135 lpcd) has been fixed for calculating domestic water demand of the people residing in these wards. Twenty wards have been identified as Group C in AMC. The percentage details of major land-use are given below (Table 2.5).

Table 2.5: Land-use Characteristics of 'C' Category Wards

Ward No.	Area in km^2	% of Built up areas	% of Industrial Areas	% of Agricultural Lands	% of Coal Mining Areas	% of Others	Category
2	6.75	42.50	1.20	55.10	0.00	1.20	C
6	12.02	43.40	2.75	53.50	0.00	0.35	C
8	4.24	39.10	2.50	52.50	1.25	4.65	C
9	2.10	33.25	3.50	54.35	0.78	8.12	C
16	4.15	22.25	2.50	50.25	4.56	20.44	C
32	2.77	32.25	0.00	67.25	0.00	0.50	C
38	4.71	32.25	1.35	62.75	0.00	3.65	C
62	0.64	29.35	0.00	51.25	4.52	14.88	C
69	0.93	30.25	0.00	57.45	2.30	10.00	C
72	4.09	31.65	0.00	58.25	0.00	10.10	C
73	6.01	34.25	2.54	57.95	0.00	5.26	C
74	3.69	36.75	3.52	52.54	0.00	7.19	C

87	0.30	32.50	0.00	54.50	0.00	13.00	C
94	1.90	32.35	0.00	56.50	0.00	11.15	C
99	1.32	31.95	0.00	54.76	0.00	13.29	C
100	3.28	27.30	0.00	58.25	0.00	14.45	C
101	6.20	36.52	0.00	50.75	3.45	9.28	C
102	8.94	37.12	0.00	53.75	2.75	6.38	C
103	2.23	32.15	0.00	55.25	0.00	12.60	C
106	6.99	28.65	0.00	60.20	0.00	11.15	C

Source: Computed by the Author

Group D: Asansol Municipal Corporation is famous for coal mining. Coal mining is the integral parts of AMC. Coal mining is the prime activities of wards under this category along with small residential unit. Among the 106 wards of AMC, 6 wards have been identified as Group D. The details land-use pattern are provided below in tabulated form (Table 2.6).

Table 2.6: Land-use Characteristics of 'D' Category Wards

Ward No.	Area in km^2	% of Built up areas	% of Industrial Areas	% of Agricultural Lands	% of Coal Mining Areas	% of Others	Category
13	5.12	32.75	3.20	6.50	53.25	4.30	D
17	1.59	18.95	0.00	5.60	68.65	6.80	D
20	1.61	26.25	0.00	13.20	59.25	1.30	D
35	0.28	19.25	0.00	4.75	68.95	7.05	D
66	0.31	26.35	0.00	2.35	57.35	13.95	D
91	0.41	25.65	1.35	2.10	59.35	11.55	D

Source: Computed by the Author

2.3.2 Analysis of Population Trend

According to the Census of India (2011) total population of Asansol Municipal Corporation is 1243414. Based on the Census population records from 1951, an attempt to predict the future population of AMC has been made using three traditional methods including arithmetical increase method, geometric increase method and incremental growth method. Finally, using these methods population of AMC for the year 2021, 2031, 2041 and 2051 have been predicted for calculating the future domestic water demand. An average value of three methods has been used in this study for minimizing the prediction error. There is observed a steady growth of population in AMC which follows a near perfect second order polynomial curve (Fig. 2.6). As per the prediction, the population of AMC for the year 2051 will be 2704763 whereas population of 2011 was 1243414.The details of predicted population for different decades have been mentioned below in table (Table 2.8).

Table 2.7: Calculation for Population Prediction

Year	Population	Increase	Incremental Increase	% Growth	Geometric Mean
1951	182104				0.345
1961	286539	104435		0.57	
1971	370800	84261	-20174	0.29	
1981	628991	258191	173930	0.70	
1991	938067	309076	50885	0.49	
2001	1067369	129302	-179774	0.14	
2011	1243414	176045	46743	0.16	
	Total	1061310	71610		
	Average	176885	14322		

Source: Computed by the Author

Table 2.8: Population Prediction

Year	Methods	Predicted Population	Average Predicted Population
2021	Arithmetical Increase	1420299	1509104
	Geometric Growth	1672391	
	Incremental Increase	1434621	
2031	Arithmetical Increase	1597184	1828900
	Geometric Growth	2249367	
	Incremental Increase	1640150	
2041	Arithmetical Increase	1774069	2219823
	Geometric Growth	3025398	
	Incremental Increase	1860001	
2051	Arithmetical Increase	1950954	2704763
	Geometric Growth	4069161	
	Incremental Increase	2094174	

Source: Computed by the Author

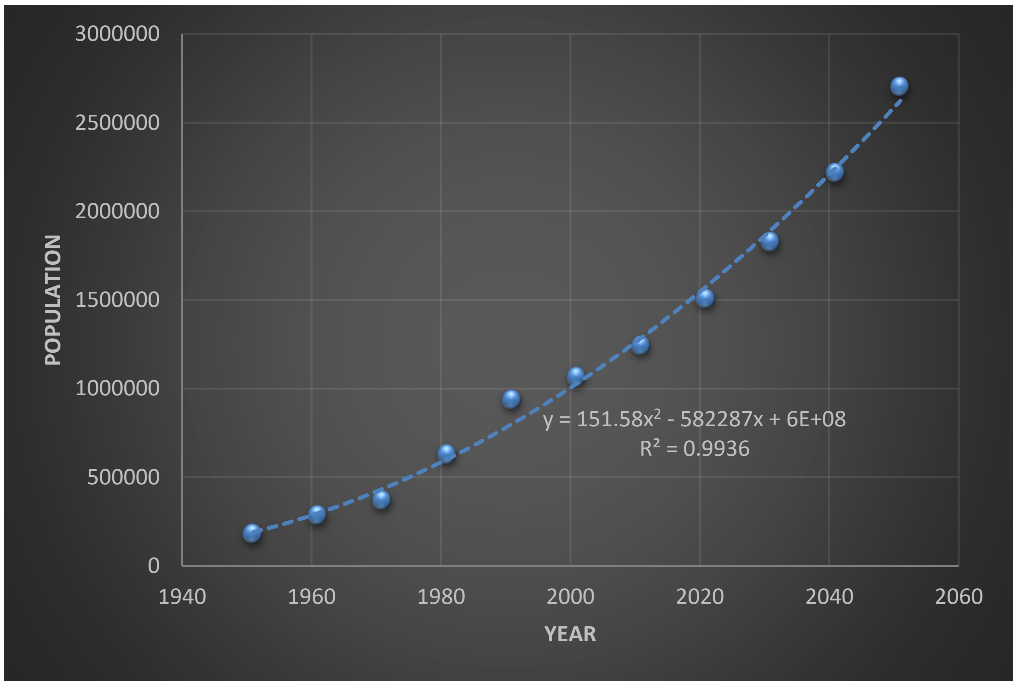

Fig.2.5: Trend of Population in AMC

2.3.3 Sectoral water demand

As per the calculation of water demand following the Indian Standard Code of basic requirements for water supply in urban areas (IS 1172:1993), the total domestic water demand of people living in AMC as per census,2011 is 22210 MG yearly. As per the present calculation yearly water demand for agriculture is 56726 MG whereas yearly water demand for industrial sector is 233888 MG. The largest water consuming sector of AMC is industrial sector which is followed by agricultural and domestic sector (Fig 2.6).

Table 2.9: Water demand Calculation (Domestic)

Ward Category	Total Number of Ward	Total Population	Water Requirement(lpcd)	Requirement in MGD
A	77	954349	954349*200=190869800	50.42
B	3	31375	31375*150=4706250	1.24
C	20	198570	198570*135=26806950	7.08
D	6	59120	59120*135=7981200	2.11
	Total	1243414	230364200	60.85
	Average Water requirement (lpcd)		**185.2674974**	

Source: Computed by the Author

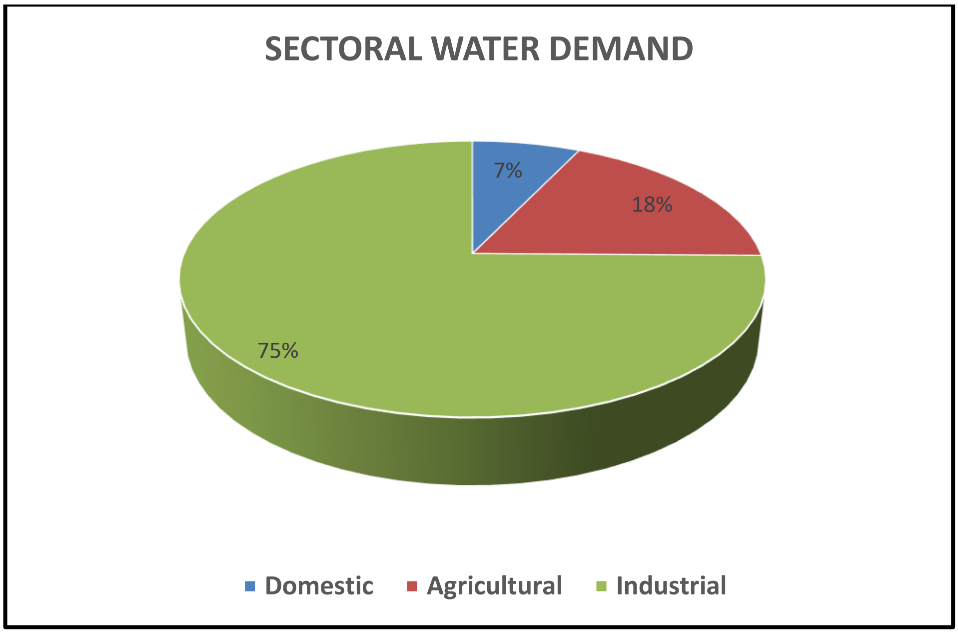

Fig.2.6: Pattern of Sectoral Water Demand

2.3.4 Prediction of domestic water demand and demand supply gap

A rising trend of domestic water demand along with population growth is observed in AMC. As per the information collected from the Asansol Municipal Corporation office, the total present water supply from all sources is 45.58mgd (Table 2.11). According to the result of present study, the total domestic water demand of people living in AMC will be 80.58mgd in 2051 (Table 2.10). As per the present condition the supply is fixed unless any further initiatives will take by the AMC authority. The details water projects in AMC along with the capacities are given below (Table 2.11). There is observed a huge demand supply gap in AMC which is increasing day by day as the supply is constant as per present situation. The pattern of water demand and supply gap in AMC has been depicted using table and diagram (Table 2.12).

Table 2.10: Future Water Demand Calculation (Domestic)

Year	Total /Predicted Population	Increase	Additional Demand	Total Demand
2011	1243414	0	0.00 MGD	60.85 MGD
2021	1509104	265690	10.81 MGD	71.66 MGD
2031	1828900	319796	13.01 MGD	73.86 MGD
2041	2219823	390923	15.9 MGD	76.75 MGD
2051	2704763	484940	19.73 MGD	80.58

Source: Computed by the Author

Table 2.11: Details of Water Project and Supply

Project Area	Capacity(MGD)	Remarks
Kalajharia(Asansol)	8.04	Surface 2MGD and Underground 6.04 MGD
Dihika(Asansol)	8.24	Total Surface
Bhutabhuri(Asansol)	5.00	Underground
Damra(Asansol)	5.00	Underground
Suryanagore(Asansol)	1.50	Surface
Kalajharia(Asansol)	0.30	Surface
Kalyaneswari(Asansol)	0.50	Surface
Jamuria	5.00	Underground
Chinakuri1(Kulti)	5.00	Underground
Chinakuri 2(Kulti)	5.00	Infiltration Gallery
Barakar(Kulti)	1.00	Surface
Ramnagore(Kulti)	1.00	Surface
Total	45.58	

Source: Asansol Municipal Corporation, Engineering Section

The calculation of the domestic water demand and supply gap has been based on the assumption that the current water supply provided by the AMC remains constant. This approach has been adopted due to the lack of reliable information regarding potential changes in water availability from AMC in the future. As a result, the present water supply levels are treated as fixed, and any fluctuations or adjustments that may occur over time are not accounted for in this analysis.

Table 2.12: Water Demand and Supply Gap Calculation

Year	Actual Demand(MGD)	Actual Supply(MGD)	Gap(MGD)
2011	60.85	45.58	15.27
2021	71.66	45.58	26.08
2031	73.86	45.58	28.28
2041	76.75	45.58	31.17
2051	80.58	45.58	35.00

Source: Computed by the Author

2.4 Conclusion

Proper water resource management is impossible without knowing the existing water demand and sources of supply in any urban area. The water demand is controlled by the pattern of water uses which is determined by the activities of the stakeholders. The AMC has 106 wards dominated by various activities. The pattern of water demand varies according to the major activities and associated life style of the people. The AMC has experienced a steady population growth that will remain same in future. The result of population prediction indicates that in 2051 the total population will be almost 28 million. The existing water supply by AMC is not sufficient for meeting the demand of the people. It is observed that there is a huge water demand and supply gap which is rising continuously. According to the population of 2011 census the demand supply gap is only 6mgd whereas in 2051 the gap will be almost 35mgd. Following the UN Sustainable goals it is really critical to ensure safe and clean drinking water for all the people of AMC without ensuring alternatives sources or increasing water use efficiency.

In calculating the demand and supply gap, as well as forecasting future water demand, only domestic water consumption has been considered, despite the substantial additional demand from industrial and agricultural sectors. This is because the water supplied by the AMC is primarily used for domestic purposes and very small-scale industries. Most large-scale industries operate their own water treatment facilities and collect water directly from groundwater or rivers separately. Similarly, agricultural water needs are largely met through direct rainfall and river water, rather than relying on AMC's supply. Therefore, industrial and agricultural water demands do not significantly affect the water supplied by AMC. For this reason, only domestic water demand has been taken into account in the calculation of the demand-supply gap and in predictions for future water demand.

This study highlights the significant challenge faced by the AMC regarding water security. The findings indicate an urgent need to rethink the water resource potential available to AMC in order to ensure sustainable water management. Without proactive measures, maintaining a reliable supply of safe and clean water for all residents could become increasingly difficult. To address this issue, it is critical to develop strategies that enhance the long-term sustainability of water resources, ensuring that AMC can meet future demands while safeguarding public health and well-being.

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CHAPTER-3

SURFACE WATER DYNAMICS AND INTERPLAY BETWEEN LAND SURFACE TEMPERATURE, VEGETATION COVER AND URBAN GROWTH

Abstract

Land surface temperature (LST), vegetation and water are very crucial for maintaining a healthy urban ecosystem. Asansol is one of the fast growing urban industrial agglomerations of West Bengal in Eastern India. In the last few decades the city has experienced a rapid urban industrial expansion along with the population growth which is associated with the continuous increase of LST and decrease of surface water bodies. Considering this this chapter has been designed to explain the dynamics of surface water bodies, vegetation cover and nature of LST changes over the last thirty years utilizing the Landsat imageries in GIS platforms. In this study for explaining the nature of changing surface water, land surface temperature, vegetation cover and their inter relationship in the last thirty years. Landsat 5TM images of May and October for the year 1990, 2000 and 2010 and Landsat 8 OLI images of May and October for 2020 have been utilized in GIS platform. LST and different indices NDVI, MNDWI and NDBI have been extracted for analyzing the nature of change along with image classification. The results of the study depict that LST is increasing continuously. In the first decade (1990 to 2000) LST increased at 0.24°C/year followed by an increasing rate of 0.33°C/year in the second decade (2000 to 2010) and 0.37°C/year in the last decade (2010 to 2020). Same trend is also perceived for built up area, where it increased at 0.96km^2/year, 1.71km^2/year, and 2.49km^2/year in corresponding decades. On the other hand, the vegetation cover is continuously decreasing (1.59km^2/year, 0.75km^2/year and 0.49km^2/year in consecutive decades) as well as the surface water bodies (0.62km^2/year in, 0.41km^2/year, and 0.25km^2/year in corresponding three decades) over the last thirty years. Correlation and regression analysis of land surface temperature and various indices shows positive relation between LST and NDBI, negative relation between LST and MNDWI, and also between LST and NDVI. Urban-industrial expansion is the important factor for increasing temperature and transforming vegetation and surface water bodies.

3.1. Introduction

It has been observed throughout the World that areas under surface water bodies(wetlands) and vegetation covered areas are extremely sensitive in terms of urban-industrial expansion although both of which have a significant importance for maintaining urban ecological balance. Over the last decades remote sensing data plays an important role in research of various disciplines. LST is the fundamental factor that controls the biological, chemical and physical methods on the earth (Pu et al., 2006). The LSTs taken out from satellite derived sensors have been used in several studies like heat-balance, climate modelling and observation of global change (Bhattacharya et al., 2010; Fall et al., 2010). Despite LST assessment, the TIR region of the electromagnetic spectrum has enormous prospective to determine land surface allied variations in any region, and is widely used in various segments in Earth science (Alexander, 2020; Khan et al., 2020).

Landsat imagery is very useful for interpreting the land surface temperature and the interrelationship between LST and various LULC indices. Relationship between LST and NDVI has been analysed using pre-monsoon Landsat images of various timespan in Raipur city of India, result of which shows a rising trend of land surface temperature and negative relation between LST and NDVI throughout the period of observation (Guha et al., 2020). The study of LULC Changes and LST of Saudi Arabian cities using Landsat images has shown that urbanization is associated with an increase in the land surface temperature over the last few decades (Rahman et al., 2017). Spatial variation of urban land surface temperature in Tehran city of Iran is greatly related to NDVI, LULC, altitude which has been analysed by utilizing the Landsat 8 imagery (Shafizadeh-Moghadam et al., 2020). A series of Landsat imageries have been utilised for understanding the influence of urbanization on surface urban heat island in sub-tropical desert cities including Beer Sheva in Israel, Hotan in China, Jodhpur in India, Kharga in Egypt, and Las Vegas in USA (Fan et al., 2017). Landsat images of different seasons have been utilized for the plotting of LST during 1990 to 2016 in Barrackpore city of West Bengal and various spatial indices including NDVI, NDBI and NDWI are also have been derived, the result of that studies shows a rising LST and negative association between LST and NDVI (Das et al., 2020).

Land use and land cover change and its impact on LST has been analysed using Landsat images of 1993 and 2018, result of which shows that temperature is increasing continuously due to the urban industrial and mining activities in Asansol Subdivision (Das et al., 2020). Land surface temperature study of Asansol Durgapur region using Landsat images over the period 1993 to 2015 shows that LST increases 0.06℃ yearly in winter and 0.43℃ yearly in summer (Choudhury et al., 2019).

Urbanization is categorized by the quick transformation of agrarian land, water bodies, and vegetation cover, into a settlement (Ding and Shi, 2013). The unprecedented modification of land use patterns sometimes creates serious environmental problems like Urban Heat Island. LST and UHI concepts are used to describe the varying nature of LULC pattern in diverse urban regions (Arnfield, 2003; Memon et al., 2008; Mirzaei, 2015; Rinner & Hussain, 2011; Zhao et al., 2016). Recently various LULC indices like NDVI, NDWI, NDBI are frequently used in LST associated studies to analysis their influence on fluctuating urban ecological status (Amiri et al., 2009; Kuang et al., 2015; Li et al., 2011; Peng et al., 2016; Song et al., 2014). For accommodating the fast growing urban population, the paved land cover has increased the effects of which is increased land surface temperature (Ramachandra, 2012). Urbanisation and industrialisation along with fast changes in land use/land cover are accountable for environmental problems like air pollution, water pollution, greenhouse gas emissions, and boosted urban heat islands (Shao et al., 2006; Chan and Yao, 2008). Rapid transformation of land use/land cover owing to urban expansion intensely affects biodiversity and ecosystem function, in addition to local and regional climate (Luck & Wu, 2002). LST differs based on surface reflectance and roughness of diverse land use/land cover pattern. Asansol Municipal Corporation has failed to maintain per capita share of green space in the context of sustainability (Siddique et al., 2020).

A comprehensive study on the nature of changing LST and transformation of vegetative land and surface water covered area and their inter relationship in Asansol Municipal Corporation (AMC) over the last thirty years is crucial for sustainable development. Asansol Municipal Corporation has been selected as the present study area due to the following reasons: 1. Asansol is the 2nd largest urban industrial agglomeration of West Bengal in Eastern India after Kolkata. 2. Coal mining activities play a vital role in the study area which is associated with the development of various kinds of small, medium and large industries. 3. Rapid urbanization and transformation of landuse and landcover are very prominent in Asansol Municipal Corporation along with rising population. 4. Urbanization, industrial expansion, land conversion all are highly related to land surface temperature change. This study will provide the answer of the following research questions- What is the status of surface water bodies ? What are the primary drivers of reducing surface water over last few decades? How does land use change impact the spatial distribution and connectivity of surface water bodies? The present study has been designed to achieve the following objectives: to assess the changes in Land Surface Temperature (LST) over the past three decades, analyse the transformation of vegetation cover and surface water bodies, and explain the interrelationship among LST, Normalized Difference Vegetation Index (NDVI), Modified Normalized Difference Water Index (MNDWI), and Normalized Difference Built-up Index (NDBI).

The present study will help to understand the methods of extracting LST and various spatial indices including NDVI, NDBI and MNDWI from Landsat imageries and how to explain the relationship between LST and various spatial indices. This study also will help the urban planner to rethink the policy regarding urban industrial expansion in different urban agglomerations in the world.

3.2. Materials and Methods

3.2.1. Acquiring Landsat 5TM and Landsat 8 OLI Images

Landsat 5TM images of May and October (1990, 2000 & 2010) and Landsat 8 OLI images of May and October (2020) have been derived from USGS Earth Explorer (Table 3.1). All the collected sets of data were pre-referenced with WGS84 datum and Universal Transverse Mercator Projection system but atmospheric and radiometric correction have been done in software environments (Erdas Imagine 2014).

3.2.2. Method of Extraction of LSTs

The LSTs for the months of May in 1990, 2000, 2010 & 2020 have been extracted from thermal band 6 of Landsat 5 and 10 of Landsat 8 images following the method previously used by different scholars and scientists. Detailed procedures for taking out of LST have been labelled in numerous literatures (Asgarian et al., 2015; Choudhury et al., 2019; Das et al., 2020; Ding & Shi, 2013; Govind & Ramesh, 2019). Following five steps have been performed systematically in ArcGIS 10.3 software for extracting the LST from thermal band.

Exchange of Digital Number (DN) into Top of Atmospheric (TOA) Radiance: Normally, the Landsat TM sensors capture reflected solar energy and convert these data to radiance following the rescaling into DN values. This is why it is essential to convert the DN values to TOA radiance. The formula given below has been utilized for calculating spectral radiance ($L\lambda$) from Landsat 5 imagery.

Lλ = Lminλ + [(Lmaxλ – Lminλ)/ (QCALmax – QCALmin)*QCAL]

Where,

QCALmin is1, Lmaxλ & Lminλ are the spectral radiances for the band 6(Lmaxλ = 15.303, Lminλ = 1.238), QCAL = Digital number of each pixel, QCALmax is 255

For calculating spectral radiance (Lλ) from Landsat 8 images following calculation has been used.

Lλ = ML*QCAL + AL

Where

Lλ = Spectral Radiance of atmospheric top

ML = band specific multiplicative factor of rescaling (0.0003342)

QCAL = Quantized and calibrated value of Standard Product Pixel (band 10 image)

AL = band specific additive factor of rescaling (0.1)

Table 3.1: Details of Image Specification

Satellite	Sensor	Path/Row	Year	Month	Bands	Resolution	Wavelength
Landsat-8	OLI & TIRS(Operational Land Imager and Thermal Infrared Sensor)	139/44	2020	May & October	Band 1-Coastal aerosal	30	0.43-0.45
					Band 2-Blue	30	0.45-0.51
					Band 3-Green	30	0.53-0.59
					Band 4-Red	30	0.64-0.67
					Band 5- Near Infrared(NIR)	30	0.85-0.88
					Band 6- SWIR 1	30	1.57-1.65
					Band 7- SWIR 2	30	2.11-2.29
					Band 8- Panchromatic	15	0.50-0.68
					Band 9- Cirrus	30	1.36-1.38
					Band 10- Thermal Infrared(TIRS) 1	100	10.6-11.19
					Band 11- Thermal Infrared(TIRS) 2	100	11.50-12.51
Landsat-5	Thematic Mapper	139/44	1990, 2000 & 2010	May & October	Band 1-Visible Blue	30	0.45 - 0.52
					Band 2- Visible Green	30	0.52 - 0.60
					Band 3-Visible Red	30	0.63 - 0.69
					Band 4-NIR	30	0.76 - 0.90
					Band 5- SWIR 1	30	1.55 - 1.75
					Band 6-Thermal	120	10.40 - 12.50
					Band 7- SWIR 2	30	2.08 - 2.35

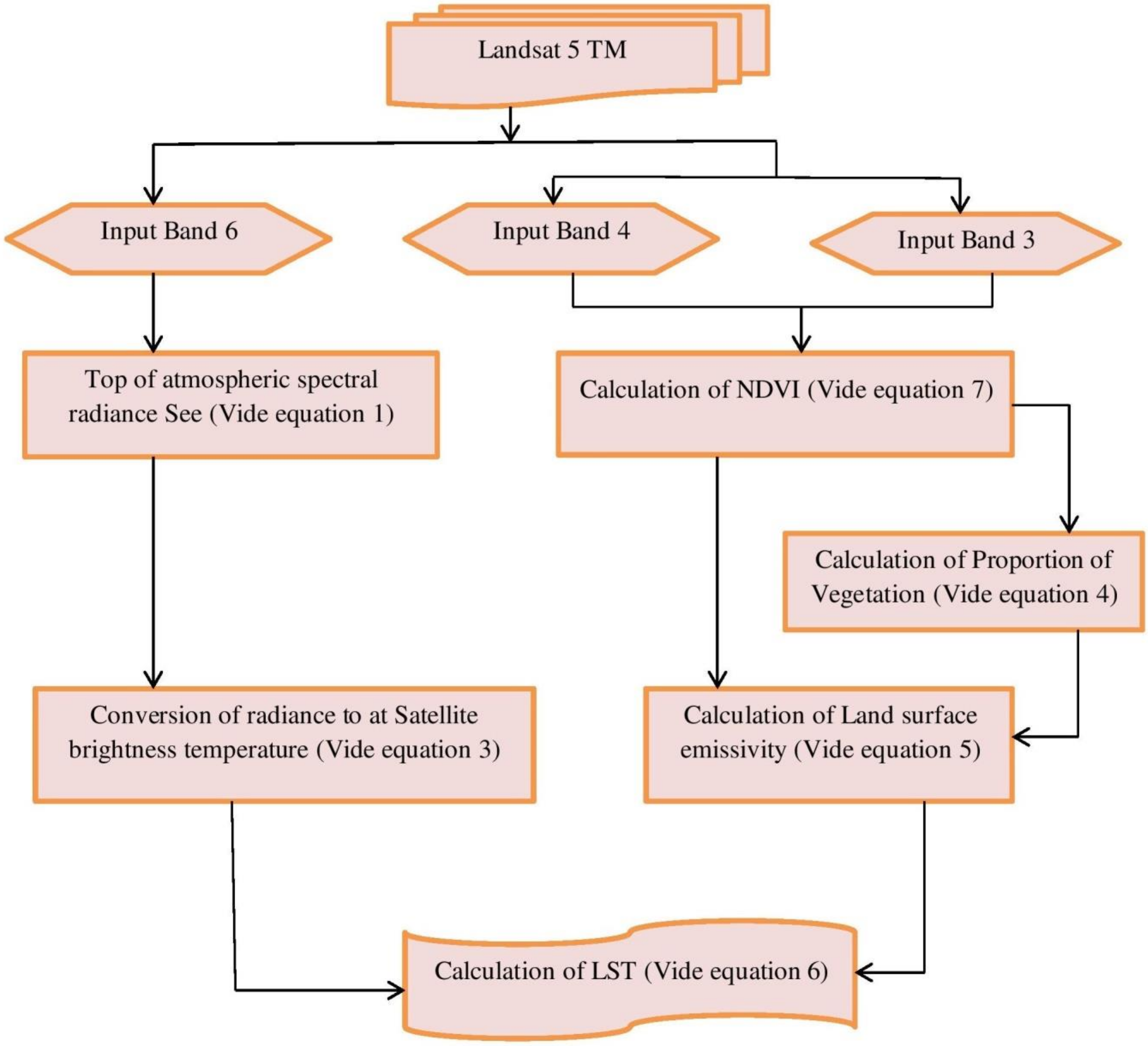

Fig.3.1: Extraction of LST from Landsat 5 TM imageries

Conversion of spectral radiance to At-satellite brightness temperature (BT): Brightness temperature indicates the blackbody temperature. It is required to convert the spectral radiance to at satellite brightness temperature for extracting the LST from Landsat images. Equation given below has been applied for converting radiance to brightness temperature (BT).

$$BT = \left(\frac{K2}{In[(\frac{K1}{L\lambda})+1]}\right) - 273.15$$

Where

BT = At-satellite brightness temperature

K_1 = Band Constant (774.8853 for band 10 of Landsat 8)

K_2 = Band Constant (121.0789 for band 10 of Landsat 8)

$L\lambda$ = TOA spectral radiance [see equation (1)]

273.15 is used for converting temperature (Kelvin to Celsius).

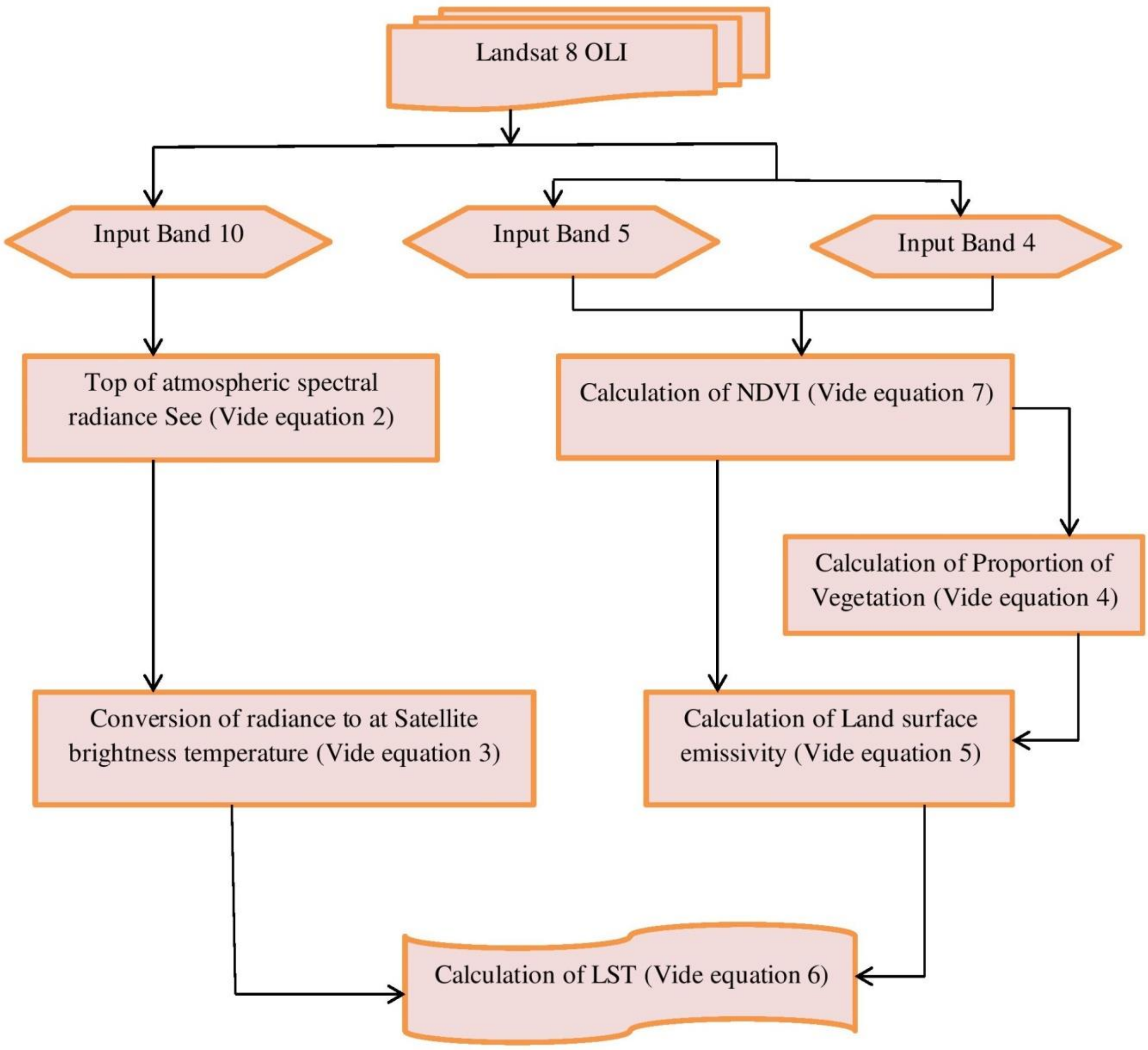

Fig.3.2: Extraction of LST from Landsat 8 OLI imageries

Proportion of vegetation (Pv): Accurate estimation of land surface emissivity is crucial for predicting the LST. There are several approaches to calculate land surface emissivity among which the NDVI threshold approach requires the calculation of proportion of vegetation. Proportion of vegetation can be found from NDVI applying subsequent equation (Pv).

$$Pv = [(NDVI - NDVI_{min})/(NDVI_{max} - NDVI_{min})]^2$$

Land surface emissivity (e): As land surface emissivity is the indicator of material composition it is important to calculate the land surface emissivity for predicting LST from Landsat images. Now, it is easy to find corrected emissivity by applying the given equation (e).

$$e = 0.0004*Pv + 0.986$$

Land Surface Temperature (LST): Finally, next formula is applied for calculating ground surface temperature (Fig 3.3).

$$LST = \frac{BT}{[1 + \{\left(\lambda * \frac{BT}{\rho}\right) * Ln(e)\}]}$$

Where, LST = Land surface temperature, λ = wavelength of emitted radiance, $\rho = h*c/\sigma$ ($1.438*10^{-2}$ m K), σ = Boltzmann constant ($1.38 * 10^{-23}$ J/K), h = Planck's constant ($6.626 * 10^{-34}$ J s), e= emissivity, c = light velocity ($2.998 * 10^{8}$ m/s).

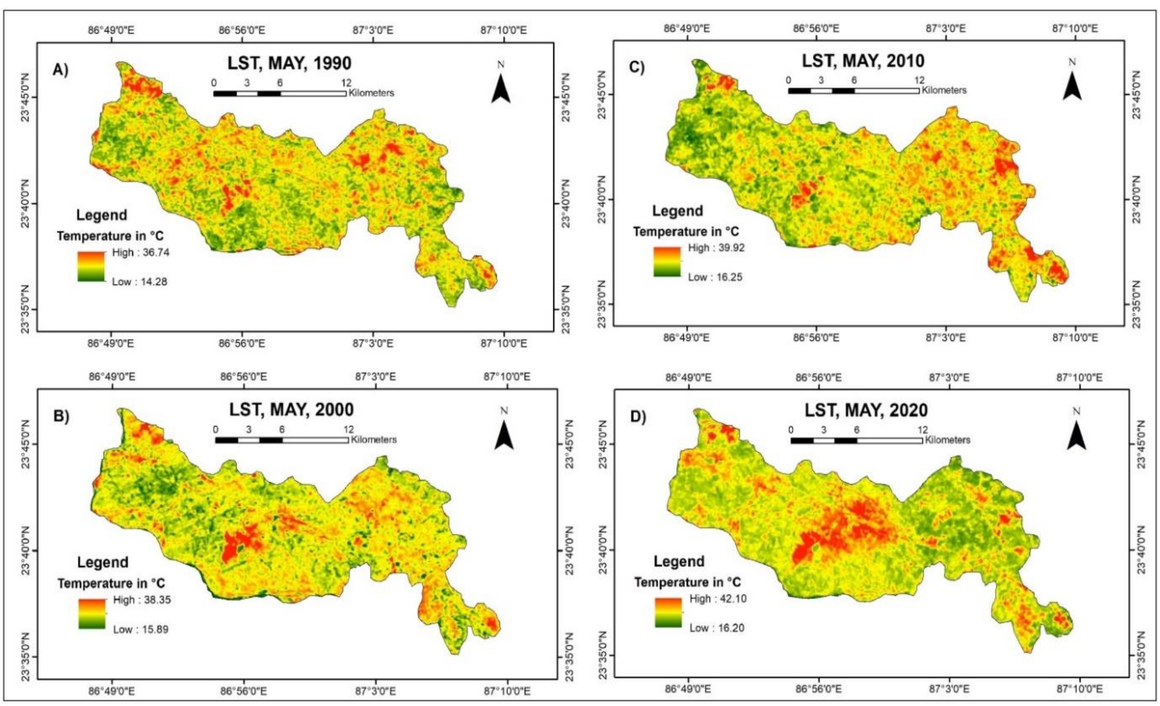

Fig.3.3: A) LST map of May, 1990 B) May, 2000 C) May, 2010 D) May, 2020

3.2.3. Methods for computing different spatial indices

Normalized Difference Vegetation Index (NDVI) is a popular technique for estimating the density of vegetation on the basis of the difference between visible and near infrared reflectance of vegetation cover which has been extracted by the following method in ArcGIS 10.3 (Townshend & Justice, 1986).

$$\text{NDVI} = \frac{(\textbf{NIR Band} - \textbf{R Band})}{(\textbf{NIR Band} + \textbf{R Band})}$$

Using the reflectance values from the red and near-infrared bands, the NDVI formula is applied pixel-by-pixel across the image to generate an NDVI map. The values of NDVI typically range from **-1 to +1**:

- ❖ Negative values (close to -1) correspond to non-vegetated surfaces, such as water, snow, or barren land.
- ❖ Values close to 0 indicate bare soil or sparsely vegetated areas.
- ❖ Positive values (between 0.2 and 1) represent increasing levels of healthy, dense vegetation.

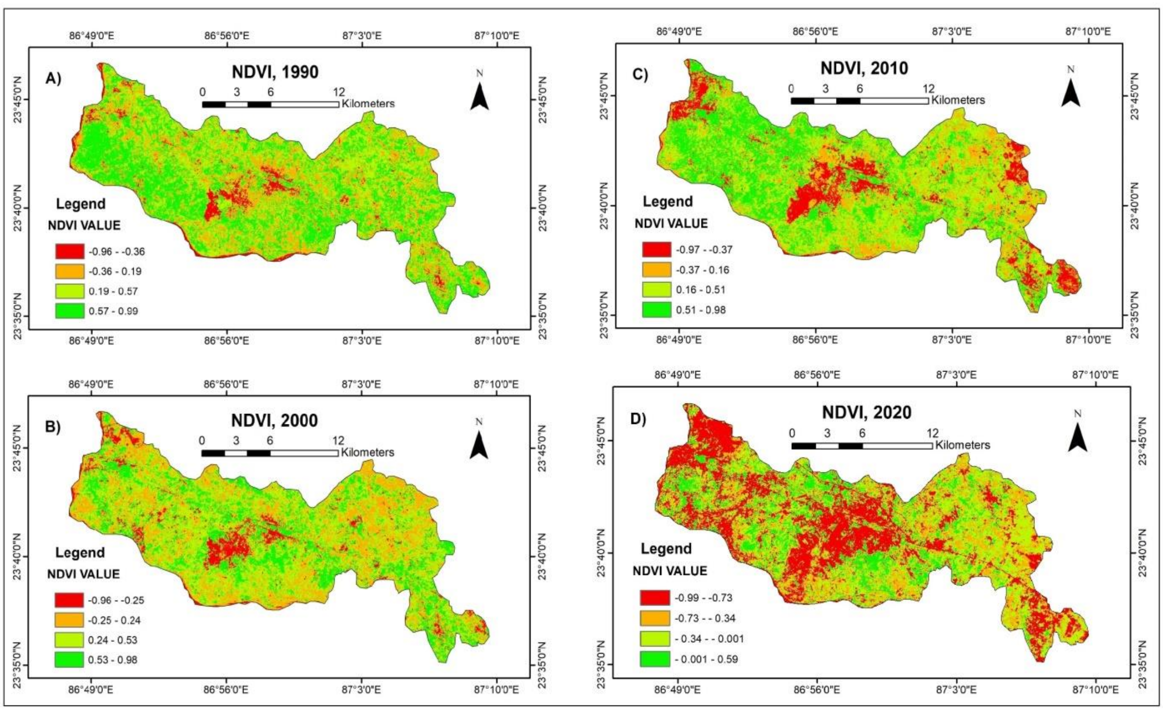

Fig.3.4: A) NDVI map of 1990 B) 2000 C) 2010 D) 2020

Normalized Difference Water Index (NDWI) is useful for identifying the surface water bodies. It is observed that sometimes NDWI fails to give good quality results, a consequence of which is the development of Modified Normalized Difference Water Index by Xu, 2005. The following formula is used to calculate MNDWI (Xu, 2005).

.

$$\text{MNDWI} = \frac{(\textbf{Green band} - \textbf{SWIR band})}{(\textbf{Green band} + \textbf{SWIR BAND})}$$

The MNDWI formula is applied pixel-by-pixel to the satellite image, comparing the reflectance in the green and SWIR bands. The resulting values typically range from -1 to +1:

- ❖ Positive values (closer to 1) indicate water bodies, as water reflects green light but absorbs SWIR.
- ❖ Negative values (closer to -1) correspond to non-water surfaces such as built-up areas, vegetation, and bare land.

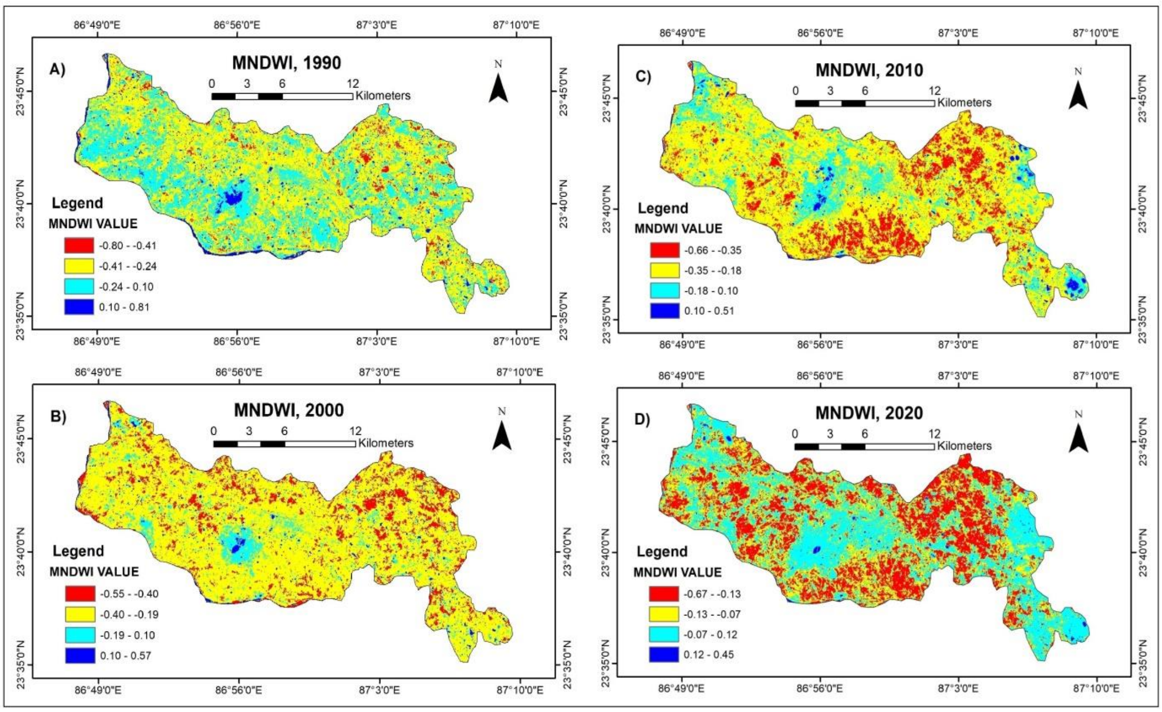

Fig.3.5: A) MNDWI map of October, 1990 B) October, 2000 C) October, 2010 and D) October, 2020

Normalized Difference Built up Index (NDBI) is another spatial index from which we can analyse the pattern of built-up area. For deriving NDBI value from satellite imagery the following formula has been used (Zha et al., 2003).

$$\text{NDBI} = \frac{(\boldsymbol{SWIR\ band - NIR\ band})}{(\boldsymbol{SWIR\ band + NIR\ band})}$$

The NDBI formula is applied pixel-by-pixel to the image, comparing the reflectance values from the SWIR and NIR bands. The resulting NDBI values typically range from -1 to +1:

- ❖ Positive values (closer to +1) indicate built-up or developed areas.
- ❖ Negative values (closer to -1) indicate non-built-up land covers such as vegetation or water bodies.

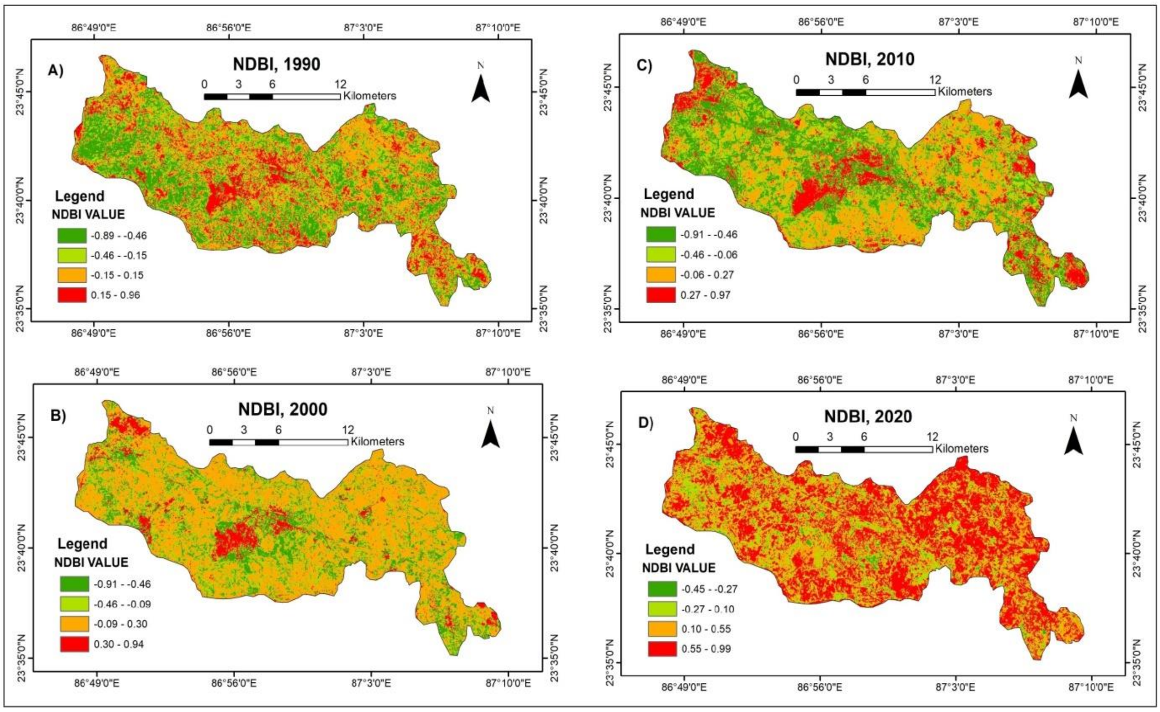

Fig.3.6: A) NDBI map of 1990 B) 2000 C) 2010 D) 2020

3.2.4. Accuracy assessment method of land use classes

In present work, accuracy calculation has been done by using a confusion matrix or error matrix based on the identification of real and expected values of pixels (Jupp, 1989; Pal & Ziaul, 2017). One hundred and sixty five sample places have been carefully chosen from Google earth and matched them with the LULC map for confirmation. For calculating the overall accuracy the following equation has been utilized.

$$T = \frac{\Sigma Dii}{N}$$

where,

T = Overall accuracy, ΣDii = Total number of pixels which are correctly classified, N = Total number of pixels in data matrix. Producer's and User's accuracy assessment have been identified by applying given formulas (Story & Congalton, 1986).

$$\text{Producer's accuracy} = \frac{Diagonal\ value\ of\ column}{Column\ total} \times 100$$

$$\text{User's accuracy} = \frac{\text{Diagonal value of row}}{\text{Row total}} \times 100$$

Kappa coefficient is more sophisticated than overall accuracy (Das et al., 2020; Foody, 1992; Pal & Ziaul, 2017). The following formula has been used for finding the Kappa coefficient value.

$$\text{Kappa co-efficient (K)} = \frac{\frac{\Sigma a}{N} - \Sigma ef}{1 - \Sigma ef}$$

where,

a = Diagonal frequency, N = Total number of frequency, ef = expected frequency.

$$\text{Expected frequency (ef)} = \frac{\text{Row total x Column total}}{N}$$

The K value ranges between 0 to 1 indicating 1 as almost perfect agreement and 0 as poor agreement (Landis & Koch, 1977).

3.2.5. Methods for calculating rate of change and Regression analysis

For the measurement of the last thirty years' trend of rising temperature grid wise extracted values of LST for each year (1990, 2000, 2010 and 2020) have been used by incorporating statistics and raster calculator tools in ArcGIS 10.3 Software (Table 3.2). For analysing the change of surface water bodies, vegetation and built up area, single feature supervised image classification techniques incorporating the associated spatial indices (MNDWI for water bodies, NDBI for built up area and NDVI for vegetation) for each year have been performed separately for surface water bodies, vegetation and built up area using Erdas Imagine 2014 software (Fig 3.8, 3.9 & 3.10). Accuracy assessment (Kappa Co-efficient) has been done using Google earth for each year separately (Table 3.2). Finally, on the basis of these maps aerial changes have been computed (Table 3.4).

ArcGIS and MS-Excel both have been used for correlation and regression analysis between LST and spatial indices. Following two steps have been performed-1. Firstly values of LST, NDVI, NDBI and MNDWI have been extracted using a reference grid (Fig.3.7) in ArcGIS utilizing the extract multi values to point tools from the extraction tool under Spatial Analyst Tools. 2. Finally, grid wise extracted values of LST, NDVI, NDBI and MNDWI from the respective attribute table have been used for calculating correlation and regression in the MS-Excel environment (Fig.3.11).

Table 3.2: Accuracy Assessment

Year	Land use Category	Built up area	Vegetation	Water body	Others	Total	User's Accuracy	Kappa Co-efficient
1990	Built up area	47	2		1	50	94.00	
	Vegetation	1	47		2	50	94.00	
	Water body		1	34		35	97.10	0.92
	Others	1		1	28	30	93.30	
	Total	49	50	35	31	165		
	Producer's Accuracy	95.90	94.00	97.10	90.30			
	Over all Accuracy	94.55						
2000	Built up area	46	1	1	2	50	92.00	
	Vegetation	1	48	1		50	96.00	
	Water body		1	33	1	35	94.29	
	Others	1	1		28	30	93.30	
	Total	48	51	35	31	165		0.91
	Producer's Accuracy	95.84	94.10	94.29	90.32			
	Over all Accuracy	93.94						
2010	Built up area	45	2	1	2	50	90.00	
	Vegetation	2	46	1	1	50	92.00	
	Water body	1	1	32	1	35	91.40	0.88
	Others	1	1	1	27	30	90.00	
	Total	49	50	35	31	165		
	Producer's Accuracy	91.84	92.00	91.43	87.10			
	Over all Accuracy	90.91						
2020	Built up area	47	1		2	50	94.00	
	Vegetation	1	45	2	2	50	90.00	
	Water body	1	1	31	2	35	88.57	0.87
	Others	1	1	2	26	30	86.67	
	Total	50	48	35	32	165		
	Producer's Accuracy	94.00	93.75	88.57	81.25			
	Over all Accuracy	90.30						

Source: Calculated by the Author

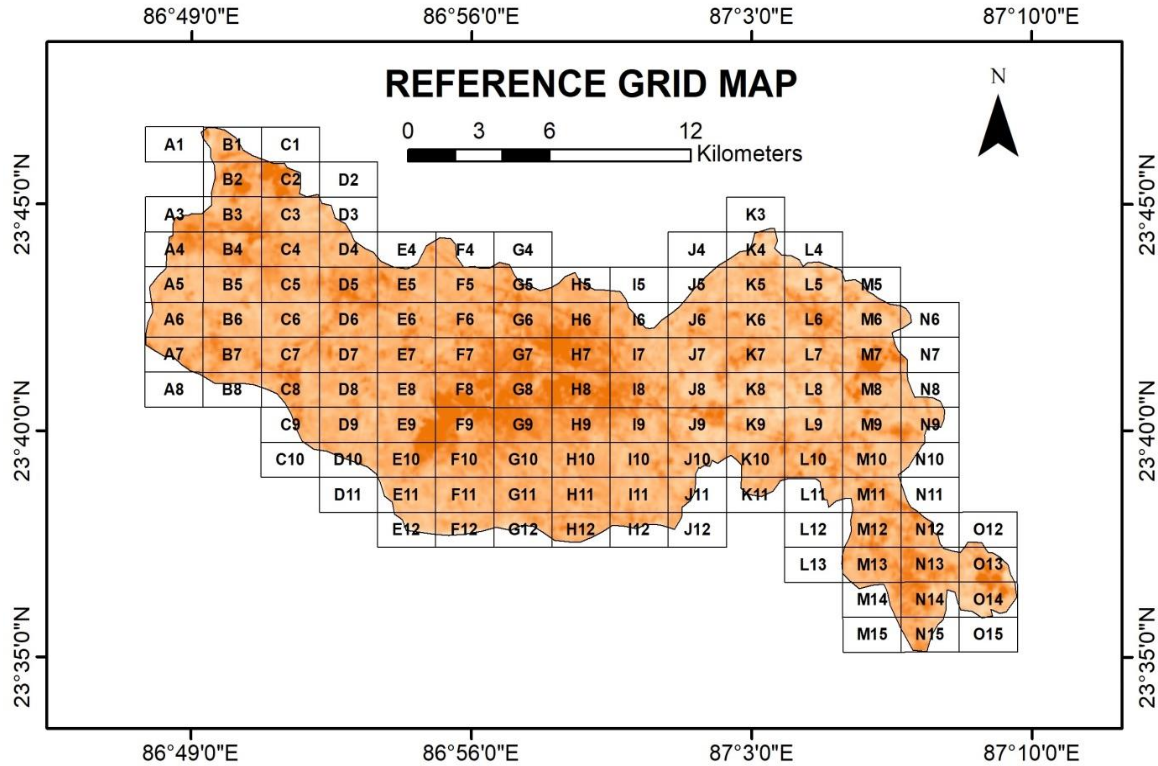

Fig.3.7: Grid map of the study area

3.3. Results and Discussion

3.3.1. Analysis of LSTs change

For the analysis of the nature of LST change in the last thirty years of Asansol Municipal Corporation (AMC) LST maps of May, 1990, 2000, 2010 and 2020 have been prepared separately (Fig. 3.3). In general, a rising trend of temperature is found for each year. It is clear from the maps of LST that maximum range of temperature has changed from 36.74℃ to 38.35℃ in between 1990 to 2000, 38.35℃ to 39.92℃ in between 2000 to 2010 and from 39.92℃ to 42.10℃ during 2010 to 2020. Minimum range of temperature has also increased except for the last decade. For calculating the rate of increasing temperature, a reference grid map (Fig.3.7) has been used for extracting the temperature values in ArcGIS platform. Rate of temperature change during 1990 to 2000, 2000 to 2010 and 2010 to 2020 have been calculated separately (Table 3.3). It is observed that the rate of rising temperature varies during the three decades. In the first decade, temperature has increased at a rate of 0.24℃ yearly whereas the increasing rate of temperature in the second decade is 0.33℃/year. In

Table 3.3: Calculation of Land Surface Temperature Change

Temperature change	1990 -2000			2000-2010		2010-2020	
Grid	LST in °C May,1990	LST in °C May,2000	Difference	LST in °C May,2010	Difference	LST in °C May, 2020	Difference
A5	22.603	24.294	1.691	25.145	0.851	31.663	6.518
A6	21.470	21.712	0.242	25.254	3.542	31.775	6.521
B4	20.368	22.184	1.815	22.956	0.772	30.339	7.383
B5	21.905	24.123	2.218	24.001	-0.122	26.554	2.553
B6	22.110	22.265	0.155	23.125	0.860	24.254	1.129
C4	19.416	21.187	1.771	22.520	1.333	30.557	8.037
C5	20.116	22.801	2.685	23.652	0.851	30.857	7.205
C6	18.904	21.119	2.215	23.257	2.138	29.995	6.738
C7	19.648	23.009	3.361	26.552	3.543	29.850	3.298
D6	20.439	23.689	3.250	26.536	2.847	30.599	4.063
D7	20.782	22.480	1.698	27.100	4.620	30.457	3.357
D8	21.446	22.790	1.343	26.996	4.206	29.214	2.218
E6	19.627	23.705	4.078	25.025	1.320	30.859	5.834
E7	19.866	23.588	3.722	27.569	3.981	30.786	3.217
E8	19.932	24.107	4.175	28.253	4.146	31.120	2.867
E9	19.658	23.193	3.536	28.352	5.159	31.254	2.902
F6	19.842	23.290	3.447	27.254	3.964	31.225	3.971
F7	27.025	29.125	2.100	31.210	2.085	33.257	2.047
F8	28.124	29.453	1.329	31.215	1.762	34.125	2.910
F9	19.847	23.748	3.901	24.102	0.354	24.200	0.098
F10	19.249	23.099	3.849	23.000	-0.099	25.254	2.254
G6	27.420	29.235	1.815	30.544	1.309	34.352	3.808
G7	29.125	30.254	1.129	30.589	0.335	34.201	3.612
G8	28.125	31.100	2.975	31.100	0.000	35.125	4.025
G9	19.797	22.642	2.845	30.995	8.353	33.254	2.259
G10	19.790	22.284	2.493	30.554	8.270	34.335	3.781
H6	21.703	24.520	2.817	29.425	4.905	34.334	4.909
H7	22.320	23.746	1.426	29.245	5.499	34.320	5.075
H8	23.024	24.123	1.099	29.112	4.989	33.995	4.883
H9	24.254	23.050	-1.204	28.996	5.946	33.558	4.562
H10	23.025	23.588	0.563	23.550	-0.038	28.298	4.748
I7	27.200	29.420	2.220	31.123	1.703	33.997	2.874
I8	27.120	28.890	1.770	31.100	2.210	33.989	2.889
I9	19.425	22.778	3.353	30.235	7.457	33.994	3.759
I10	19.285	22.079	2.794	30.998	8.919	33.457	2.459
J7	19.662	22.163	2.501	28.995	6.832	31.547	2.552
J8	19.811	22.642	2.831	28.856	6.214	32.869	4.013
J9	20.276	24.269	3.993	28.556	4.287	32.854	4.298
K6	21.302	25.377	4.075	28.253	2.876	31.995	3.742
K7	21.325	24.752	3.427	27.998	3.246	30.998	3.000
K8	19.755	22.716	2.961	27.126	4.410	30.587	3.461
K9	19.016	22.010	2.993	26.996	4.986	26.998	0.002
L7	21.749	25.311	3.562	26.268	0.957	29.532	3.264
L8	19.967	22.311	2.344	24.247	1.936	29.996	5.749
L9	20.432	24.429	3.997	26.876	2.447	29.887	3.011
M9	19.280	22.935	3.655	28.500	5.565	29.220	0.720
M10	19.107	21.975	2.868	28.560	6.585	31.956	3.396
N13	26.143	26.452	0.309	28.254	1.802	31.254	3.000
N14	26.035	26.500	0.465	28.548	2.048	30.998	2.450
O14	19.145	22.550	3.405	25.480	2.930	29.254	3.774
Rate of increased	0.24°C/Year			0.33°C/Year		0.37°C/Year	

Source: Computed by the author using Arc GIS 10.3 and MS-Excel

last decade, the rate of increasing temperature is 0.37℃/year. The rate of temperature change in different decades indicates a steady increase of temperature. It is evident from previous literature that land use/land cover transformation associated with urban-industrialization processes is highly responsible for rising temperature (Choudhury, et al., 2018; Das, et al., 2020).

3.3.2. Analysis of change of surface water bodies, vegetation and built up area

For identifying the temporal change of surface water bodies four separate post monsoon (October) maps for the year 1990, 2000, 2010 and 2020 (Fig.3.8) have been prepared incorporating the algorithms of MNDWI (Fig.3.5) in software environment. Finally, area under surface water coverage has been calculated for each year. It is observed that surface water bodies are constantly decreasing which indicates the severe transformation of water bodies. In the first decade, the rate of decreasing surface water bodies is 0.62km^2/year whereas in the second decade, the rate is 0.41km^2/year. Ultimately, in the last decade it has been reduced to 0.25km^2/year (Table 3.4). In 1990 total area under surface water bodies was 17.32km^2 whereas in 2020 only 4.58km^2 is found which is very alarming in the context of maintaining urban ecology, specifically water resource management.

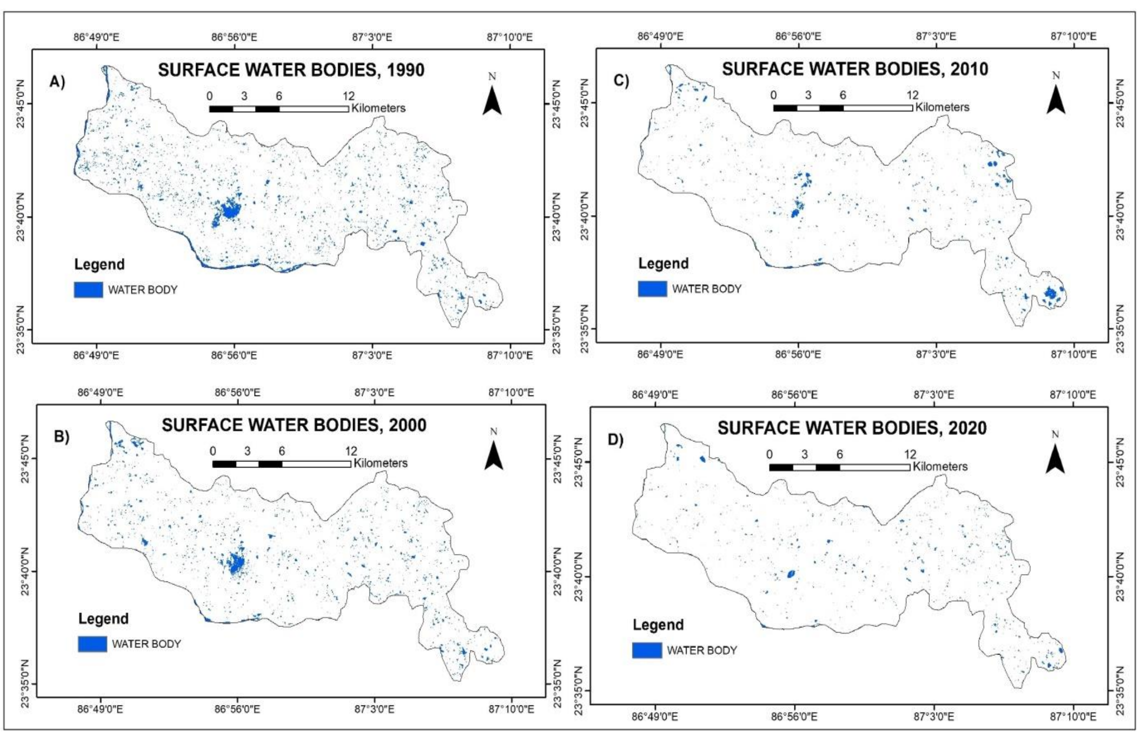

Fig.3.8: A) Surface water coverage map of October, 1990 B) October, 2000 C) October, 2010 D) October, 2020

Similar techniques have been applied also for the preparation of vegetation cover maps of October, 1990, 2000, 2010, and 2020(Fig.3.9) followed by the preparation of built up area maps (Fig.3.10). A decreasing trend of vegetation cover is observed comparing the calculated area under vegetation in different years (Table.3.4). In the first decade, vegetation cover has decreased at 1.59km^2/year whereas in the second decade the rate is 0.75km^2/year. Ultimately in the last decade the transforming rate is 0.49km^2/year (Table.3.4).

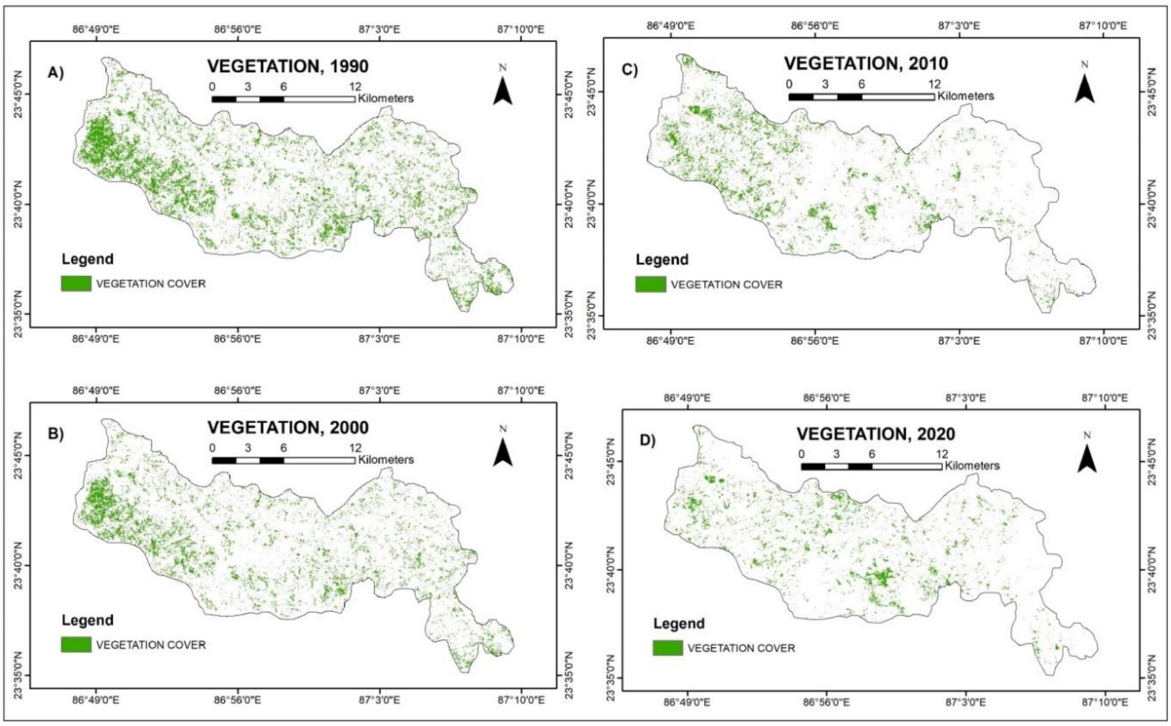

Fig.3.9: A) Vegetation covers map of October, 1990 B) October, 2000 C) October, 2010 D) October, 2020

On the other hand, it is found that built up areas are continuously increasing over the last thirty years which is nothing but a symbol of urban-industrial expansion of the study area. Total built up area in 1990 was only 25.59km^2 but in 2020 built up area is 77.29km^2. Great variation is observed in expansion of built up area during the last thirty years. In the first decade, the expansion rate of built up area was only 0.96km^2 yearly whereas in the last decade, 2.49km^2 yearly expansion is observed (Table.3.4). In the middle phase the built up area has increased at 1.71km^2/year.

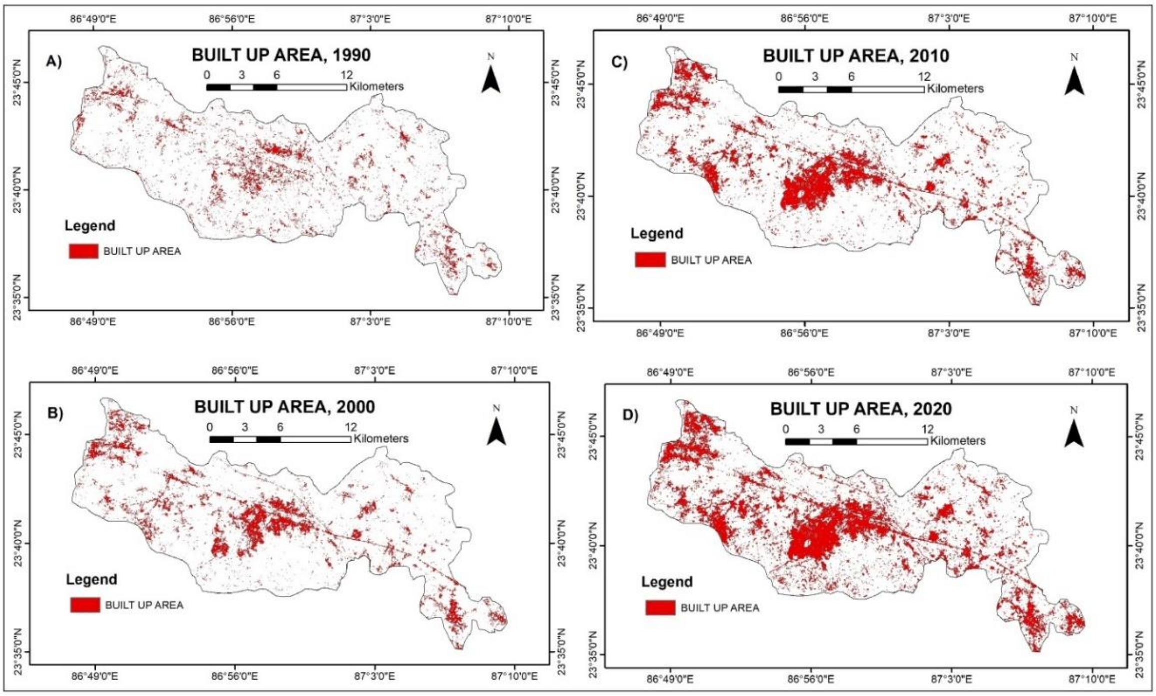

Fig.3.10: A) Built- up area map of 1990 B) 2000 C) 2010 D) 2020

Table 3.4: Rate of changing Built up area, Vegetation and Water bodies

Area under Vegetation(Km^2)		**Change (km^2)**	**Area under Water bodies(km^2)**		**Change (km^2)**	**Built up area(Km^2)**		**Change (km^2)**
1990	2000	-15.88	1990	2000	-6.16	1990	2000	9.68
48.54	32.66		17.32	11.16		25.59	35.27	
Decreasing at 1.59km^2/year			**Decreasing at 0.62 km^2/year**			**Increasing at 0.96 km^2/year**		
1990	2010	-7.54	2000	2010	-4.09	2000	2010	17.08
32.66	25.12		11.16	7.07		35.27	52.35	
Decreasing at 0.75km^2/year			**Decreasing at 0.41km^2/year**			**Increasing at 1.71 km^2/year**		
2010	2020	-4.87	2010	2020	-2.49	2010	2020	24.94
25.12	20.25		7.07	4.58		52.35	77.29	
Decreasing at 0.49km^2/year			**Decreasing at 0.25km^2/year**			**Increasing at 2.49 km^2/year**		

Source: Computed by Author using Arc GIS 10.3

3.3.3. Analysis of Association between LST and others spatial indices

It is clear from the correlation and regression analysis, the LST is highly positively associated with NDBI (r = 0.91 for the year 2010 and 0.88 for 2020 and R^2= 0.89 and 0.89 respectively) (Table.3.5 and Fig.3.11). The association between LST and NDVI is negative for each year which is evident from r and R^2 values (r = -0.90 in 2010 and -0.87 in 2020, R^2=0.85 and 0.77). Similarly strongly negative association is observed between LST and MNDWI (r = -0.92 in 2010 and -0.93 in 2020, R^2=0.85 and 0.88). All the correlations are significant at 0.01 levels (2-tailed). One of the interesting facts is observed here that the degree of negative relationship between LST and NDVI has slightly decreased in 2020(r = -0.90 in 2010 and -0.87 in 2020).

The same trend is also found for the relationship between LST and NDBI which is cleared from r value of 2010 and 2020(r =0.91 and 0.88). But in the case of relation between LST and MNDWI, the degree of association has slightly increased in 2020 from 2010(r =-0.92 and -0.93). By comparing the grid wise extracted LST and MNDWI values from LST maps and MNDWI maps and which have been prepared for 1990, 2000, 2010 and 2020 (Fig 3.3 & 3.5), it is also concluded that there is significant negative relation between LST and surface water bodies. Accordingly the positive relation between LST and NDBI and negative relation between LST and NDVI are also established by analysing the grid wise extracted values of LST, NDBI and NDVI from series of NDBI,NDVI and LST maps of 1990, 2000, 2010 and 2020(Fig 3.3, 3.4 & 3.6). Finally, high negative association between LST and MNDWI is depicted also from r and R^2 values (r =-0.92 for 2010 and -0.93for 2020, R^2= 0.85 and 0.88 respectively). From the previous discussion it is proved that the vegetation covers and surface water bodies in AMC are decreasing on a regular basis which area is considered as the pervious surfaces having low temperature. Alternatively, the built up area is continuously increased which ultimately helps to create impervious surfaces having high temperature.

Table 3.5: Product Moment Coefficient of Correlation

	2010			2020		
	NDVI	MNDWI	NDBI	NDVI	MNDWI	NDBI
LST	-0.90	-0.92	0.91	-0.87	-0.93	0.88
All the correlations are significant at 0.01 level(2- tailed)						

Source: Computed by the author in SPSS

From the trend of land conversion, it is concluded that a major part of surface water bodies and vegetative land have been converted into built up areas (settlement, industry, commercial complex etc.) as last decade built up area increased at 2.49km^2/year. From the correlation and regression analysis it is evidenced NDVI and MNDWI are negatively associated with LST, which indicates that a significant portion of vegetation and surface water body is required to control the surface temperature. On the other hand, as NDBI is positively associated with LST, there should be at least some control over urban industrial expansion within the premises of AMC. Land transformation accompanied with rapid urbanisation is mainly responsible for mounting LST in the last thirty years.

Land surface temperature of Asansol Urban Area is constantly rising but comparative studies of LST proved that the yearly rate of temperature change is also gradually increasing at different rates. In the study of LST during 1993 to 2018 yearly rates of increasing temperature were 0.15℃ in winter and 0.19℃ in summer (Das et al., 2020). The present study depicts that in the first decade, temperature has increased at a rate of 0.24℃ yearly, and the increasing rate of temperature in the second decade is 0.33℃/year. In the last decade, the rate of increasing temperature is 0.37℃/year. It is evident that the rate of temperature change during different time periods in Asansol Municipal Corporation varies based on expansion of different kinds of urban industrial activities.

The present study has the following limitations: 1.The spatial resolution of thermal bands of Landsat 5 and Landsat 8 are 120m and 100m respectively but they are delivered by USGS as 30m after cubic convolution resampling which may create an error on accuracy of the result. 2. LST extraction from satellites is a very challenging process due to the variability of earth surfaces and requires a proper knowledge about the atmospheric conditions, sensor specification (spectral resolution, spatial resolution, viewing angle, signal to noise ratio etc.). 3. The present work also is not free from some inherent errors related to image capturing.

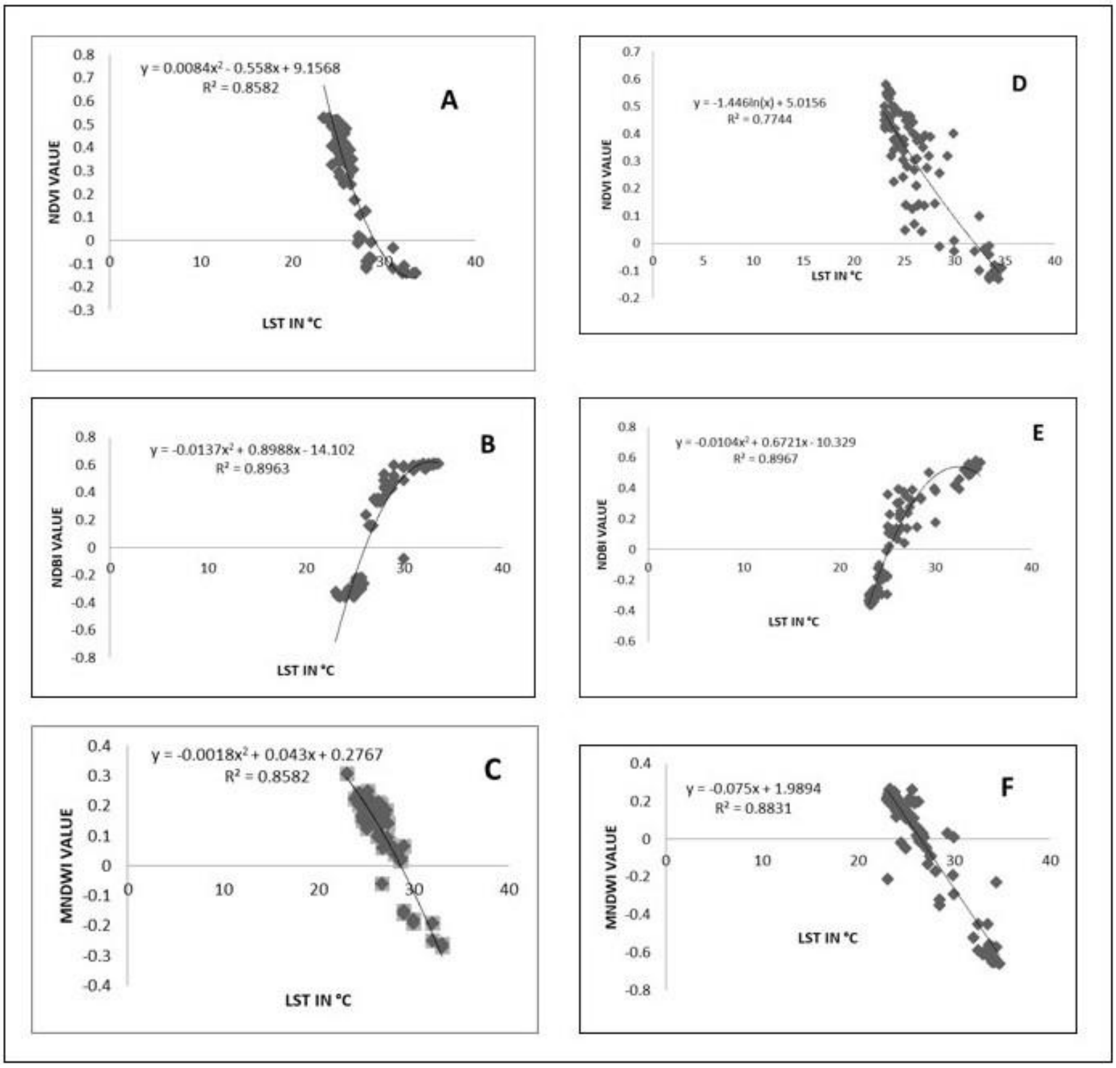

Fig.3.11: A) Regression analysis of NDVI on LST in 2010 B) NDBI on LST in 2010 C) MNDWI on LST in 2010 D) NDVI on LST in 2020 E) NDBI on LST in 2020 F) MNDWI on LST in 2020

3.4. Conclusion

Surface water bodies and vegetation are two essential parts of the ecosystem for any area; both are under threat along with alarming LSTs. The total area under vegetation cover in AMC was 48.54km^2 in 1990 whereas only 20.25 km^2 is observed in 2020. The rate of decreasing vegetation cover was 1.59km^2/year during 1st decade whereas in the last decade the rate is 0.49km^2/year. The total area under surface water bodies was 17.32 km^2 in 1990 but in 2020 existing area under surface water is only 4.58 km^2. On the other hand total built up areas were only 25.59 km2 in 1990 whereas in 2020 77.29 km^2 areas are observed in AMC. Increasing rate of built up area was 0.96km^2 yearly during 1900 to 2000 but the increasing rate is 1.71km^2/year during 2010 to 2020. The maximum range of temperature during 1990 was 36.74°C in AUA but in 2020 it is 42.10°C. Temperature has been rising continuously but at varying rates starting from 0.24°C yearly in 1st decade and 0.33°C yearly during the last decade. A negative association between LST and NDVI is observed. Similarly a negative association between LST and MNDWI is also observed in this study area but a positive association between LST and NDBI is found in AMC. Land surface temperature rising at 0.37°C/year in the last decade is really a warning for the ecological health of AMC. Conversion of surface water bodies into built up or any other form is another menace followed by the conversion of vegetative land.

The surface water bodies in Asansol are experiencing a concerning decline, primarily due to rapid urbanization, industrialization, and over-extraction of water resources. Once abundant, these natural water sources are shrinking or disappearing, unable to keep pace with the city's escalating water demand. Asansol, a growing industrial hub, witnesses significant pressure on its water resources, with increasing consumption from both domestic and industrial sectors. Additionally, pollution from industrial effluents and urban waste has further degraded these water bodies, rendering them unfit for use.

The reduction in surface water is exacerbating the water scarcity in Asansol, forcing reliance on groundwater, which is also depleting rapidly. This unsustainable water management, coupled with insufficient replenishment of surface water bodies, poses a significant challenge. Without urgent measures to restore and preserve these water bodies, Asansol may face severe water shortages in the near future, threatening its economic and social stability.

Escalating LST and disorganised land alteration is a potential threat for the sustainable future of Asansol. There is an urgent need to review the existing policies regarding land transformation considering the growing land surface temperature and associated problems. It should be better to include the nature of LST, conversion of vegetation and water bodies as essential parts of urban planning.

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DELINEATING GROUNDWATER POTENTIAL ZONES OF ASANSOL MUNICIPAL CORPORATION USING AHP AND FR MODEL

Abstract

Excessive withdrawals of groundwater for meeting the diverse socio-economic demand of modern communities have made the ecological health of aquifers most critical all over the world. The present chapter has been designed to assess the groundwater potentiality of Asansol Municipal Corporation (AMC) in Paschim Burdwan district of West Bengal. Two popular methods, AHP and FR have been applied for to examine the groundwater potentiality by utilizing nine thematic layers which include geology, slope, geomorphology, rainfall, drainage, lineament, vegetation, soil texture and land-use/land-cover in GIS environment. Receiver Operating Characteristics (ROC) curve has been prepared based on fifty observation wells data for validating the results of both methods. A significant difference has been observed between the results of two methods. The distributional pattern of groundwater potential areas by AHP method portrays that only 5.15% area comes under very high potential zone, whereas FR model shows that 9.85% area comes under very high potential zone. The result of validation based on area under curve (AUC) proves that the accuracy of the AHP method is good whereas the accuracy of the FR model is very good as the AUC value of AHP is 0.792 and the AUC value of FR model is 0.834. The present methodology may be convenient for identifying groundwater potential zones across the world for being scientific, cost effective and less time consuming in nature.

4.1. Introduction

Groundwater is a major dynamic natural resource, which is under threat. In the last few decades, the pattern of groundwater withdrawal has been changing rapidly throughout the world. Groundwater resource management is now becoming a major concern of present-day environmentalists to maintain the availability in a sustainable manner. The continuous high rising mandate for groundwater because of increasing population size, extension of cultivated part under irrigation and multidimensional commercial processes along with violation of environmental law has amplified the pressure on sustainable groundwater consumption (Mondal & Dolai, 2017). Groundwater is the key to all kinds of developmental activities as around 42%, 36% and 27% of total groundwater extraction are globally used in the agrarian sector, domestic and manufacturing sector correspondingly (Taylor et al, 2013). In India 30% urban population and around 90% rural people are directly dependent on groundwater for fulfilling the basic needs (Agarwal & Garg, 2016). Unfortunately, overuse of groundwater in an unscientific way along with spatial scarcity are everywhere in the Indian subcontinent (Rodell et al., 2009).

In general, the groundwater potentiality indicates the obtainability and the possibility of subsurface water occurrence in a specific region (Rodell et al., 2009). Recently, a variety of techniques has been used to examine the probable groundwater occurrence condition. Remote sensing and GIS has now arisen as a very important tool for retrieving, preserving and analysing the subsurface water (Gupta & Srivastava, 2010). Remotely sensed images have been utilised for effectively plotting and extraction of morphology, lithology, slope, fissures, renew and discharge zones, lineament and LULC (Agarwal & Garg, 2016; Dar et al., 2010). There are many problems connected with groundwater including over draft and contamination which became the subject of global concern (Gleeson et al., 2012; Gorelick and Zheng, 2015; Richey et al., 2015; Chang et al., 2017; Achu et al.,2020). Various techniques based on controlling factors of groundwater availability are generally used for predicting the groundwater potentiality as groundwater is beyond our physical observation. Many researchers in the world including India (Agarwal & Garg, 2016; Arulbalaji et al., 2019; Chakrabortty et al., 2018; Dar et al., 2010; Gupta & Srivastava, 2010; Kanta et al., 2017; Malik et al., 2016; Naghibi et al., 2016; Oh et al., 2011; Pal et al., 2020; Patra et al., 2018; Pinto et al., 2017; Saranya & Saravanan, 2020; Shekhar & Pandey, 2015) have successfully applied geospatial technology based AHP methods for characterizing the subsurface water availability. There is a significant variation in selecting the thematic layers and assignment of weights based on regional hydro-geomorphological characteristics.

Except the traditional GIS based methods recently, SVM, Deep learning, Machine learning have been used successfully for identifying the Groundwater potential zones in different parts of the world. AHP based MCDM now has been accepted globally for handling complex decision-making problems (Agarwal & Garg, 2016). Recently machine learning has been applied using advance technology for solving the real world problems including groundwater prospect zonation plotting (Rahmati et al.,2019; Nguyen et al., 2020). Random Forest, RBFC and ANN models had been used to predict the groundwater prospective in Bangladesh and India by Pal et al (Pal et al.,2020). For understanding, the spatially explicit environmental models related to natural phenomena, hybrid and ensemble techniques have a great contribution (Chhetri, 2018; Jaafari et al.,2019; Bui et al.,2019; Pham et al., 2019). The application of hybrid and ensemble methods for groundwater potentiality mapping have quite good results. Accuracy assessment of any model is very important for scientific research. ROC curve analysis has been used for accuracy assessment of models by various researchers in different fields including earth science.

For effective water resource planning it's essential to recognize the groundwater condition of any region. The maximum work had been performed to analyse the groundwater potentiality of the entire river basin, but for effective urban water resource management finding the groundwater potentiality of areas having complex geo-hydrological setup along with social diversity is important.

Considering the above facts, the current work has been designed to determine the groundwater potential zones (GPZ) in Asansol Urban Agglomeration by applying the RS and GIS based AHP and FR model. This work will provide the answer of questions like- What is the current state of groundwater availability, and does it exhibit spatial variation? Does groundwater have the potentiality to fulfil the present water demand? Is it feasible to expand groundwater utilization to meet the growing demand? Nine thematic layers ensuring significant influence on groundwater potentiality of my study area have been utilised for both methods.

The present chapter will assists the readers to understand the subsurface water conditions of AMC along with the understanding of the process of applying AHP and FR models for identifying the groundwater prospective zones of area having this kind of complex geo-hydrological setup. This work also will help to understand how mining activity influences on the groundwater availability in a region. The primary advantages of these methods are economic compatibility, scientific principle and based on freely obtainable data.

4.2. Materials and Methods

4.2.1 Assemblage of necessary materials

The current work is associated with different types of data which were composed from several sources. Topographical sheets of the entire study area bearing the number 73I/13, 73I/14 and 73M/2 were composed from the SOI, Kolkata. The SRTM DEM (30m) was downloaded from the earthexplorer.usgs.gov.in. The geological quadrangle sheets (73M &

73I) also have been collected from the GSI. West Bengal Soil sheet (NBSS LUP) was acquired from NBSS, Kolkata afterward the obtaining of free Landsat 8(OLI) imagery of September, 2021 from the USGS website. Required precipitation information has been collected from the office of Irrigation and Waterways Department, Durgapur Division, West Bengal. Fifteen years (2005 to 2020) groundwater level data (CGWB) of different stations under the AMC were acquired from the website of India Water Resources Information System. Finally, post monsoon groundwater level of fifty observation wells under study area have been measured in November, 2020,2021 &2022 for validating the present work. All the sources and additional information are given below in a tabular format (Table 4.1).

Table 4.1: Data Sources of all Thematic Layers

Sl. No	Thematic Layers	Sources	Pixel Size(Resampled)
1	Geological Unit	The geological quadrangle sheets (73M & 73I). Collected from the GSI. Scale: 1:250000	50*50m
2	Geomorphological Map	Bhukosh Geospatial data 250k.shp. Bhukosh Geospatial/Maps Data Download Package. Job ID: 4a8bf608-00b0-40ac-83a3-8f1b1d390d9d. gsi.gov.in	50*50m
3	Slope	SRTM(30m)https://earthexplorer.usgs.gov/	50*50m
4	Soil Texture	West Bengal Soil sheet (NBSS LUP). Acquired from NBSS, Kolkata. Scale:1:500000	50*50m
5	Rainfall	Irrigation & Waterways Department, Durgapur Division, West Bengal	50*50m
6	LULC	Landsat 8(OLI). September,2021.https://earthexplorer.usgs.gov/	50*50m
7	Lineament Density	SRTM(30m)https://earthexplorer.usgs.gov/	50*50m
8	Drainage Density	SRTM(30m)https://earthexplorer.usgs.gov/	50*50m
9	NDVI	Landsat 8(OLI). September,2021.https://earthexplorer.usgs.gov/	50*50m

4.2.2 Creation of Different Thematic Layers

Digital Elevation Model has been utilized for the preparation of four layers including drainage density, lineament density, and slope map which was created by gathering necessary altitude evidence from topographical sheets in ArcGIS. ArcGIS has been used for preparing drainage density, slope, lineament density from DEM. For creating the Drainage density map following sequential processes comprising the creation of flow direction, flow gathering and river network have been performed utilizing the DEM in ArcGIS 10.3.

The Soil sheet (NBSS, LUP) of West Bengal and Geological quadrangle sheets bearing the number 73M and 73I have been used for preparing the soil texture map and geological division of AMC in ArcGIS 10.3 software. Simple digitizing technique in ArcGIS has been used for creating these two layers after proper geo-referencing.

Landsat 8 image was used to prepare the LULC and NDVI maps after performing the essential radiometric and geometric correction. Supervised image classification procedure was utilised to create LULC maps. For the accuracy, assessment of classified image Kappa Coefficient method has been performed with the help of Google Earth and ArcGIS software. NDVI is a standard procedure for assessing the density of vegetation based on the difference between visible and near infrared reflectance of vegetation cover which was extracted by the following method in ArcGIS 10.3 (Townshend & Justice, 1986).

$$\text{NDVI} = \frac{(\boldsymbol{NIR\ Band} - \boldsymbol{R\ Band})}{(\boldsymbol{NIR\ Band} + \boldsymbol{R\ Band})}$$

The value of NDVI ranges between +1 to -1 where, moderate NDVI value (approx.0.2 to 0.5) resulted from sparse vegetation like shrubs and grasslands high NDVI values (approx.0.6 to 0.9) correspond to dense vegetation such as temperate and tropical forests.

For creating the mean annual rainfall map of AMC IDW tool in ArcGIS has been used. Last ten years rainfall data (2010 to 2020) collected from the office of IWD, Durgapur Division was used for this purpose.

4.2.3 Weight assigned by AHP Method

Thomas L. Saaty was established the Analytical Hierarchy Process (AHP) as a mathematical technique for solving the process of multi-criteria decision making in 1970 (Hell et al., 2013; Podvezko, 2009). In this method experts' opinion is used to given the rank and weights by producing a organised eigenvalue pairwise judgment matrix for taking the ultimate decision (Saranya & Saravanan, 2020). It is generally used to determine the choice complications in a multi-criteria condition (Forman & Gass, 2001). An extensive use of this technique for making decision in multi-criteria situation has been observed recently (Mallick et al., 2019).

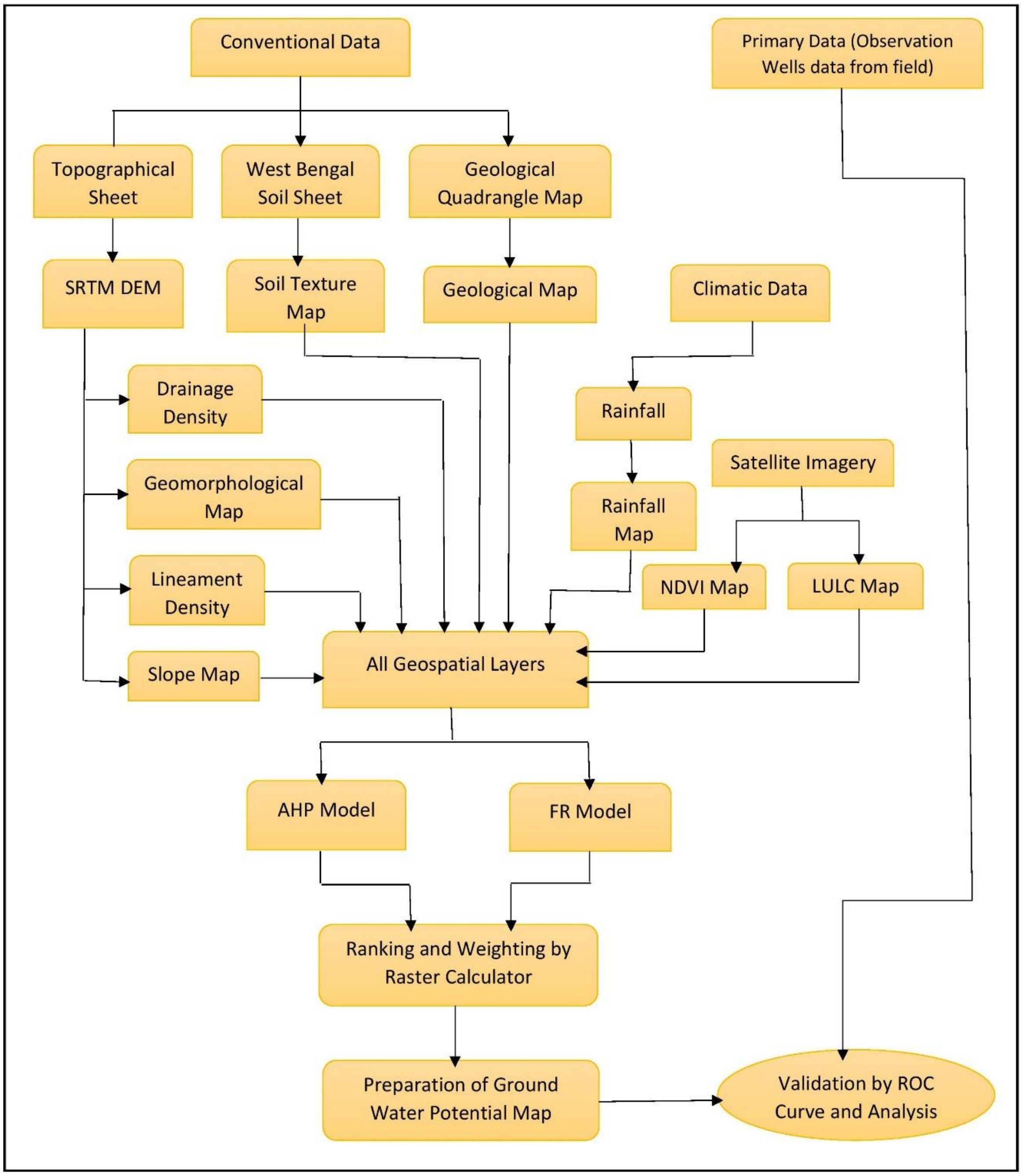

Fig.4.1: Methodological Flow Chart

AHP is a semi-numerical structured process widely designed for organizing and analysing complex decision. The score indicates in AHP method the importance of every single aspect and the predilection values are set for each constraint following the Saaty's 1 to 9 scale for computing the proportional importance in association with aims (Saaty, 1977). Considering the general factors controlling ground water recharge nine significant thematic layers comprising area of depression, lithological component, slope, precipitation, textural pattern of soil, lineament density, drainage density, LULC and NDVI which control the rate of groundwater recharge in any geographical area by dropping the rate of overland flow and enhancing the down ward movement of water were utilized in AHP method. The assignment of rank and weights of nine layers have been done on the basis of the effect of existing layer on groundwater recharge as the prime intention of this effort is to detect the groundwater potentiality zones.

The total procedures involved in this method have been performed with the help of MS-Excel and ArcGIS. AHP method includes the following steps which was discussed in various writings (Jenifer & Jha, 2017; Mallick et al., 2019; Pal et al., 2020; Patra et al., 2018; Haldar & Majumder, 2022).

Pairwise comparison and Establishment of Judgemental Matrices (P)

A pairwise comparison matrix is used to establish the judgemental matrix in AHP methods based on the all-selected criteria consider to solve a specific problem. Ultimately on the basis of the result of pairwise comparison matrix final weights are assigned for each layer.

$$P = \begin{bmatrix} P11 & P12 & P1n \\ P21 & P22 & P2n \\ P1n & P2n & \mathrm{Pnn} \end{bmatrix}$$

Where, P_n specifies the n^{th} indicator element and P_{nn} is the judgement matrix element.

Normalization of Weight

In AHP method it is essential to normalized the weights of each criterion used in this method which is done by using the equation given below-

$$\mathbf{W}_n = \left(GMn / \sum_{n=1}^{Nf} GMn\right)$$

The subsequent formula is applied to estimate the Geometric mean of the i^{th} row of the judgemental matrices.

$$\mathrm{GMn} = \sqrt[Nf]{P1nP2n \ldots . PnNf}$$

Consistency Ratio (CR)

CR is essential in AHP model to judge the weights given in this method are accurate or not. . For conveying weightage only CR < 0.1 is considered in the AHP model.

$$CR = \frac{CI}{RCI}$$

Table 4.2: Pairwise Assessment Matrix, Priority and rank of the layers

Sl. No.	Layers	AHP Weightage values									Priority (%)	Rank	Normalized Weight
		1	2	3	4	5	6	7	8	9			
1	Geological Unit	1	1.20	1.40	1.50	2.00	2.00	3.00	3.00	4.00	19.00	1	0.19
2	Geomorphology	0.83	1	1.50	1.75	2.50	2.50	3.50	3.50	4.50	18.00	2	0.18
3	Slope	0.71	0.67	1	2.00	2.50	3.00	3.50	4.00	4.00	17.94	3	0.18
4	Soil Texture	0.67	0.57	0.50	1	2.00	2.00	3.00	4.00	4.50	13.94	4	0.14
5	Rainfall	0.50	0.40	0.40	0.50	1	2.00	4.00	4.50	3.00	10.85	5	0.11
6	LULC	0.50	0.40	0.33	0.50	0.50	1	1.50	2.00	2.50	7.32	6	0.07
7	Lineament Density	0.33	0.29	0.29	0.33	0.25	0.67	1	4.00	4.00	6.10	7	0.06
8	Drainage Density	0.33	0.29	0.25	0.25	0.22	0.50	0.25	1	1.50	3.67	8	0.04
9	NDVI	0.25	0.22	0.25	0.22	0.33	0.40	0.25	0.67	1	3.18	9	0.03
CR=0.04													

Source: Computed by the Author

Consistency Index (CI) can be calculated by applying the given formula.

$$CI = \frac{\lambda \max - Nf}{Nf-1}$$

λmax denotes the largest eigenvalue of judgemental matrix and can be calculated by using the equation given below.

$$\lambda max = \sum_{1}^{Nf} \frac{(PW)n}{NfWn}$$

In this equation, W signifies weight vector(Column) and standard table value has been used for RCI (Alonso & Lamata, 2006; Patra et al., 2018).

MS-Excel has been used for performing the steps including Establishment of Judgemental Matrix by pair wise assessment, calculation of standardised weight and finding the CR.

4.2.4 Extraction of Ground water potentiality zones by AHP Method

Corresponding weightage of all thematic layers and the weightages of each category under various thematic layers was properly allotted and distributed. The weights of different thematic layer have been properly distributed by using Raster calculator tool in ArcGIS. Finally, a linear sum combination procedure was applied for generating groundwater potential zones by applying a raster calculator in ArcGIS under spatial analysis tool.

Groundwater Potential Zones =

[(GLw*GLwi)+(DAw*DAwi)+(SLw*SLwi)+(STw*STwi)+(RFw*RFwi)+(LULCw*LULCwi)+(LDw*LDwi)+(DDw*DDwi)+(NDVIw*NDVIwi)]

Table 4.3: Weightage of various parameters

Category	Sub-category	AHP Weightage Values						Normalized Weight
		1	2	3	4	5	6	
Geological Unit CR = 0.06	Alluvium formation	1.00	2.50	2.50	3.50	3.50	4.00	0.34
	Barakar formation	0.40	1.00	2.50	2.50	4.00	4.50	0.25
	Kulti formation	0.40	0.40	1.00	2.50	3.50	4.50	0.18
	Panchet formation	0.29	0.40	0.40	1.00	2.50	3.00	0.11
	Raniganj formation	0.29	0.25	0.29	0.40	1.00	3.00	0.07
	Pink Granite	0.25	0.22	0.22	0.33	0.33	1.00	0.04
Geomorphology CR = 0.05	Flood plain	1.00	2.50	3.50	4.00	5.00		0.44
	Pediment-pediplain complex	0.40	1.00	2.50	3.00	4.00		0.26
	Water bodies	0.29	0.40	1.00	3.00	3.50		0.16
	Quarry and Mining dump	0.25	0.33	0.33	1.00	2.50		0.09
	River	0.20	0.25	0.29	0.40	1.00		0.06
LULC CR = 0.09	Water body	1.00	3.00	4.00	6.00	7.00		0.47
	Agricultural land	0.33	1.00	3.00	4.00	7.00		0.26
	Vegetation	0.25	0.33	1.00	4.00	7.00		0.16
	Quarry and mining	0.17	0.25	0.25	1.00	4.00		0.07
	Settlement	0.14	0.14	0.14	0.25	1.00		0.03
Slope CR = 0.01	Very Low	1.00	1.00	2.50	4.00	4.50		0.36
	Low	1.00	1.00	2.00	2.50	3.50		0.30
	Moderate	0.40	0.50	1.00	2.00	3.00		0.17
	High	0.25	0.40	0.50	1.00	2.00		0.11
	Very High	0.22	0.29	0.33	0.50	1.00		0.07
Rainfall CR = 0.02	High	1.00	1.50	2.00				0.45
	Moderate	0.67	1.00	2.00				0.35
	Low	0.50	0.50	1.00				0.20
		2.17	3.00	5.00				
Lineament Density CR = 0.08	Very High	1.00	1.50	2.50	3.00	3.50		0.35
	High	0.67	1.00	2.00	2.50	3.00		0.27
	Moderate	0.40	0.50	1.00	2.50	4.00		0.19
	Low	0.33	0.40	0.40	1.00	4.00		0.12
	Very Low	0.29	0.33	0.25	0.25	1.00		0.06
Soil CR = 0.06	Fine loamy	1.00	1.50	2.50	3.00			0.40
	Loamy	0.67	1.00	2.00	3.00			0.31
	Coarse loamy	0.40	0.50	1.00	3.00			0.19
	Coal Quarry	0.33	0.33	0.33	1.00			0.10
Drainage Density CR = 0.07	Very High	1.00	1.50	2.00	2.50	3.50		0.33
	High	0.67	1.00	1.50	2.50	3.00		0.26
	Moderate	0.50	0.67	1.00	3.00	4.00		0.23
	Low	0.40	0.40	0.33	1.00	3.50		0.12
	Very Low	0.29	0.33	0.25	0.29	1.00		0.06
NDVI CR=0.05	Very High	1.00	1.50	2.50	3.00	3.50		0.35
	High	0.67	1.00	2.00	2.50	3.00		0.27
	Moderate	0.40	0.50	1.00	2.50	4.00		0.19
	Low	0.33	0.40	0.40	1.00	4.00		0.12
	Very Low	0.29	0.33	0.25	0.25	1.00		0.06

Source: Calculated by the Author

Where, GL=Geological map, DA= Depression Area, SL=Slope map, ST=Soil texture map, RF=Rainfall map, LULC= Landuse and landcover map, DD= Drainage density, LD=Lineament density, and NDVI=Normalized Differential Water Index. The letter w specifies the standardised weightage of a definite layer and wi is the standardised weightage of each category under a thematic layer.

Groundwater potential zone map has been extracted by utilizing the Natural breaks (Jenks) technique in ArcGIS built on the linear sum combination value.

4.2.5 Frequency Ratio (FR) Model

The frequency ratio (FR) is a bivariate statistical approach which is generally used to predict the chance of availability of something on the basis of associations between one dependent variable and a set of independent variables. In ground water study, this model is used to find out the groundwater potential zone on the basis of relationships between spring wells (dependent variable) and ground water influencing factors (independent variables) (Guru et al., 2017; Naghibi et al., 2016; Oh et al., 2011). For this present study instead of direct use of spring well's location a base map indicating the high groundwater potential areas of Asansol Urban Agglomeration for FR model has been prepared using natural breaks classification method in ArcGIS 10.3 on the basis of last fifteen years average (2005 to 2020) post monsoon ground water level data (CGWB) downloaded from India Water Resources Information System website (Fig.4.2). There is a significant association between depth of water from the surface and groundwater potentiality, low depth of water from ground specifies high groundwater potentiality and vice versa (Andualem & Demeke, 2019; Mandal et al., 2021). Following this principle, areas having depth of water below 3.5 meters from ground have been treated as high potential zones. In this model, the areas of high potential zone have been used as dependent variables and the nine factors controlling availability of ground water have been used as independent variables. Finally, FR is calculated as:

$$FR = \frac{HA/TH}{TT/TS}$$

Where, FR = Frequency ratio of the class, HA = area under high potential zone in each class of the thematic layer, TH= Total area of each thematic layer under high potential zone, TT=Total area of each thematic layer and TS= Total area of the study area. In this model FR values of each class under different thematic layers have been considered as weight of that specific class for determining the groundwater potentiality.

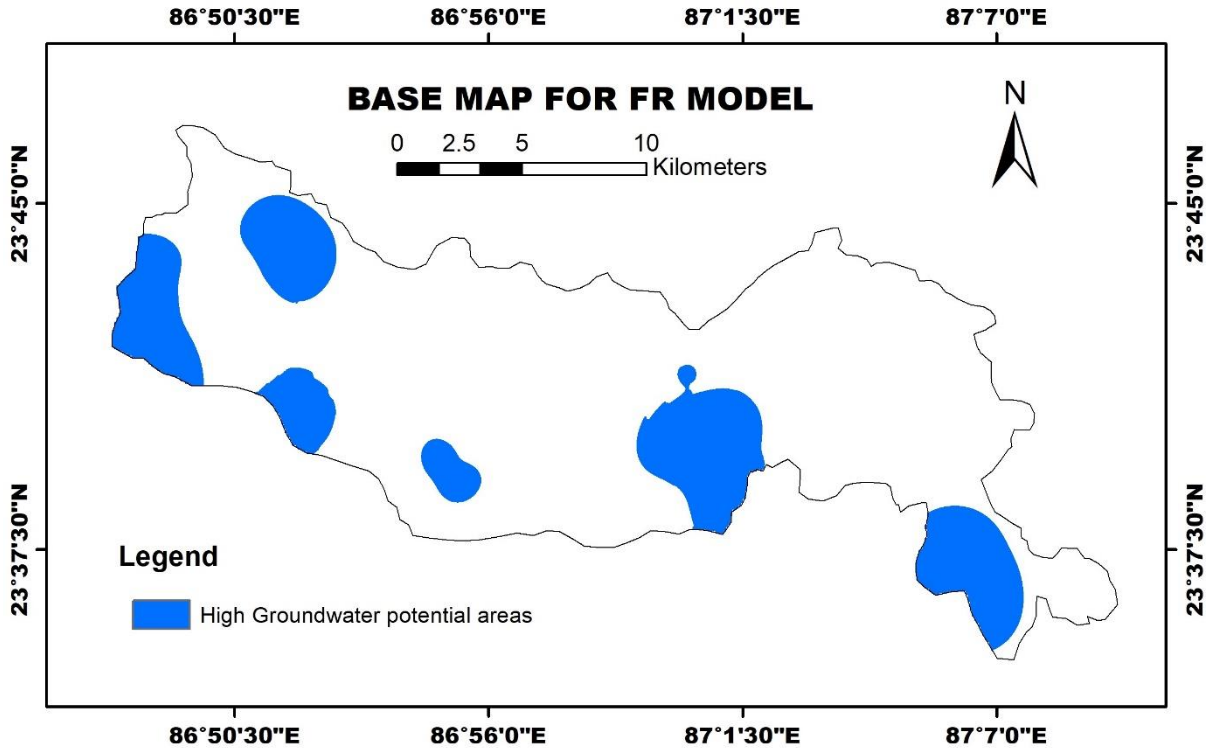

Fig.4.2: Base Map for FR model

4.2.6 Extraction of Groundwater potential Maps by FR model

For extracting the groundwater potential maps, frequency ratio values of all nine thematic layers have been utilized in ArcGIS 10.3 software. For integrating the FR values of all thematic layer's map algebra tool in ArcGIS have been used in following way-

Groundwater potential zones =

$$\sum (GL_{FR} + DA_{FR} + SL_{FR} + ST_{FR} + RF_{FR} + LULC_{FR} + LD_{FR} + DD_{FR} + NDVI_{FR})$$

Where, GL=Geological map, DA= Depression Area, SL=Slope map, ST=Soil texture map, RF=Rainfall map, LULC=Landuse and landcover map, LD=Lineament density map, DD= Drainage density map and NDVI=Normalized Differential Vegetation Index. FR indicates the frequency ratio. Finally, for extracting the groundwater potential map Natural breaks (Jenks) classification in ArcGIS 10.3 has been applied.

Table 4.4: **Calculation of Frequency Ratio of different thematic layers**

No	Factors	Sub-classes	Area	% of Area	Area under high GPZ	% of Area under high GPZ	FR
1	Geological Unit	Pink Granite	1.93	0.59	0.00	0.00	0.00
		Barakar formation	18.35	5.65	2.47	2.66	0.47
		Kulti formation	32.29	26.13	25.64	27.57	1.06
		Panchet formation	84.92	26.13	27.52	29.59	1.13
		Raniganj formation	185.29	57.01	35.12	37.76	0.66
		Alluvium formation	2.25	0.69	2.25	2.42	3.49
2	Slope	Very Low	7.24	2.23	7.12	7.66	3.44
		Low	0.82	0.25	0.79	0.85	3.37
		Moderate	0.94	0.29	0.91	0.98	3.39
		High	4.10	1.26	3.65	3.92	3.11
		Very High	312.25	95.97	80.53	86.59	0.90
3	Geomorphology	Flood plain	2.75	0.84	2.69	9.08	10.75
		Pediment-pediplain complex	4.95	1.52	3.10	10.46	6.88
		Water bodies	7.59	2.33	1.09	3.68	1.58
		Quarry and Mining dump	7.59	2.33	1.09	3.68	1.58
		River	1.25	0.38	0.51	1.72	4.48
4	Rainfall	High	162.25	49.92	42.15	45.32	0.91
		Moderate	98.53	30.31	23.27	25.02	0.83
		Low	64.25	19.77	27.58	29.66	1.50
5	Lineament Density	Very High	15.25	4.69	13.53	14.55	3.10
		High	24.10	7.41	15.24	16.39	2.21
		Moderate	89.33	27.48	17.53	18.85	0.69
		Low	65.74	20.22	21.45	23.06	1.14
		Very Low	130.70	40.20	25.25	27.15	0.68
6	Drainage Density	Very High	13.57	4.17	10.25	11.02	2.64
		High	35.48	10.91	13.45	14.46	1.33
		Moderate	40.95	12.60	17.35	18.66	1.48
		Low	44.90	13.81	13.51	14.53	1.05
		Very Low	190.22	58.51	38.44	41.33	0.71
7	LULC	Water body	4.58	1.41	4.10	4.41	3.13
		Agricultural land	217.54	66.86	67.67	72.76	1.09
		Vegetation	20.25	6.22	11.75	12.63	2.03
		Quarry and Mining	5.73	1.76	2.14	2.30	1.31
		Settlement	77.29	23.75	7.34	7.89	0.33
8	Soil	Fine loamy	12.76	3.92	0.76	0.82	0.21
		Loamy	207.16	63.66	25.75	27.69	0.43
		Coarse loamy	76.25	23.43	64.35	69.19	2.95
		Coal Quarry	29.24	8.99	2.14	2.30	0.26
9	NDVI	Very High	45.45	13.95	28.36	30.49	2.19
		High	35.21	10.81	18.25	19.62	1.82
		Moderate	78.32	24.05	21.15	22.74	0.95
		Low	91.47	28.08	10.35	11.13	0.40
		Very Low	75.24	23.10	14.89	16.01	0.69

Source: Calculated by the Author

4.2.7 Receiver Operating Characteristics curve (ROC)

In general ROC investigation is used to judge the performance of diagnostic tests and to evaluate the precision of models (Calì & Longobardi, 2015). For validating both the model AHP and FR, ROC curve has been utilized. Fifty observation wells data of depth in meters below ground level (mbgl) have been measured and used as training set for determining the AOC curve for both models. The depth of water varies from 1.2 mbgl to 14.25 mbgl which have been classified as five distinct classes following the natural break classification method and used as reference points (Mandal et al., 2021; Nasir et al., 2018). The area under curve value point towards the accuracy of the prediction (Pradhan & Lee, 2010). The range of AUC value is 0.5 to 1.0 where value nearer to 0.5 indicates inappropriateness of the model and value close to 1.0 specifies the high precision of the model (Fawcett, 2006). There are five categories of accuracy according to the AUC values: excellent (0.9 to 1.0), very good (0.8 to 0.9), good (0.7 to 0.8), average (0.6 to 0.7) and poor (0.5 to 0.6). For validating the both models two separate AOC curve analyses have been performed with the help of IBM-SPSS-22 software.

4.3. Results and Discussion

4.3.1 Layers used in AHP and FR models

4.3.1.1 Geological Unit

Geology has been considered as the most important parameter of this study as geological structure of any region directly determines the amount of groundwater recharge and availability. As infiltration and surface runoff are directly controlled by the geological formation maximum weightage was given on geology which ultimately determines the availability of groundwater in any area. All the sub categories under geology have been weighted considering the influences proportionately. Six different kinds of lithological units are observed in Asansol Urban Agglomeration. Maximum part of the study area is covered by rocks of Raniganj and Panchet formation. Barakar and Kulti formations are another two significant units observed in AMC. Sandstone, shale and coal originating in the Permian age are the main constituent elements of Raniganj, Kulti and Barakar structures belonging to the Damuda group. Panchet formation belongs to the Gondwana super group and mainly consists of Sandstone and Shale. A small portion of AMC is occupied by Pink granite and alluvium formation. Biotite and Quartz biotite and granite gneiss are main elements of Pink granite which is basically a part of Chotonagpur granite gneiss complex. Alluvium formation is a part of new alluvial deposition (Haldar & Majumder, 2022). Among these sub categories maximum weightage was given to alluvial formation considering its high permeability and porosity. Barakar, Kulti and Raniganj formations were weightage sequentially after alluvial formation based on compactness and availability of joints and fractures. Area under Pink granite formation was given minimum weightage due to its high compactness. (Fig. 4.3).

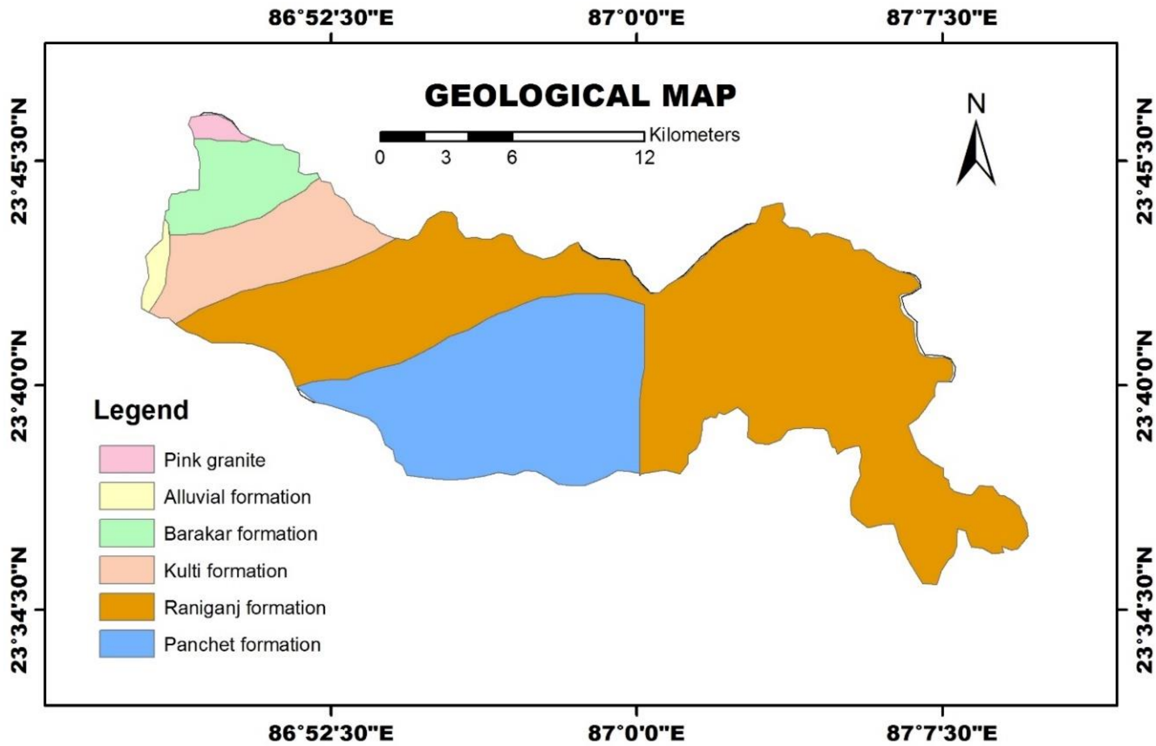

Fig.4.3: Geological Map

4.3.1.2 Geomorphology

Geomorphology has been considered as a parameter for delineating groundwater potential zone and ranked after geology as geomorphology influences groundwater availability of any region by controlling the surface runoff and infiltration rate. Geomorphology regulates the direction of surface runoff and determines the amount and infiltration rate (Alsharhan & Rizk, 2020). Mainly five distinct categories of geomorphological features are observed including pediment pediplain complex, quarry and mine dump, flood plain, surface water bodies and river (Haldar & Majumder, 2022). The maximum part of AMC is covered by a complex landform of pediment-pediplain. Quarry and mine dump is another significant feature of AMC which is observed randomly in the entire study area. Some portion is covered by flood plain associated with river Damodar. Finally, the entire region has inland water bodies like canals, ponds, rivers etc. All the sub categories under geomorphology have been weighted considering the influences proportionately. Considering the influence on ground water accumulation maximum weight was assigned to the area having flood plain. After the flood plain, the pediment-pediplain complex was assigned due to the presence of joints and fractures as these act as high infiltration zone. Inland water bodies including rivers have ranked sequentially after flood plain and pediment-pediplain complex. (Fig. 4.4)

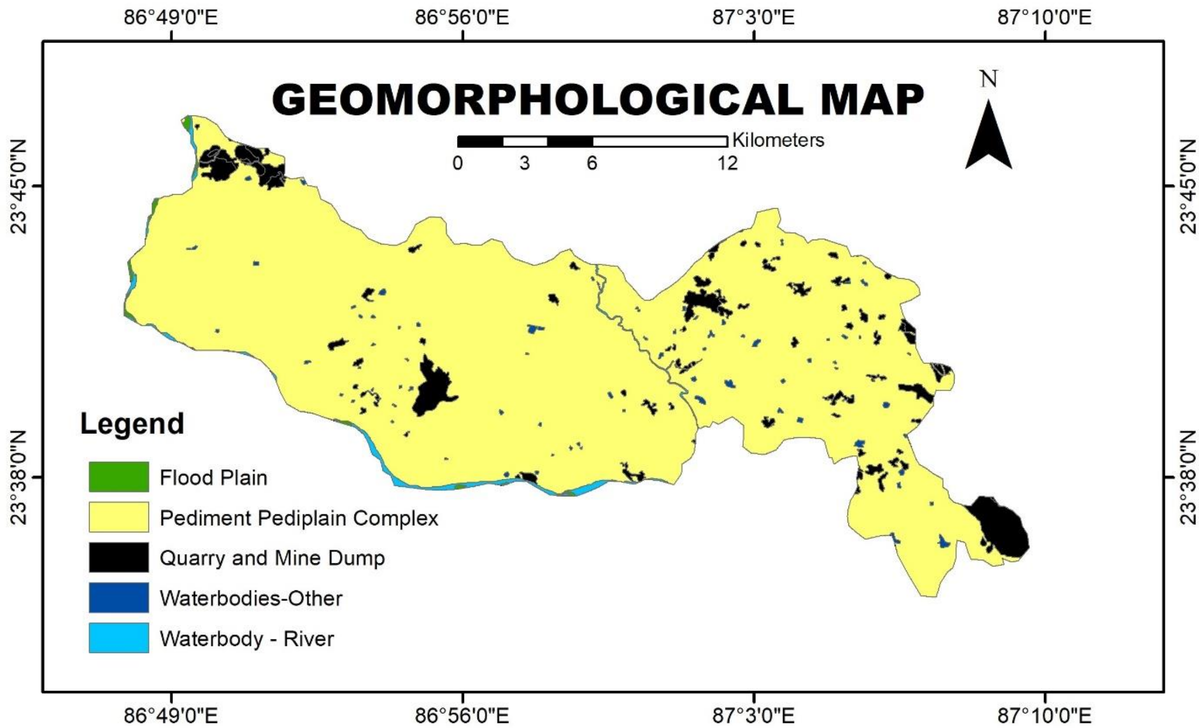

Fig.4.4: Geomorphological Map

4.3.1.3 Slope

Slope has a direct effect on groundwater recharge. Areas having great slope are connected with high surface runoff and low infiltration (Godebo, 2005). Slope has been considered which has an influence on water retention and intensity of infiltration from rainfall (Rahman et al., 2012) Major part of AMC is dominated by high slope and a minor part of AMC is characterized by very low slope. Very high slope is mainly connected with high surface runoff whereas areas having low slope are associated with slow runoff initiating infiltration. Considering these facts maximum weight was allotted to the areas ensuring low slope and minimum weight was assigned on areas dominated by very high slope. (Fig.4.5)

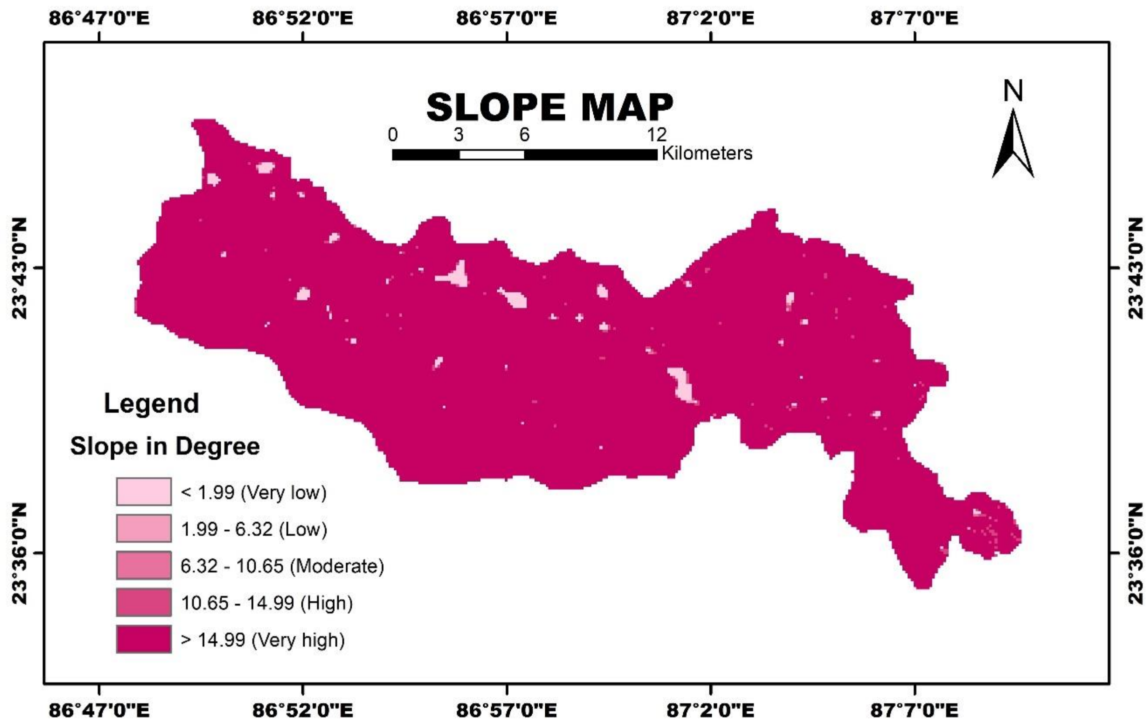

Fig.4.5: Slope Map

4.3.1.4 Soil Texture

Soil texture determines the surface water retention capacity to a large extent. Soil texture is an important expression of soil physical characteristics including porosity, permeability, structure, adhesion and consistency which have a direct influence on groundwater recharge (McGarry, 2006). AMC is mainly covered by three types of loamy variants including fine loamy, loamy and coarse loamy. Bearing in mind the porosity and permeability state of these soil varieties, maximum weight for delineating groundwater potentiality was assigned to coarse loamy soil due to its high permeability. Proportionately loamy and fine loamy have been weighted after coarse loamy. (Fig.4.6)

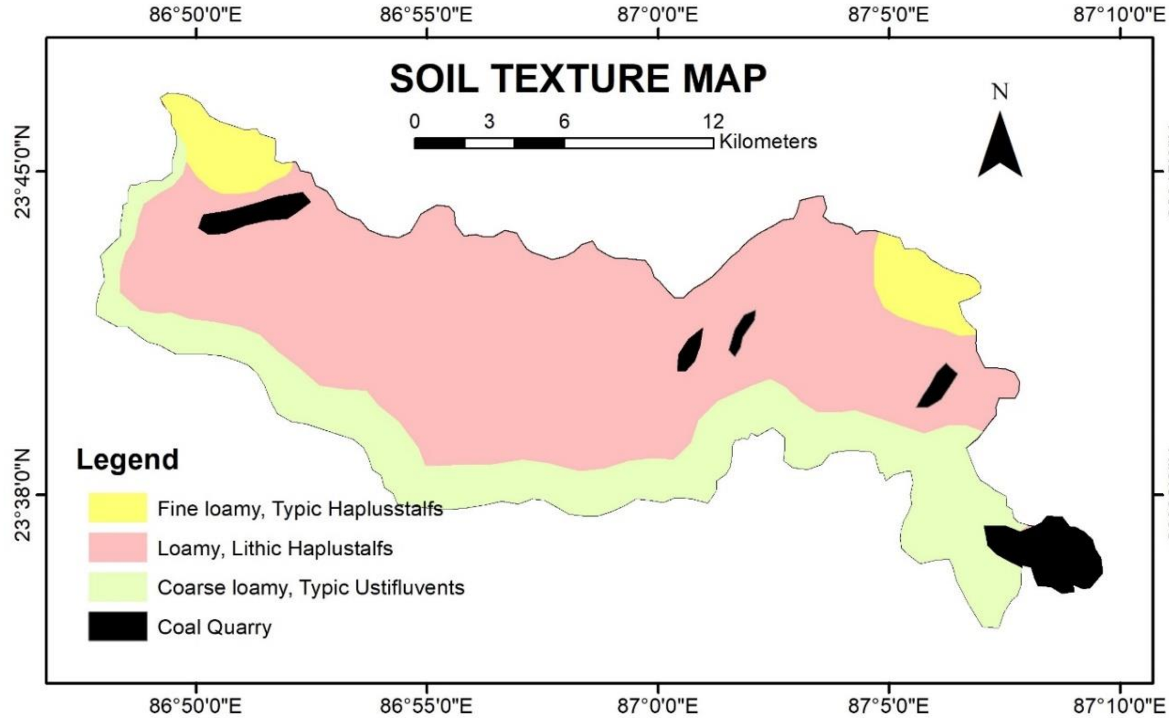

Fig.4.6: Soil Texture Map

4.3.1.5 Rainfall Distribution

Hydrological cycle of any area is directly controlled by rainfall which has a momentous role in groundwater recharge. The prime source of ground water recharge in AMC is rainfall. Considering the influences of rainfall on hydro-geological setup of any area it has been included in present study as a significant layer. The prime source of groundwater renew in AMC is rainfall. Although the mean rainfall of AMC is greater than 1200 mm, a minor deviation is perceived in rainfall distribution throughout the AMC. Mainly south west part of AMC is dominated by high rainfall whereas comparatively low precipitation is witnessed in the north eastern part of AMC. Taking into consideration the influence of rainfall to groundwater recharge, supreme weight was assigned to the area getting high precipitation followed by the areas under medium and low precipitation. (Fig.4.7)

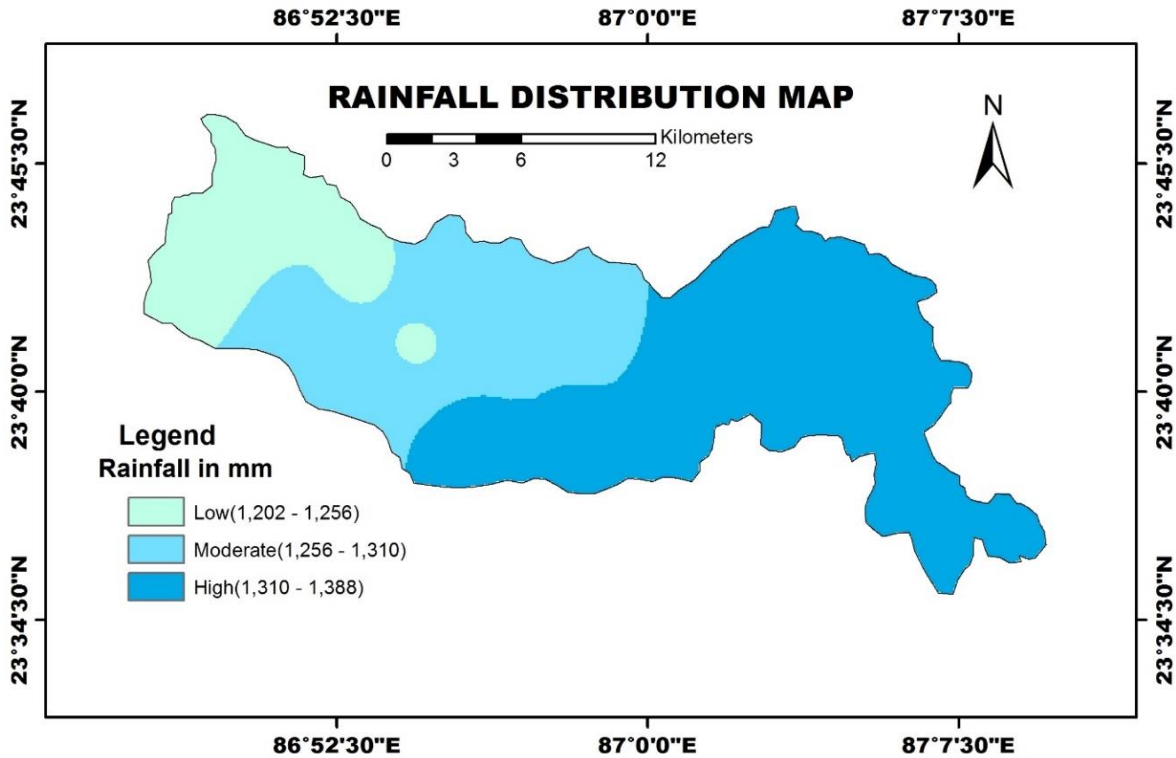

Fig.4.7: Rainfall Distribution Map

4.3.1.6 Land use and Land cover

LULC study is very crucial for demarcating groundwater prospective zones as it has a direct effect on overland flow, evapotranspiration and infiltration. Five major categories of LULC have been observed in the study area. Around 24% of AMC is occupied by urban settlement which is non-conducive for groundwater recharge. Around 66% of the area of AMC is covered by Agricultural land. Some portion of study area is shielded by quarry and mining areas. Others two significant units are quarry and mining (2%) and vegetation (7%). Accuracy assessment also has been done by Kappa Coefficient method using Google Earth, which proves that classification accuracy is almost perfect (Table.4.5). All the sub categories under LULC have been weighted considering the influences proportionately. Water bodies, water logged areas, agrarian lands are considered as decent for groundwater recharge whereas absolute urban areas are treated as insignificant for groundwater recharge due to less infiltration (Agarwal & Garg, 2016). By analysing the LULC pattern of AUC and considering the influences on groundwater recharge maximum weight has been given on water bodies because of its high probability of infiltration, which is followed by agricultural land and minimum weight has been assigned on settlement areas. Agricultural land is considered as a high groundwater recharge area due to its high permeability and low compactness. Minimum weightage was given in areas having settlement as continuous growth of urban industrial activities obstructs the natural infiltration process. Expansion of urban areas ultimately converts the natural surface into paved surface by constructing building, industry and transport networks along with other commercial activities, which ultimately hinders the natural infiltration process. (Fig.4.8)

Table 4.5: Assessment of Accuracy

Classes	Agricultural land	Built up area	Vegetation	Water body	Quarry and mining	Total	User's Accuracy	Kappa Co-efficient
Agricultural land	146		2	1	1	150	97.33	
Built up area	1	147		1	1	150	98	
Vegetation	1	1	76	1	1	80	95	
Water body	1	1	1	77		80	96.25	
Quarry and mining	1		1	1	47	50	94	0.95
Total	150	149	80	81	50	510		
Producer's Accuracy	97.33	98.65	95	95.06	94			
Over all Accuracy	96.66							

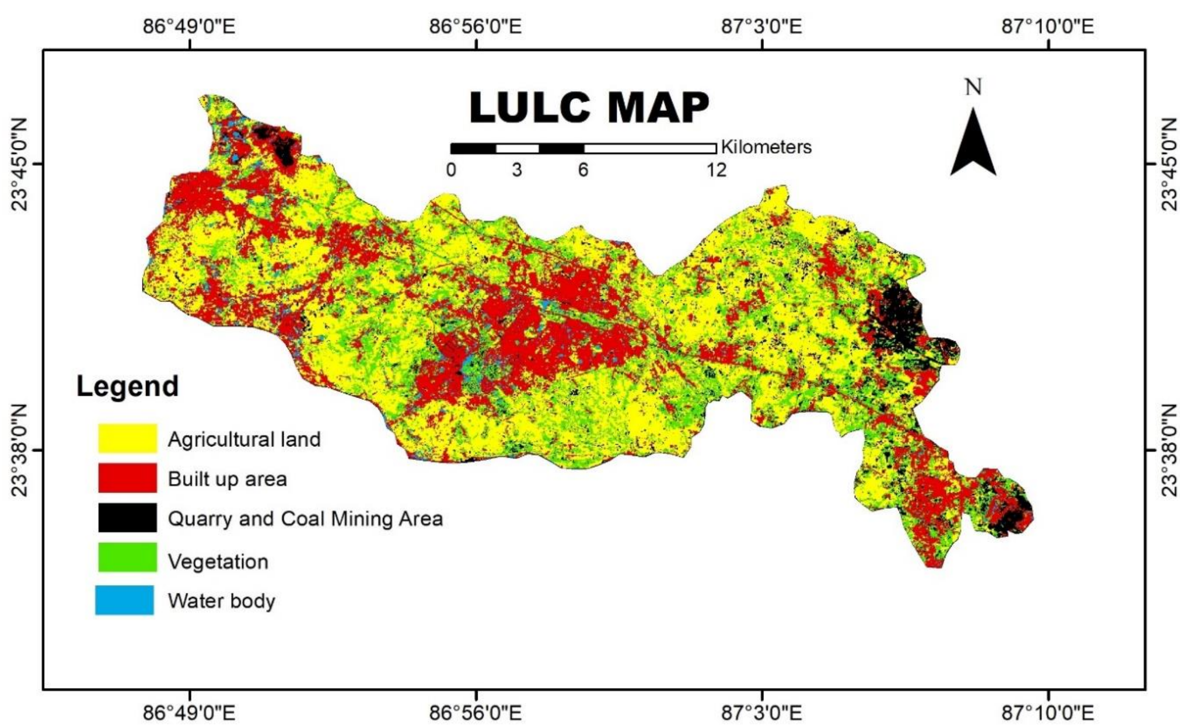

Fig.4.8: Land use/Land cover map

4.3.1.7 Lineament Density

Lineament, large scale linear features are surficial expression of underlying geological structure of any area associated with joints, faults of hard rock which is considered as a good groundwater recharge zone (Dar et al., 2010). Lineament, generally treated as the indication of high groundwater potentiality, has been used here for identifying groundwater prospective zones in Asansol Urban Agglomeration. Five categories of lineament density zones are observed in AMC which have been weighted proportionately. A great variation of distribution patterns of lineament density zones is found starting from very small areas under very high lineament density zones and maximum coverage of very low lineament density zones. Considering the impacts of lineament density on groundwater availability, the largest weight was assigned to areas ensuring high lineament density and smallest weight to areas having low lineament density. (Fig. 4.9)

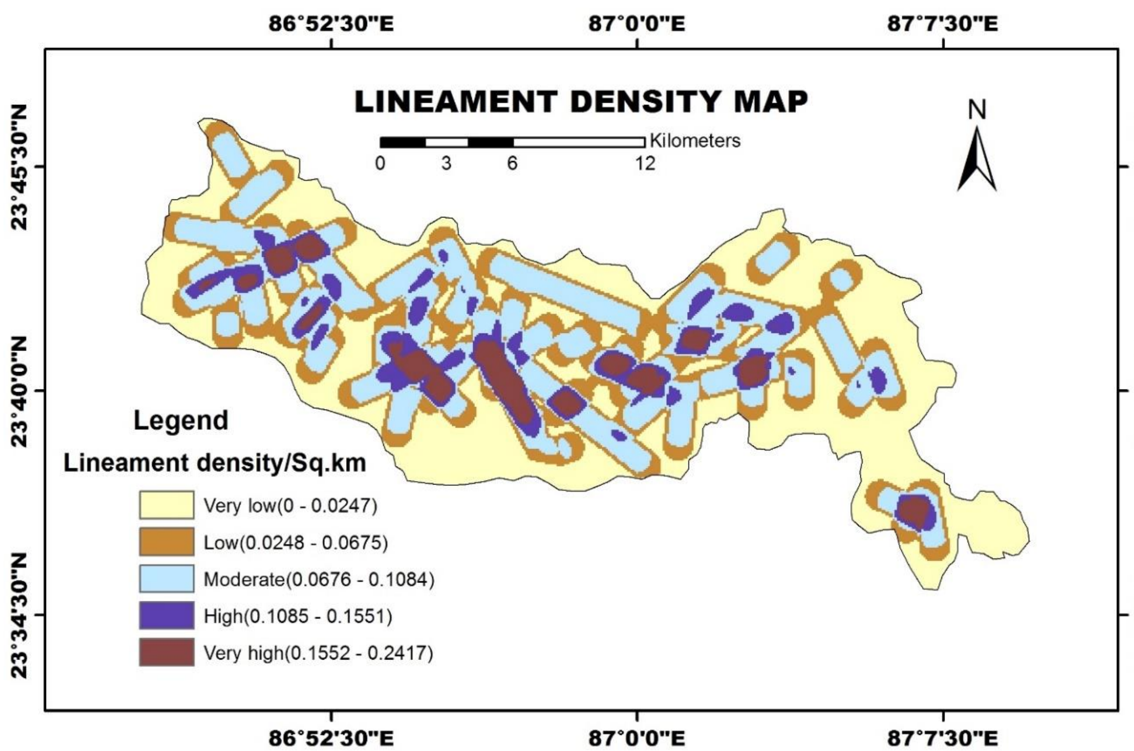

Fig.4.9: Lineament Density Map

4.3.1.8 Drainage Density

Drainage density indicates the natural dissection of topography by channels which ultimately reflects the tendency of the basin to generate surface runoff (Patra et al., 2018). In general, negative association is observed between drainage density and groundwater recharge as maximum water drains out from the basin, especially in areas with low alluvial formation Five categories of drainage density are found ranging from very high to very low. Distribution pattern of drainage density shows that the major portion of Asansol Urban Agglomeration is under very low drainage density, which is followed by the low, moderate, high and very high. Considering the influences of drainage density on groundwater recharge minimum weight was assigned to areas ensuring high drainage density and vice versa. (Fig.4.10)

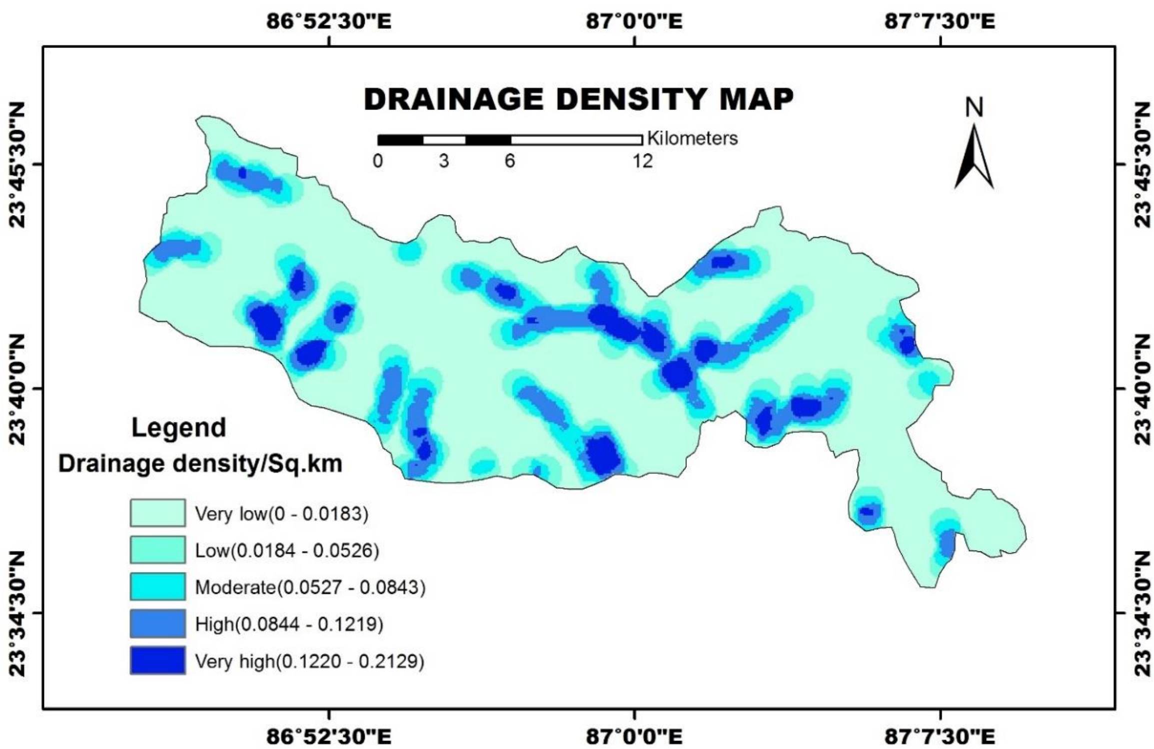

Fig.4.10: Drainage Density Map

4.3.1.9 Normalized Differential Vegetation Index (NDVI)

NDVI is used to study the vegetation health of any region. Vegetation has a great influence on groundwater recharge as vegetation covers directly help to reduce the rate of surface runoff and consequently increase the infiltration rate. NDVI value 0 denotes that there is no green vegetation whereas NDVI value 1 indicates the maximum vegetation density. On the basis of NDVI values five different categories have been recognized in the present study area. As vegetation covers positively act to groundwater recharge, supreme weight was allotted to areas ensuring high NDVI value whereas minimum weightage has been assigned to areas ensuring low NDVI value. (Fig.4.11)

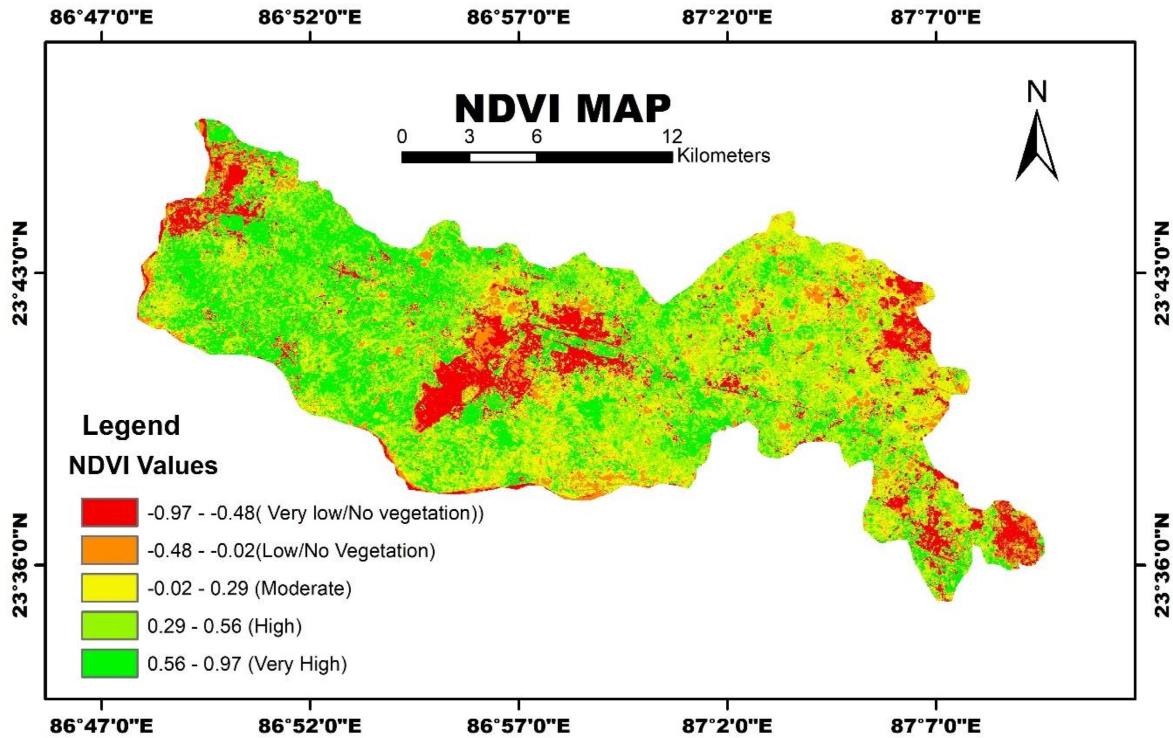

Fig.4.11: Normalized Differential Vegetation Index Map

4.3.2 Groundwater potential zones (GPZ)

Five distinct groundwater prospective zones have been identified by AHP method. Only 5.15% of Asansol Urban Agglomeration is covered by a very high groundwater potential zone. Very high potential zone is associated with an area having coarse soil texture, high lineament density, low slope and large depression and a Damuda group of rocks. The 9.25% area of AMC is covered by high groundwater potential zones followed by the 26.35% coverage of moderate groundwater potential zones. Other two categories are low and very low groundwater potential zones which cover 39.5% and 19.75% areas of AMC respectively. Areas of low and very low groundwater potential zone are associated with very high slope, fine soil texture, lack of vegetation cover and urbanization. (Fig.4.12).

Five distinctive groundwater potential zones also have been delineated by FR model. The 9.85% area of Asansol Urban Agglomeration is covered by a very high groundwater potential zone which is associated with high rainfall, high lineament density, coarse loamy soil texture, low slope and vegetation cover and high NDVI value. 13.75% area of AMC comes under the category of high groundwater potential zones which is followed by the 33.93% area covered by moderate groundwater potential zone. 32.35% area of AMC is covered by low groundwater potential zone and only 10.12% area comes under the very low category. Low groundwater potential zones are also connected with high slope, fine loamy soil texture, urbanization and low NDVI value. (Fig.4.13)

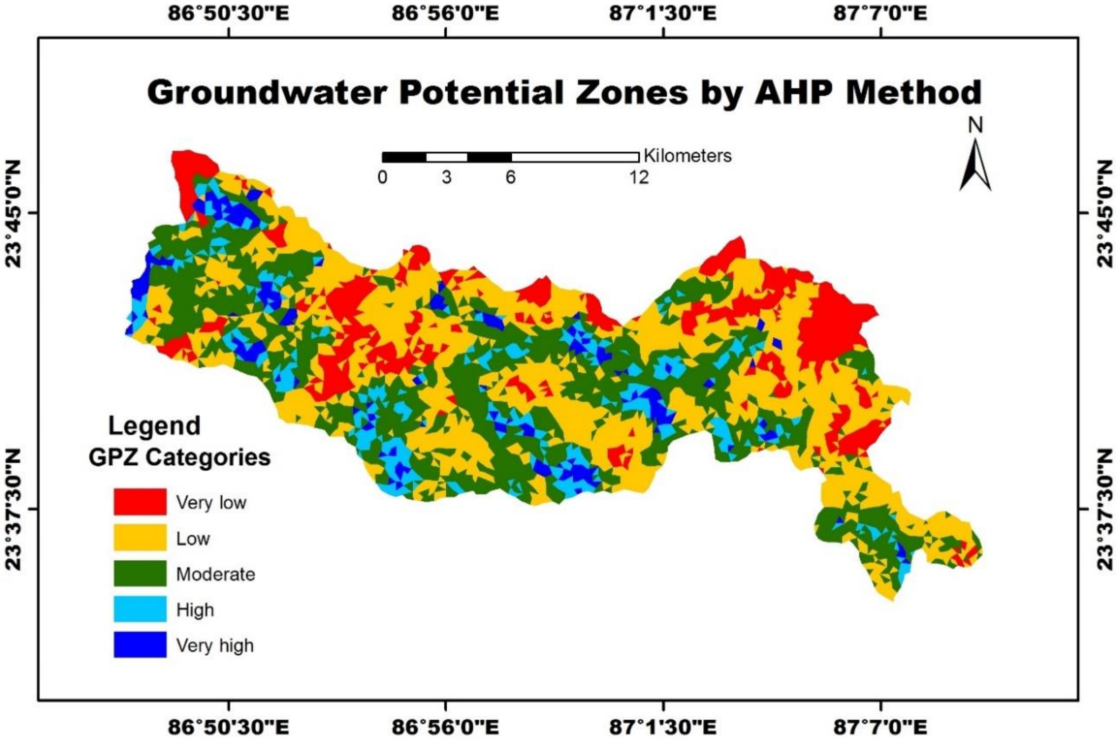

Fig.4.12: Groundwater potential zones delineated by AHP method

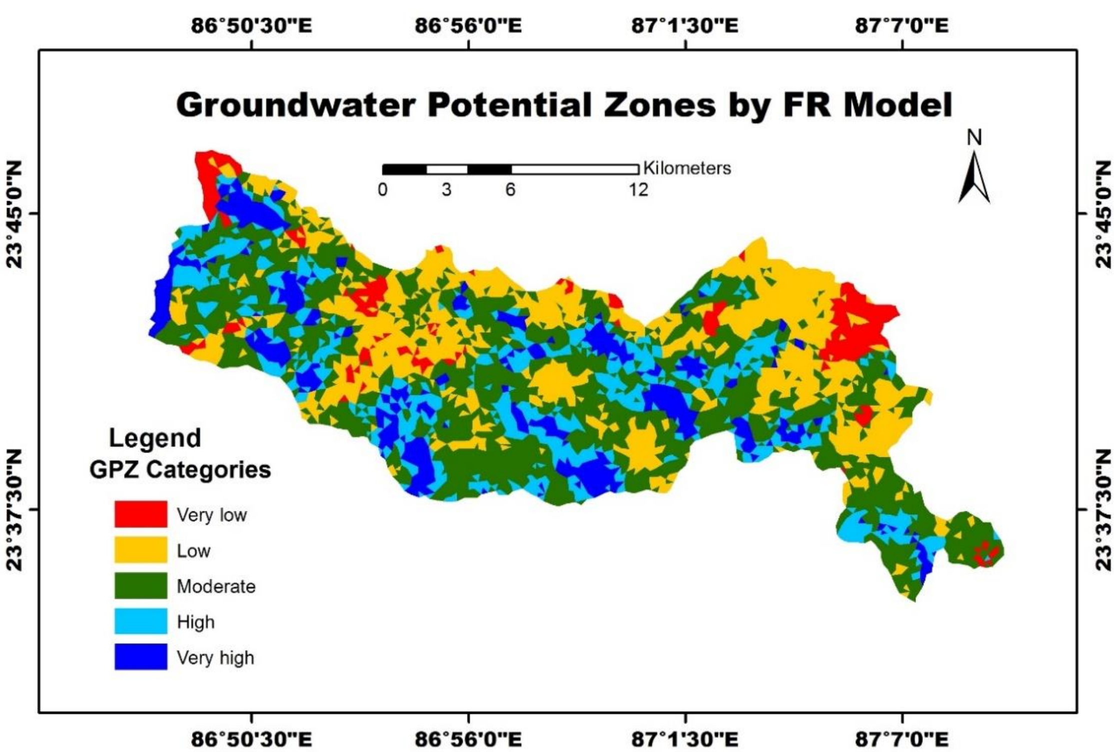

Fig.4.13: Groundwater potential zones delineated by FR model

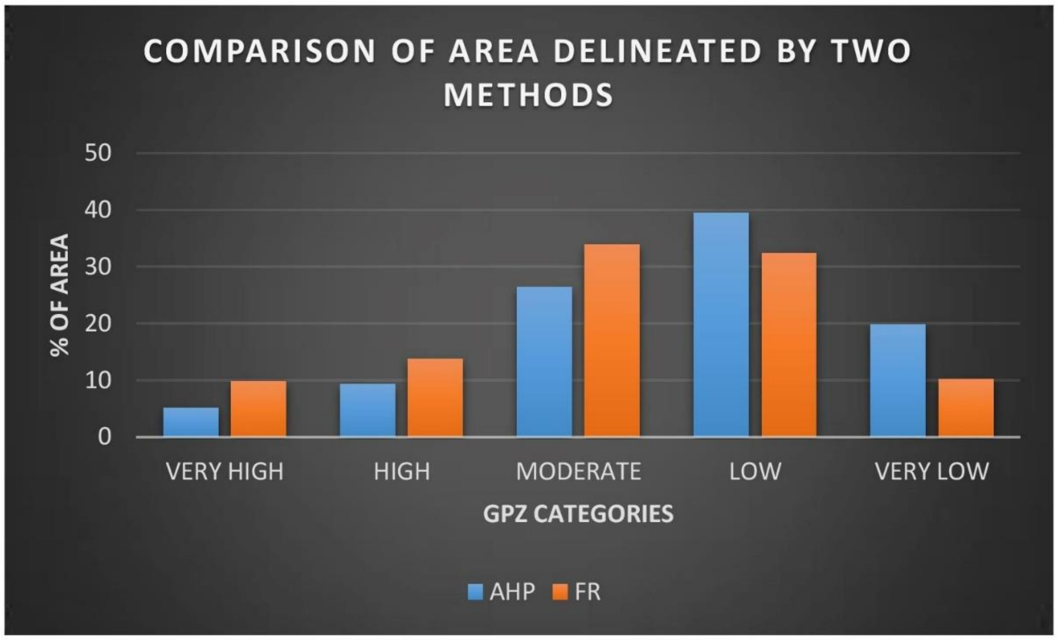

Fig.4.14: Comparison of groundwater potential areas by two methods

The results of two models depict a clear spatial coincidence among the distributional pattern of various groundwater potential zones in Asansol Urban Agglomeration. From the result of both models, it is clear that very high and high groundwater potential zones in this area are observed across the southern and south-western margin. High groundwater potentiality observed in these areas due to the following reasons- 1. Geologically these areas come under the alluvial formation, which have a high porosity or permeability leading to high infiltration rate. 2. Geomorphologically these areas come under flood plain region, which are generally considered as areas having good groundwater available due to less compactness and high infiltration. 3. These high groundwater potential areas fall under the agricultural land and water bodies corresponding to landuse-landcover patterns, which also act as high recharge zones compared to built-up areas. 4. While considering the average slope, these areas also come under low to moderate slope, which create the high infiltration by reducing surface runoff. 5. Similarly, these areas also come under a high rainfall zone, which is essential for groundwater recharge. 6. From the NDVI map, it is also clear that these high groundwater potential zones have maximum vegetation compared to surrounding regions, which also have positive impacts on groundwater recharge. 7. These high groundwater potential areas have coarse loamy soil, which is associated with high permeability 8. Similarly, considering lineament density and drainage density, these areas have very low drainage density and comparatively high lineament density, which create a suitable environment for groundwater recharge. On the other hand, the maximum part of the study area have moderate, low and very low groundwater potential zones covering the middlemost part, north-east and eastern part of the study area. These areas have low to very low groundwater potentiality for the following reasons- 1. Geologically these areas fall under Barakar, Kulti and Raniganj formations which are associated with high compactness and coal formation having very low infiltration capacity. 2. As per geomorphological division these areas come under pediment-pediplain complexes, which also have low infiltration capacity compared to flood plain. 3. These areas are mostly covered by settlement and associated urban industrial activities, which have direct negative impacts on groundwater recharge by obstructing the natural infiltration process. 4. These areas experience low precipitation compared to surrounding regions, which also reduces the probability of groundwater recharge. 5. The NDVI map clearly depicts that these areas have low vegetation compared to surrounding areas, which also reduces the chance of groundwater recharge by increasing the probability of surface runoff. 6. These areas are dominated by fine loamy soil, which has low permeability and porosity. 7. Mainly high to very high slope is observed in these areas which also act negatively for groundwater recharge.

One thing is important here that although a spatial coincidence is observed in various groundwater potential zones of two models, a remarkable difference is found in the areal extension of various groundwater potential zones delineated by AHP and FR models. The AHP and FR both models have their advantages and disadvantages. FR model is basically based on ground reality whereas application of AHP to some extent depends on theoretical knowledge. Acquiring authentic data for the application of FR model is quite difficult and not available for the whole region whereas preparation of required data for the application of AHP model is comparatively easy and available. On the other hand, a very high expertise knowledge is essential for assigning the weightage of various thematic layers in AHP model as the result of the study totally depends on the priority and weightage of different thematic layers.

4.3.3 Validation of the Models

Receiver Operating Characteristics (ROC) curve analysis for both models has been performed separately utilizing the fifty observation wells data collected from the field as test data set with the help of IBM-SPSS-22 software. (Table.4.6). For validating the models by ROC, point (observation wells) wise extracted values of AHP and FR from the both maps of final GPZ by ArcGIS and observation wells data as reference points have been utilized (Nasir et al., 2018). In this study, the multi-classes data has been converted to binary data for applying the ROC curve. For this purposes based on five categories of groundwater potential zone resulting from AHP and FR models , five validation classes also has been considered based on the depth of observation data such as (<3mgbl= Very High, 3-5mgbl=High, 5-7mgbl=moderate, 7-9mgbl=Low and >9mgbl=Very Low). Finally, by comparing this with potential zones, scores have been assigned as 0 or 1. If the validation category matches with groundwater potential zone category, then the model performance is positive (1) otherwise negative (0). From the results of ROC curve analysis it proved that the results of both models (AHP and FR) are valid as the value of Area Under Curve (AUC) for both models is greater than 0.6. The value of AUC for the FR model is 0.853 which signifies that the accuracy of the model is very good whereas the value of AUC for the AHP model is 0.792 which signifies the good accuracy of the model. (Fig.4.15).

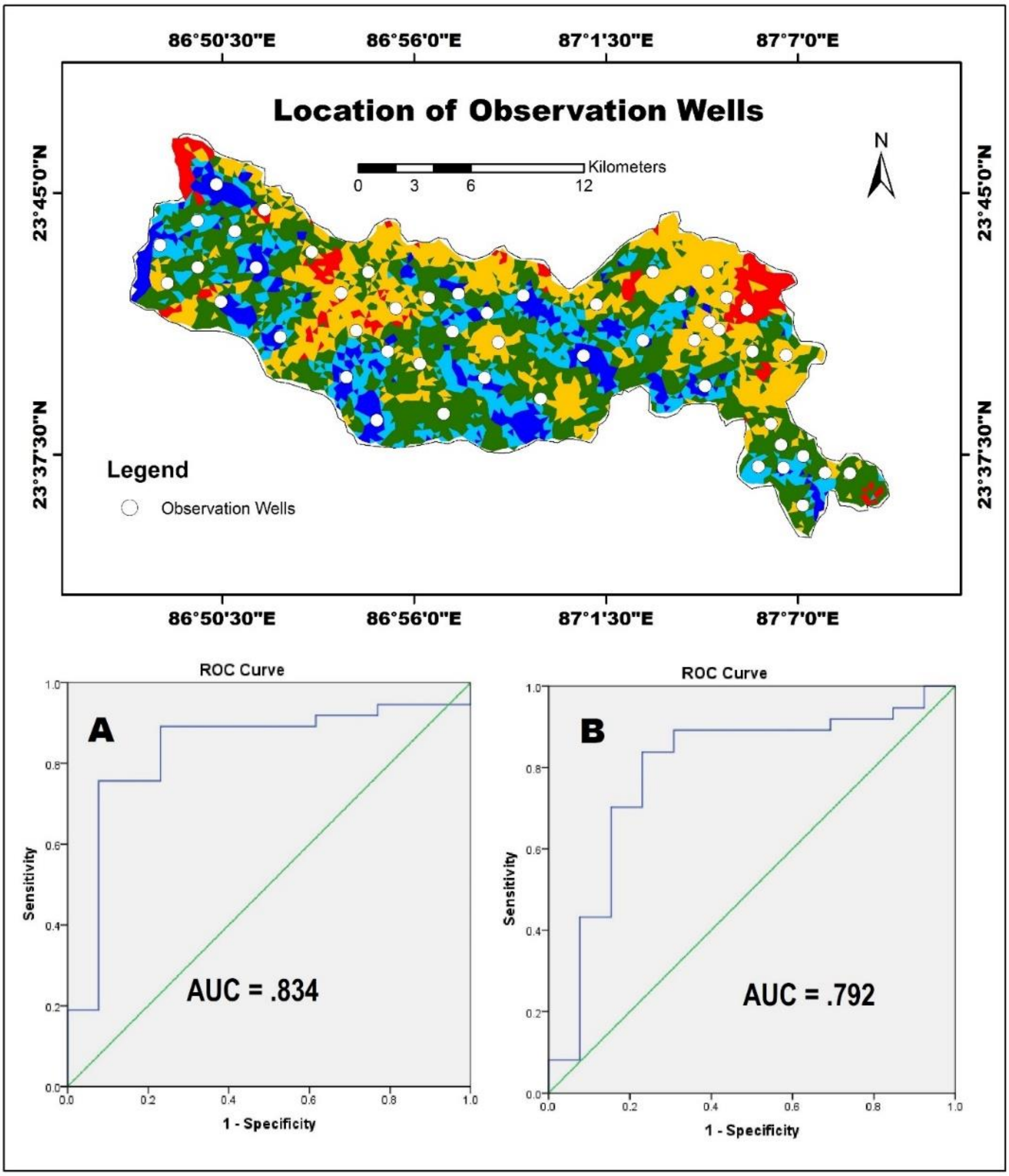

Fig. 4.15: Location of Observation Wells and A) ROC curve for AHP B) ROC curve for FR model

Table 4.6: **Details of Observation Wells**

Observation Wells	Latitude	Longitude	Locality	Water depth(mbgl)	Actual Classes	Agree with AHP	Agree with FR
OW1	23.754	86.837	Kulti	7.980	Low	1	1
OW2	23.724	86.811	Kulti	3.930	High	0	1
OW3	23.663	86.901	Burnpur	5.420	Moderate	1	1
OW4	23.619	87.110	Raniganj	2.900	Very High	0	0
OW5	23.695	87.092	Jamuria	7.150	Low	1	1
OW6	23.712	87.074	Jamuria	5.700	Moderate	0	1
OW7	23.689	87.075	Jamuria	3.850	High	1	1
OW8	23.701	87.083	Jamuria	3.550	High	1	1
OW9	23.616	87.142	Raniganj	2.430	Very High	0	0
OW10	23.617	87.131	Raniganj	2.100	Very High	1	1
OW11	23.601	87.120	Raniganj	2.560	Very High	0	0
OW12	23.662	87.097	Raniganj	2.770	Very High	1	1
OW13	23.658	87.073	Raniganj	2.030	Very High	0	1
OW14	23.696	86.925	Asansol	2.270	Very High	1	0
OW15	23.702	86.898	Asansol	4.650	High	0	1
OW16	23.714	86.858	Kulti	4.560	High	1	1
OW17	23.682	86.869	Burnpur	3.940	High	1	1
OW18	23.641	86.915	Asansol	3.250	High	0	0
OW19	23.662	86.967	Asansol	2.490	Very High	1	1
OW20	23.650	86.941	Asansol	7.900	Low	1	0
OW21	23.703	86.954	Asansol	4.120	High	1	1
OW22	23.673	87.014	Asansol	5.600	Moderate	1	1
OW23	23.679	86.974	Asansol	4.200	High	1	0
OW24	23.698	87.021	Asansol	14.250	Very Low	1	1
OW25	23.679	87.068	Jamuria	12.150	Very Low	1	1
OW26	23.684	87.079	Jamuria	8.500	Low	1	1
OW27	23.684	86.906	Asansol	5.750	Moderate	1	1
OW28	23.713	86.912	Asansol	5.630	Moderate	1	1
OW29	23.714	86.830	Burnpur	3.200	High	0	0
OW30	23.731	86.847	Kulti	5.560	Moderate	1	1
OW31	23.732	86.848	Kulti	5.960	Moderate	1	1
OW32	23.668	86.937	Asansol	7.800	Low	1	1
OW33	23.701	86.986	Asansol	3.200	High	0	0
OW34	23.640	87.104	Raniganj	5.302	Moderate	1	1
OW35	23.675	87.094	Jamuria	7.230	Moderate	1	1
OW36	23.712	87.048	Jamuria	7.560	Moderate	1	1
OW37	23.652	86.993	Asansol	3.312	High	0	0
OW38	23.644	86.946	Asansol	5.542	Moderate	1	1
OW39	23.721	86.885	Kulti	6.550	Moderate	1	1
OW40	23.698	86.841	Kulti	2.520	Very High	0	0
OW41	23.680	87.042	Asansol	5.550	Moderate	1	1
OW42	23.683	86.951	Asansol	6.532	Moderate	1	1
OW43	23.675	86.920	Asansol	5.524	Moderate	1	1
OW44	23.672	87.110	Jamuria	9.45	Very Low	1	1
OW45	23.630	87.108	Raniganj	5.520	Moderate	1	1
OW46	23.625	87.119	Raniganj	4.550	High	1	1
OW47	23.743	86.861	Kulti	8.550	Low	0	1
OW48	23.707	86.815	Kulti	6.650	Moderate	1	1
OW49	23.693	86.969	Asansol	5.210	Moderate	1	1
OW50	23.701	87.059	Jamuria	8.546	Low	1	1
1=Agree, O= Disagree							

Source: Prepared based on observation

4.4. Conclusion

Groundwater resource management is very crucial for maintaining the water availability in a sustainable manner, which is quite impossible without the proper investigation of groundwater conditions of any region. The present study area has a long-term experience of summer water crisis. Urban areas having such a complex hydro-geomorphological setup along with mining activities, it is essential to manage all kinds of water resources following the scientific principles of water resource management. In this context, the result of the current work may contribute significant input to the planner.

The five distinct categories groundwater prospect zones are identified in the Asansol Urban Agglomeration. The results of the study indicate that significant spatial variation of groundwater prospective zones are observed in the entire study area, which is associated with hydro-geomorphological characteristics including drainage condition, lineament density, soil texture, vegetation cover, slope, amount of rainfall etc. The results of two models depict a clear spatial coincidence among the distributional pattern of various groundwater potential zones in Asansol Urban Agglomeration. From the result of both models, it is clear that very high and high groundwater potential zones in this area are observed across the southern and south-western margin consisting of areas having alluvial formation, flood plain, coarse loamy soil, high vegetation cover, agricultural land, low drainage density and high lineament density. On the other hand, the maximum part of the study area experienced moderate, low and very low groundwater potential zones covering the middlemost part, north-east and eastern part of the study area. These areas are mainly associated with Kulti, Barakar and Raniganj formations, pediment-pediplain complex, built-up areas along with urban, commercial and industrial activities, fine soil texture and very low vegetation and rainfall. Although a spatial coincidence is observed in various groundwater potential zones of two models, a remarkable difference is found in the areal extension of various groundwater potential zones delineated by AHP and FR models. Only 5.15% area is delineated by AHP as a very high groundwater potential zone in Asansol Urban Agglomeration whereas 9.85% area is recognized as a very high groundwater prospective zone by FR model. Although results of both models (AHP and FR) are valid according to the ROC curve analysis but significant difference is observed in accuracy of the two models. Values of AUC prove that accuracy of FR model is very good whereas accuracy of the AHP model is good. FR model is basically based on ground reality whereas application of AHP to some extent depends on theoretical knowledge. Acquiring authentic data for the application of FR model is quite difficult and not available for the whole region whereas preparation of required data for the application of AHP model is comparatively easy and available. On the other hand, a very high expertise knowledge is essential for assigning the weightage of various thematic layers in AHP model as the result of the study totally depends on the priority and weightage of different thematic layers.

As groundwater is the main source of sweet water, any kind of scientific analysis regarding groundwater is very helpful for sustainable water resource management. Present study may also be useful for sustainable groundwater resource management all over the world. Application of the models depend on the geo-hydrological setup of any areas and to some extent on the judgemental capability of the researchers. Proper application of these models will definitely bring the fruitful result, which ultimately will help to sustainable groundwater resources management of any regions in the world.

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IDENTIFYING SUITABLE LOCATION FOR SURFACE RAINWATER HARVESTING STRUCTURE AND ASSESSING ITS POTENTIALITY

Abstract

Water crisis is the biggest problems for the living organisms in maximum part of the world. The scientists and researchers are always try to address this problem by introducing several methods and techniques for sustainable water resource management. Surface rainwater harvesting presents a sustainable solution to water scarcity, particularly in urban areas where traditional water sources are under strain. Rainwater harvesting is old but auspicious technology of sustainable water resource management. In general, the immediate barriers for installing rainwater harvesting techniques is a universal problem which includes the availability of suitable place, initial cost, lack of desired, sound technology etc. The present chapter mainly focuses on finding suitable locations for surface rainwater harvesting structures and assessing the potentiality surface rainwater harvesting in opencast mining pits and mining pit channels within the Asansol Municipal Corporation in West Bengal, India. The identification of appropriate locations for RWH structure has been made by utilizing eight different thematic layers which include surface elevation, land-use/land-cover, drainage, depression, geology, slope, rainfall and lineament density in GIS environment. The validation and characterization of these suitable location have been made using Google Earth and associated thematic layers. The repurposing of defunct and operational mining pits for rainwater collection provides a dual benefit: mitigating water scarcity and addressing environmental concerns related to abandon mining sites. The potentiality of surface rainwater harvesting have been analyzed by using the non-functioning pit as natural reservoir and connecting the mining pit channels for increasing the surface runoff. The high resolution google earth image along with primary field measurement has been utilized for this work. The result of the study depicts that most of the identified locations as high (10.62%) and very high (4.12%) are suitable for constructing any kind of natural or manmade RWH structure and the proper utilization of non-functioning mining pit and pit channels have a huge potentiality of surface rainwater

harvesting in Asansol Municipal Corporation. This innovative rainwater harvesting strategy not only provides a sustainable water resource but also contributes to the reclamation of degraded mining landscapes. By transforming mining pits into functional water reservoirs, the Asansol Municipal Corporation can enhance its water security, promote sustainable urban development, and set a precedent for other regions facing similar challenges.

5.1. Introduction

Water scarcity is a pressing challenge facing urban areas worldwide, exacerbated by rapid urbanization, population growth, and climate change. In regions like Asansol, West Bengal, India, this issue is particularly acute, where industrialization and urban expansion have placed immense pressure on local water resources. Increasing water scarcity and the gradual decline in water quality from point and non-point sources of pollution are creating a significant threat to sustainable human development (Jha et al., 2014). Rapid population growth and human activities, combined with the impacts of global environmental change, have greatly heightened the vulnerability of human systems to fluctuations in water quantity and quality (Nazemi & Madani, 2018). Asansol, once a thriving coal-mining hub, has witnessed the transformation of its landscape due to extensive open cast mining activities. However, the legacy of mining has left behind vast, abandoned pits and channels, presenting both challenges and opportunities for sustainable water management. Highly urbanized cities continually face challenges in establishing a sustainable urban water system (An et al., 2015). Rainwater harvesting is regarded as a viable method to decrease water demand and serves as a crucial alternative resource for domestic and irrigation water supply (Assayed et al., 2013). In order to assure the reliability of rainwater harvesting as alternative water resources particularly for decentralized urban construction, the rainwater collection and storage system should be designed in a more scientific manner (Islam et al., 2014). In recent years, the concept of rainwater harvesting has gained prominence as a viable solution to mitigate water scarcity and enhance water security in urban areas. Rainwater harvesting involves collecting, storing, and utilizing rainwater for various purposes, including irrigation, industrial processes, and domestic consumption. The benefits of rainwater harvesting (RWH) in decreasing surface runoff and mitigating flood risks in urban areas were highlighted, along with its effect on groundwater recharge (Nachshon et al., 2016). While traditional rainwater harvesting techniques typically rely on rooftop catchment systems or surface water reservoirs, the utilization of open cast mining pits and channels represents a novel and potentially transformative approach.

Urban water supply security is typically measured by per capita water availability at the city level. However, the services citizens actually receive depend on several factors: (1) the city's access to water, (2) infrastructure for water treatment, storage, and distribution, (3) financial resources for constructing and maintaining this infrastructure, and (4) effective management for regulating and operating the water system (Krueger et al., 2019). Urban areas are highly vulnerable systems due to significant environmental pressures, large ecological footprints, and a heavy reliance on water from distant sources (Angrill et al., 2011). Traditionally, a city's water supply system has been planned by assessing water supply security. However, incorporating non-traditional water sources and accounting for climate change impacts now makes this assessment more complex. When modelling urban water supply systems, including non-traditional water sources adds to the complexity, and the uncertainty introduced by climate change impacts further complicates the evaluation of urban water supply security (Paton et al., 2014). Many countries have explored decentralized systems like rainwater harvesting (RWH) networks, which hold potential for supplementing existing centralized systems to help mitigate the water crisis (Temesgen et al., 2016). The current decision support frameworks should integrate the strengths of adaptive management and integrated urban water management at both strategic and operational levels. They emphasize that incorporating social learning and engagement is essential for achieving this integration (Pearson et al., 2010). At present accessibility of fresh water throughout world is decreasing progressively mainly because of increasing urban industrial activities and over draft of ground water which requires alternative water managing scheme (Selvam et al., 2015; Tiwari et al., 2015, 2018). For addressing the problems of disparity between water availability and requirement under varying climatic situations rainwater harvesting is a very useful technique (Kanta et al., 2017).

In India Rain Water Harvesting(RWH) techniques is very useful as rainfall occurs only for 3-4 months during rainy season (Rahimi, 2017). The potential advantages from RWH are reducing potable water demand from main water sources, reducing overflow into urban storm water , and reduction of overflow risk from storm events (Eroksuz & Rahman, 2010; He et al., 2009; Roon, 2007; Villarreal & Dixon, 2005; Zhang et al., 2012). Many traditional RWH system in India either not working properly or fail to meet the rising demand of modern communities (Singh & Ravindranath, 2006). In Indian history of water development, the past two decades are characterized by a boom in water harvesting which remarkably different from traditional harvesting in terms of purpose and context due to scientific and technological up gradation (Kumar et al., 1998). RWH is treated as a sustainable technique for urban water cycle management which also helps to restrict the unscientific rising tendency of surface and ground water extraction (Matos et al., 2015). In developing countries, the possibility of RWH as an substitute water source in city spaces have been unnoticed (Temesgen et al., 2016). Public participation is the key factor for emerging RWH as an alternative which is mainly a local intervention with local benefits on ecosystems and human livelihood. RWH is a practical choice for water supply and a low cost mitigation approach for urban runoff (Nnaji & Mama, 2014). RWH is the auspicious means of augmenting the limited surface and underground water resources in areas where present water availability is insufficient to encounter the rising requirement (Aladenola & Adeboye, 2010).

RWH is the simple technique of collecting rainwater and use accordingly. Surface RWH is the process of storing rainwater on naturally depressed surface area or on constructing artificial storage on earth surface. It is really hard for water engineers to select appropriate area for RWH structure together with evaluation of RWH potential (Al-ghobari & Dewidar, 2021). It is very essential to find the appropriate area of surface RWH based on physical parameters like geology, geomorphology, slope, drainage, soil, vegetation, rainfall and lineament to enhance the rate of natural storage on surface.

Opencast mining in the Asansol Municipal areas of West Bengal, India, has been a pivotal aspect of the region's industrial landscape for over a century. This mining method, employed extensively in these coal-rich regions, involves the surface extraction of coal deposits through the removal of overlying soil and rock layers. The process encompasses site preparation, drilling, blasting, material extraction, and pit formation, resulting in expansive mining pits that shape the local geography. The history of mining in Asansol and Raniganj dates back to the late 19th century when British colonial rulers initiated large-scale coal extraction to fuel the burgeoning industrial revolution. Since then, opencast mining has evolved into a sophisticated operation, employing advanced machinery and techniques to extract coal efficiently from shallow depths. Open cast mining, characterized by large excavations to extract minerals or ores, often leaves behind vast, deep depressions once mining operations cease. These excavations, if not rehabilitated properly, can become ecological liabilities, leading to soil erosion, habitat degradation, and groundwater pollution. Presently, opencast mining in Asansol is characterized by the systematic excavation of coal seams using heavy equipment such as excavators, haul trucks, and draglines.

Mining pit channels refer to the excavated pathways or channels created during open-cast mining operations to access and extract mineral deposits, typically coal, from beneath the earth's surface. These channels are formed through the systematic removal of overlying soil, rock, and other geological materials to expose the mineral seam. As mining progresses, the channels expand and deepen, often resulting in large, open pits that define the mining landscape. Mining pit channels in the Asansol and Raniganj areas of West Bengal, India, represent a significant aspect of the region's mining landscape. These channels, formed through opencast mining operations, play a crucial role in the extraction of coal and other minerals from the earth's crust. Mining pit channels are the result of systematic excavation and removal of overlying soil and rock layers to expose mineral deposits, primarily coal. These channels vary in size and shape, ranging from small, shallow pits to vast, expansive excavations spanning several hectares. Mining frequently changes the landscape significantly, impacting groundwater, surface water, and environmental resources (Raghavendra & Deka, 2015). The formation of these channels alters the natural topography, creating distinctive features across the landscape.

The utilization of open cast mining pits and pit channels for surface rainwater harvesting in Asansol Municipal Corporation presents an innovative solution to address water scarcity in the region while repurposing industrial landscapes for environmental benefit. The quarry sites of Chasnala mining area in Dhanbad can be effectively used for surface runoff storage structure (Kumar, 2016). This initiative involves assessing abandoned mining pits for suitability, designing infrastructure such as retention structures and pipelines, and implementing rainwater collection and storage systems. Collected rainwater undergoes treatment processes and is distributed for various uses, including agricultural irrigation and groundwater recharge. Benefits include enhanced water security, environmental restoration, and community development. Through responsible land use practices and stakeholder engagement, this project demonstrates a sustainable approach to water management in Asansol Municipal Corporation.

Here is how utilizing open cast mining pits for surface rainwater harvesting can be implemented:

Assessment and Planning: The first step involves assessing abandoned open cast mining pits for their suitability for rainwater harvesting. Factors such as size, depth, geological composition, and proximity to water sources should be considered. Detailed hydrogeological studies may be necessary to determine the potential for rainwater collection and storage.

Design and Infrastructure Development: Based on the assessment, engineers and environmental specialists can design infrastructure for rainwater harvesting. This may include constructing retention structures such as dams, weirs, and silt traps to capture and retain rainwater runoff within the mining pits. Additionally, lining the pits with impermeable materials can prevent seepage and maximize water storage capacity.

Water Collection and Storage: During rainfall events, water collected on the surface of the mining pits is directed towards designated collection points using channels or pipelines. This water is then stored within the pits for later use. Depending on the scale and purpose of the rainwater harvesting project, storage reservoirs or tanks may be installed to store excess water during periods of heavy rainfall.

Water Treatment and Distribution: Prior to distribution, collected rainwater may undergo treatment processes to improve its quality and suitability for various uses. Treatment methods may include filtration, sedimentation, and disinfection to remove impurities and pathogens. Once treated, the harvested rainwater can be distributed for agricultural irrigation, industrial processes, groundwater recharge, or potable water supply, depending on local needs and regulations.

Monitoring and Maintenance: Regular monitoring and maintenance of rainwater harvesting infrastructure are essential to ensure optimal performance and longevity. This includes inspecting retention structures for signs of erosion or damage, testing water quality, and clearing debris to prevent blockages. Additionally, ongoing community engagement and stakeholder involvement can help foster a sense of ownership and ensure the sustainability of the project.

Surface rainwater harvesting holds significant importance for Asansol Municipal Corporation, particularly in addressing the challenges of water scarcity and ensuring sustainable urban water management. Asansol, like many rapidly growing urban areas, faces increasing demand for water due to population growth, industrialization, and urban expansion. Surface Rainwater Harvesting can help alleviate pressure on the city's traditional water sources, such as rivers and groundwater, which are often overexploited. By capturing and storing rainwater, the city can not only reduce flooding and waterlogging during monsoon seasons but also create a reliable supplementary water source for domestic, agricultural, and industrial use. Furthermore, rainwater harvesting contributes to groundwater recharge, improving the long-term water security of the region. Incorporating this practice into Asansol's urban planning is essential for achieving a more resilient and sustainable water management system. The Asansol Municipal Corporation, with its history of coal mining and industrialization, provides a unique context for exploring the utilization of abandoned mining infrastructure for rainwater harvesting. The region's extensive network of open cast mining pits and channels, once sites of intensive resource extraction, now stands as dormant reservoirs awaiting repurposing. By harnessing these abandoned mining sites for rainwater harvesting, Asansol has the opportunity to address its water scarcity challenges while simultaneously reclaiming degraded landscapes and promoting environmental sustainability.

From the above discussion it is clear that RWH has a multiple advantages starting from reducing pressure on main water source, urban flood control, low cost etc. Considering the immense importance of RWH, the present chapter has been designed to identify the suitable location for surface rainwater harvesting and assessing the potentiality of surface rainwater harvesting in opencast mining pits and pit channels within Asansol Municipal Corporation. This chapter has been designed on the basis of following research questions provide the answer- Is it possible to introduce surface rainwater harvesting in AMC? Are there any suitable places for constructing surface rainwater harvesting structure? What are the potential storage capacities of open cast mining pits for surface rainwater harvesting? How do interconnected mining pit channels contribute to the augmentation of surface water storage capacities?

The significance of this study lies in its potential to address multiple interconnected challenges facing Asansol and similar urban areas. Firstly, by leveraging abandoned mining infrastructure for rainwater harvesting, the region can tap into alternative water sources to alleviate pressure on existing water supply systems. Secondly, the utilization of open cast mining pits and channels for rainwater harvesting offers a sustainable solution to the problem of abandoned mine reclamation. Rather than allowing these sites to remain as ecological liabilities, repurposing them for water storage and conservation contributes to environmental restoration and biodiversity conservation. Thirdly, rainwater harvesting has the potential to generate socio-economic benefits for local communities in the Asansol Municipal Corporation. By providing access to reliable water resources, rainwater harvesting supports agricultural livelihoods, enhances food security, and stimulates economic growth.

5.2. Materials and Methods

5.2.1 Materials and Methods of Identifying Suitable Location

The materials and methods used in this study, including the collection of data, preparation of thematic layers, and the calculation procedures of the Analytical Hierarchy Process (AHP), have been thoroughly discussed in Chapter 4. Since the same thematic layers and methodological approach were employed for identifying suitable locations for surface rainwater harvesting (RWH) structures in this chapter, they will not be reiterated in detail here.

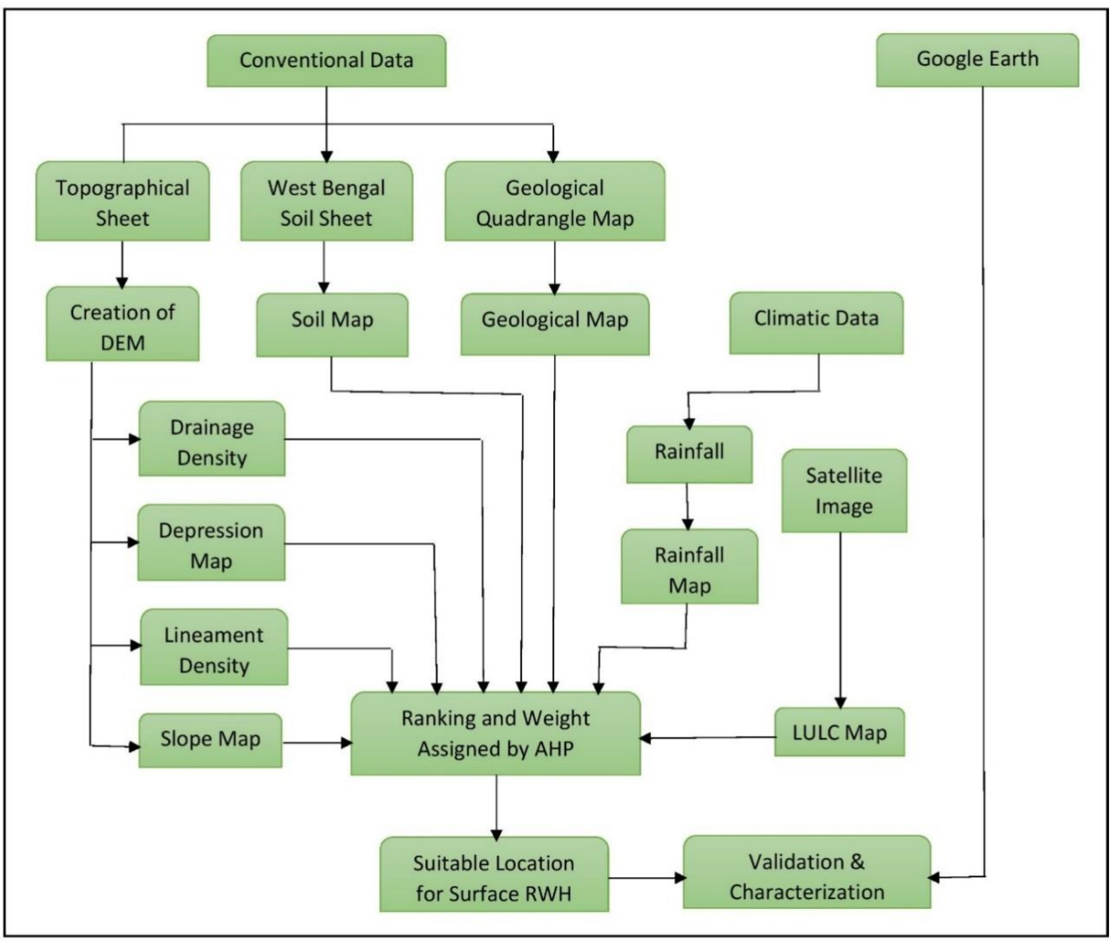

Fig.5.1: Methodological Flow Chart for Identifying Suitable Location

5.2.2 Assignment of Weight by AHP Method

Analytical Hierarchy Process (AHP) , a multi-criteria decision making tool was established by Thomas L. Saaty in 1970 (Hell et al., 2013; Podvezko, 2009). It is a organized decision-making procedure that includes using experts' knowledge to govern the rank and weights by creating an eigenvalue pairwise comparison matrix (Saranya & Saravanan, 2020). The main use of the AHP is the determination of choice difficulties in a multi-criteria situation (Forman & Gass, 2001). Recently AHP method for multi-criteria decision making has been extensively used (Mallick et al., 2019). Eight different parameters including depression area, geological unit, slope, LULC, rainfall, soil texture, lineament density and drainage density which have a direct impact on surface runoff and infiltration have been used in AHP methods. Rank and Weights for all the parameters or layers have been assigned based on the influence of each layer on accumulation of surface runoff and reducing infiltration capacity as the primary objective of this study is to find suitable location for Surface rain water harvesting. For the assignment of weights of each parameter, general controlling factors of surface runoff and infiltration have been considered. All the eight layers that have been used here have a direct influence on surface runoff and infiltration which ultimately determine the accumulation of water on the earth surface of any regions. Following the general factors controlling surface runoff and infiltration, maximum weight has been given on the depression area as it acts as a natural water accumulation point on the earth surface. In similar ways geological structure and slope have been ranked after depression by considering the influence of geological structure and slope on surface runoff and infiltration as geological structure of any regions determine infiltration rate and suitability of surface condition for accumulating water. On the other hand slope has a direct relation to surface runoff as area having high slope is used to experience high rate of surface runoff. LULCs has been considered and ranked after geological units as it acts as a direct controlling factor of surface runoff and infiltration. Urbanized areas reduce the infiltration rate whereas increasing infiltration rate is experienced in agricultural land. LULCs of any region also determine the availability of open space for constructing surface rainwater harvesting structures. Soil texture has been considered and ranked after LULC as porosity and permeability of any regions directly depend on soil texture which ultimately control the infiltration rate. Similarly, rainfall has been considered as the amount of rainfall of any region ultimately determines the possibility that how much amount of water may be harvested. Ultimately, lineament density and drainage density have been considered and ranked after soil texture as lineament density explains the condition of existing joints and cracks on the surface which helps to increase the infiltration rate. Surface stability is also determined by lineament density which is the basic prerequisite of constructing surface RWH structure. On the other hand, drainage density is associated with low slope and high accumulation of water as the river itself acts as a surface water holding unit. For assigning the proper weights and ranks for each layer, field experiment results reflected on various hydrological literature and views of different experts available on existing literature also have been considered. Finally, by combining both considerations of the general controlling factors of surface runoff and infiltration and following the views of different experts, rank and weights for each criteria have been fixed for AHP methods.

Table 5.1: Pairwise Comparison Matrix for AHP (Priority and rank of the layers)

Sl. No.	Layers	AHP Weightage values								Priority(%)	Rank	Normalized Weight
		1	2	3	4	5	6	7	8			
1	Depression Area	1	1.00	2.00	2.00	3.00	4.00	4.00	4.50	22.60	1	0.24
2	Geological Unit	1.00	1	2.00	3.00	3.00	3.00	3.50	4.50	24.17	2	0.24
3	Landuse/Landcover	0.50	0.50	1	2.00	2.50	3.00	3.50	4.00	16.19	3	0.16
4	Slope	0.50	0.33	0.50	1	3.00	3.50	4.00	3.50	13.93	4	0.14
5	Rainfall	0.33	0.33	0.40	0.33	1	3.50	4.00	4.50	9.78	5	0.10
6	Soil Texture	0.25	0.33	0.33	0.29	0.29	1	3.00	4.00	6.17	6	0.06
7	Lineament Density	0.25	0.29	0.29	0.25	0.25	0.33	1	3.50	4.44	7	0.04
8	Drainage Density	0.22	0.22	0.25	0.29	0.22	0.25	0.29	1	2.73	8	0.03
	CR=0.06											

Source: Calculated by the Author

Table 5.2 Weightage of various parameters for selecting suitable location of surface RWH

Category	**Sub-category**	**AHP Weightage Values**						**Normalized Weight**
		1	2	3	4	5	6	
Geological Unit	Pink Granite	1	3.00	3.00	4.00	4.00	6.00	0.38
	Barakar formation	0.33	1	3.00	3.00	4.00	5.00	0.25
	Kulti formation	0.33	0.33	1	3.00	4.00	4.50	0.17
CR = 0.09	Panchet formation	0.25	0.33	0.33	1	3.50	4.00	0.11
	Raniganj formation	0.25	0.25	0.25	0.29	1	3.50	0.06
	Alluvium formation	0.17	0.20	0.22	0.25	0.29	1	0.04
Depression Area	Very High	1	3.00	4.00	5.00	6.00		0.46
	High	0.33	1	3.00	4.50	5.00		0.27
	Moderate	0.25	0.33	1	3.50	4.00		0.15
CR = 0.08	Low	0.20	0.22	0.29	1	4.00		0.08
	Very Low	0.17	0.20	0.25	0.25	1		0.04
Landuse/Landcover	Agricultural Lana	1	3.00	4.00	6.00	7.00		0.47
	Vegetation	0.33	1	3.00	4.00	7.00		0.26
CR = 0.09	Water body	0.25	0.33	1	4.00	7.00		0.16
	Quarry and Mining	0.17	0.25	0.25	1	4.00		0.07
	Built up area	0.14	0.14	0.14	0.25	1		0.03
Slope	Very Low	1	1.00	3.00	4.00	5.00		0.37
	Low	1.00	1	2.00	3.00	4.00		0.31
	Moderate	0.33	0.50	1	2.00	3.00		0.16
CR = 0.01	High	0.25	0.33	0.50	1	2.00		0.10

	Very High	0.20	0.25	0.33	0.50	1		0.06
Rainfall	High	1	2.00	3.00				0.53
	Moderate	0.50	1	3.00				0.33
CR = 0.05	Low	0.33	0.33	1				0.14
Lineament Density	Very Low	1	2.00	3.00	4.00	5.00		0.41
	Low	0.50	1	2.00	2.50	3.00		0.24
CR = 0.08	Moderate	0.33	0.50	1	4.00	5.00		0.20
	High	0.25	0.40	0.25	1	5.00		0.10
	Very High	0.20	0.33	0.20	0.20	1		0.05
Soil	Fine loamy	1	2.00	3.00	4.00			0.46
	Loamy	0.50	1	2.50	3.00			0.29
CR = 0.06	Coarse loamy	0.33	0.40	1	4.00			0.18
	Coal Quarry	0.25	0.33	0.25	1			0.08
Drainage Density	Very Low	1	2.00	3.00	4.00	5.00		0.41
	Low	0.50	1	2.00	2.50	3.00		0.24
	Moderate	0.33	0.50	1	4.00	4.50		0.20
CR = 0.07	High	0.25	0.40	0.25	1	4.00		0.10
	Very High	0.20	0.33	0.22	0.25	1		0.05

Source: Calculated by the Author

5.2.3 Validation and characterization of identifying areas

Ultimately, the suitable location for surface RWH map has been validated and characterized by using google earth. For validation and characterization of suitable location 20 random points have been selected from Suitable Location for Surface Rainwater Harvesting map and the same points also have been identified in Google earth. Finally, by comparing the points in Google earth and Suitable Location for Surface Rainwater Harvesting map suitability for surface RWH has been justified. For characterization of suitable location different kinds of measurement like distance from nearest settlement, regional slope, covered area and surrounding associated features have been analysed with the help of google earth and Arc GIS 10.3 by utilizing all the thematic layers included in present study.

5.2.4 Identification and mapping of mining pits and pit channels

In the initial stage, open cast mining pits and pit channels have been identified using high resolution google earth images followed by the validation by field observation. Six major open cast mining pits purposively considering the area (>0.18km^2) and significant mining pit channels have been identified for the present study (Fig 5.2).

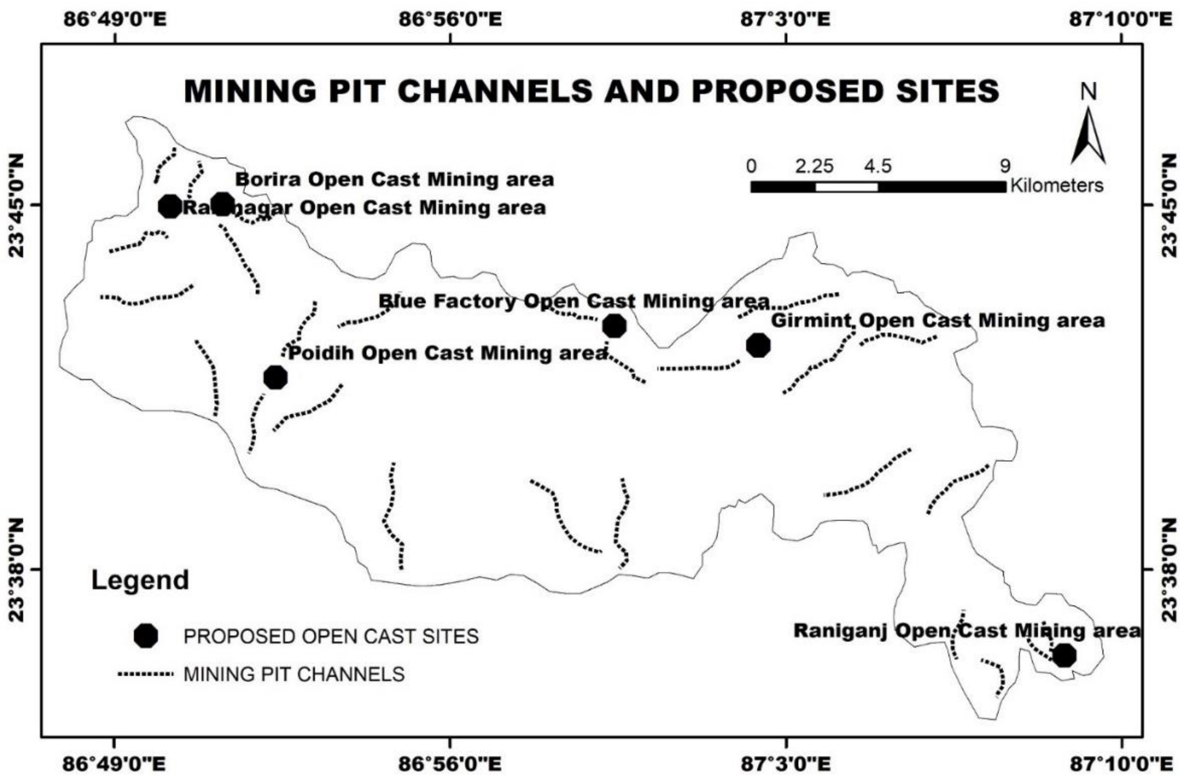

Fig.5.2: Location of Selected open cast mining pits and pit channels

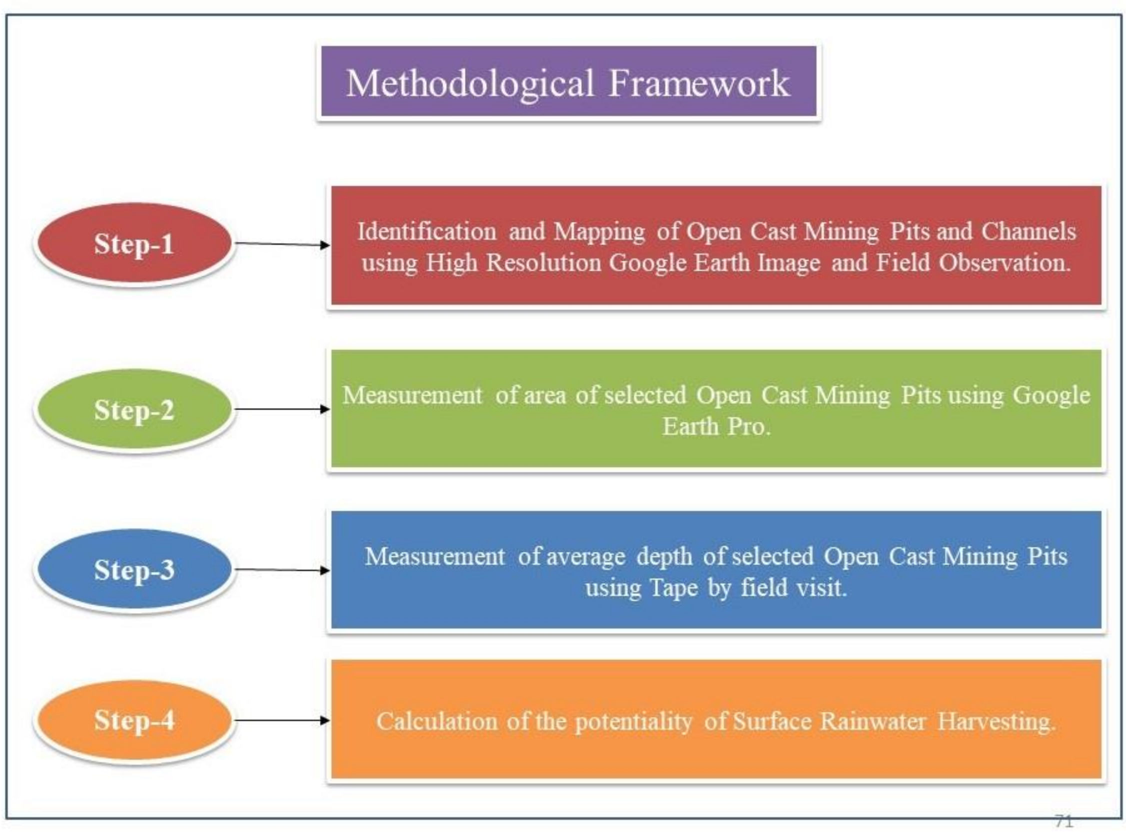

Fig.5.3: Methodological framework for Assessing the Potentiality

5.2.5 Measurement of Areas (Opencast pits)

After identifying the six major open cast mining pits, areas of these pits have been measured using measurement tools in Google Earth Pro environment.

5.2.6 Measurement of Average Depth

For the measurement of average depth of the open cast mining pits, depth of selective location of each pit has been measured in the traditional way using staff and tape. In addition, maximum depth information of each pit which is beyond measurable using staff and tape has been collected from the office of Eastern Coalfield Limited located in Asansol division. Finally, average depth of open cast mining pits have been calculated incorporating both primary and secondary information.

5.2.7 Calculation of Potential Volume

In the last stage for calculating the potential volume of rainwater which can be harvested from this open cast mining pits have been calculated using a simple method of area depth relationship as – Volume= Area x Depth.

5.3. Results and Discussion

5.3.1 Depression Area

Natural depressions serve as effective natural reservoirs, making them ideal locations for surface water harvesting (RWH). In the case of the AMC region, these depressions have been specifically identified for selecting suitable sites for surface RWH. Mining activities in the area have contributed to the formation of some large depressions, while much of the remaining landscape features minor undulating topography. Due to the capacity of large depressions to collect and store significant amounts of water, they have been assigned greater priority during the site selection process, with less weight given to areas of smaller depressions or more terrain that is moderate. (Fig. 5.4)

5.3.2 Geological Unit

Geology is very important for selecting suitable location for surface RWH as it controls the rate of infiltration. There are observed six lithological units in Asansol Municipal Corporation. A major portion of Asansol Municipal Corporation (AMC) is occupied by rocks of Raniganj formation which is followed by the structure of Panchet formation. Another two important formations are Kulti and barakar formation. Raniganj, Kulti and Barakar formation belong to Damuda group and mainly consist of sandstone, shale and coal originated in Permian age. Panchet formation is mainly consists of sandstone and shale and belongs to Gondwana super group. A minor part of AMC is composed by pink granite and alluvium formation. Pink granite is a part of Chotonagpur granite genesis complex and biotite and quartz biotite granite gneiss are main elements. Alluvium formation is a part of recent formation consists of sedimentary deposition. (Fig. 5.4)

5.3.3 Slope

Slope plays a critical role in determining suitable locations for reservoirs and rainwater harvesting (RWH) sites (Rajasekhar et al., 2020). It is a key factor because the slope directly influences the natural flow direction and velocity of surface water. In regions with steep slopes, water tends to flow rapidly, leading to quick runoff, whereas areas with gentler slopes allow for better water retention and infiltration. The AMC region, in particular, is characterized by predominantly steep slopes, which are associated with rapid surface runoff, making these areas less suitable for surface RWH. Only a small portion of AMC features very low slopes, primarily a result of past mining activities, where the terrain has been levelled or gently sloped. These areas with lower slopes are more conducive to collecting and storing rainwater, as they allow for slower water movement and greater retention capacity. As a result, during the selection process for RWH sites, the greatest weightage has been assigned to areas with very low slopes, recognizing their superior ability to retain water. Conversely, areas with steep slopes have been given minimal consideration due to their tendency for quick water runoff, which limits their potential as effective RWH locations (Fig. 5.4).

5.3.4 Land use and Land cover

Land Use and Land Cover (LULC) analysis is crucial for identifying suitable locations for surface rainwater harvesting (RWH). This study provides detailed information on the landscape, making it possible to determine areas where open land is available—essential for surface RWH. Without a thorough LULC assessment, it would be impossible to accurately identify these potential sites. In the case of the AMC region, approximately 24% of the land is covered by built-up areas, which are entirely unsuitable for surface RWH due to the impermeable nature of developed infrastructure. The dominant land use in AMC is agricultural land, covering nearly 66% of the area, making it the most viable option for RWH. Agricultural land, with its open and permeable surface, offers significant potential for capturing and storing rainwater. In addition to built-up and agricultural areas, a portion of AMC is occupied by quarry and mining sites. These areas present challenges for surface RWH, as their altered landscape may affect water retention. Other key LULC features include water bodies and vegetative cover, which are important parameters for understanding water flow and retention but may have limited direct potential for surface RWH. By thoroughly analysing the LULC patterns of AMC, agricultural land has been given the highest weightage in the selection process for RWH, as it presents the best opportunity for effective rainwater capture and storage. Built-up and other non-permeable areas, by contrast, receive minimal consideration due to their unsuitability for such purposes (Fig.5.4).

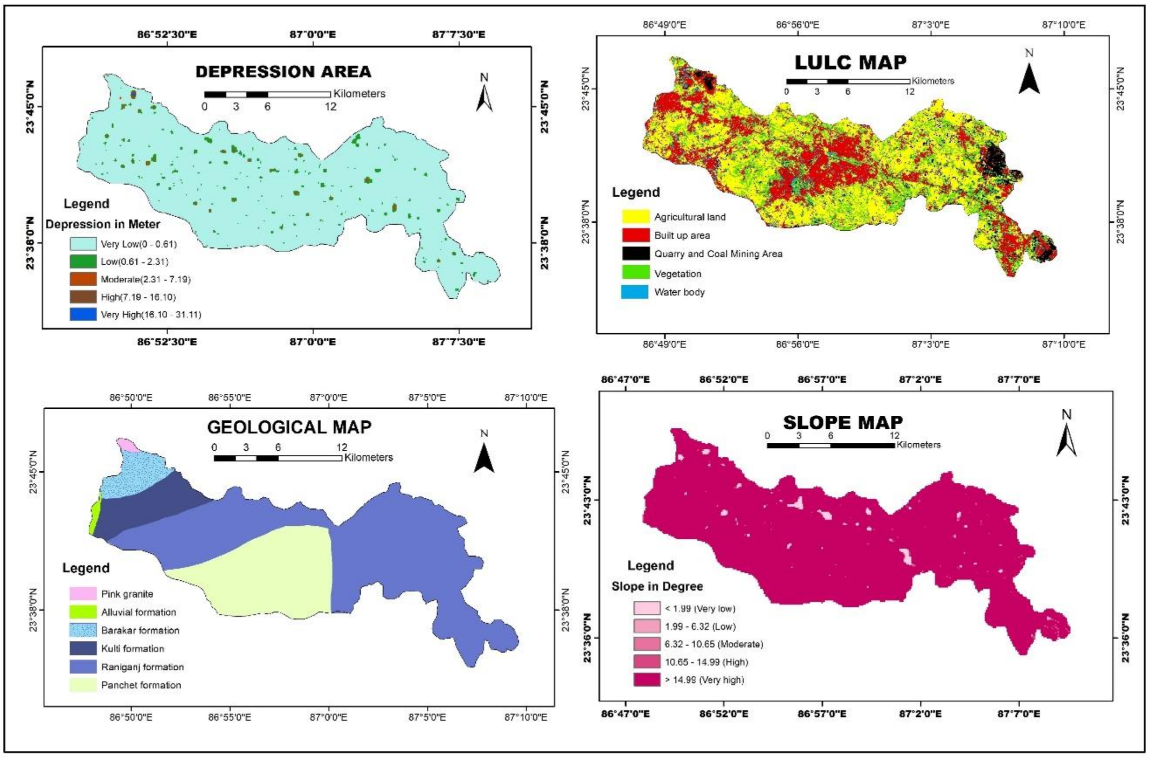

Fig.5.4: Depression area map, Geological map, Landuse/landcover map and Slope map

5.3.5 Soil Texture

The ability of soil to retain surface water is highly dependent on its texture, making soil characteristics a critical factor in selecting locations for surface rainwater harvesting (RWH). For effective surface RWH systems, soils with low permeability are ideal, as they allow water to be retained and stored rather than quickly draining away. In the AMC region, various types of loamy soils predominate. Specifically, three main varieties of loamy soil have been identified: fine loamy, loamy, and coarse loamy. Each of these soil types exhibits different levels of permeability, which directly influences their suitability for surface RWH. Fine loamy soil, due to its lower permeability, is highly effective at retaining water, making it the most favourable option for constructing RWH systems. As a result, it has been given the highest weight during the site selection process. Loamy soil, with moderate permeability, offers a balance between water retention and drainage and is considered the next best option. Coarse loamy soil, which has the highest permeability of the three, allows water to drain more quickly, reducing its retention capacity. Consequently, it has been assigned the lowest weight in the evaluation process. In summary, the fine loamy soil of AMC is regarded as the most suitable for surface RWH, followed by loamy and coarse loamy soils, based on their varying abilities to retain water. This careful consideration of soil texture ensures that the chosen sites maximize water retention and the efficiency of rainwater harvesting systems (Fig.5.5).

5.3.6 Rainfall Distribution

Rainfall is the most critical factor for any type of rainwater harvesting (RWH), as without adequate rainfall, the concept of RWH would not be feasible. In the AMC region, there is some variation in rainfall distribution, which directly affects the potential for RWH. The south-western part of AMC experiences relatively higher precipitation, making it a more favourable zone for rainwater collection. In contrast, the northern to north-eastern areas receive lower rainfall. Despite these regional differences, the overall average annual precipitation in AMC exceeds 1,200 millimetres, with the variation across the region remaining under 100 millimetres. Given the importance of rainfall in determining the effectiveness of surface RWH, areas with higher precipitation have been prioritized and assigned maximum weight during the site selection process. These regions have the greatest potential to capture and store rainwater. Conversely, areas with lower rainfall, while still contributing to the overall water resource, have been given lower priority due to their reduced capacity to support efficient RWH systems. By accounting for these variations in rainfall, the selection of RWH sites in AMC ensures that areas with higher precipitation are maximized for their potential, enhancing the overall success of rainwater harvesting efforts in the region (Fig.5.5)

5.3.7 Drainage and Lineament Density

Drainage density (DD) and surface rainwater harvesting (RWH) potential are inversely related, as established by studies (Jha et al., 2014; Karimi & Zeinivand, 2021). In areas with higher drainage density, the potential for effective RWH decreases, whereas in regions with lower drainage density, the potential increases. This relationship exists because a dense drainage network facilitates quick water runoff, reducing the capacity for water retention on the surface. Lineament density (LD), which refers to the concentration of natural fractures and faults in the landscape, also has a similar effect on surface water retention. Both drainage and lineament densities act as barriers to surface water storage by enhancing the infiltration capacity of the land. As a result, areas with high LD or DD allow more water to infiltrate into the ground, limiting the amount of water available for RWH. For the purpose of this study, five categories were established based on varying levels of drainage and lineament density. In keeping with the negative impact of high DD and LD on RWH potential, regions with higher drainage and lineament densities have been assigned lower weights in the site selection process for RWH. Conversely, areas with lower DD and LD, where water is more likely to be retained on the surface, have been given higher weightage. By carefully considering these factors, the RWH site selection process can prioritize locations where lower drainage and lineament densities contribute to greater water retention, thus maximizing the effectiveness of rainwater harvesting systems (Fig. 5.5).

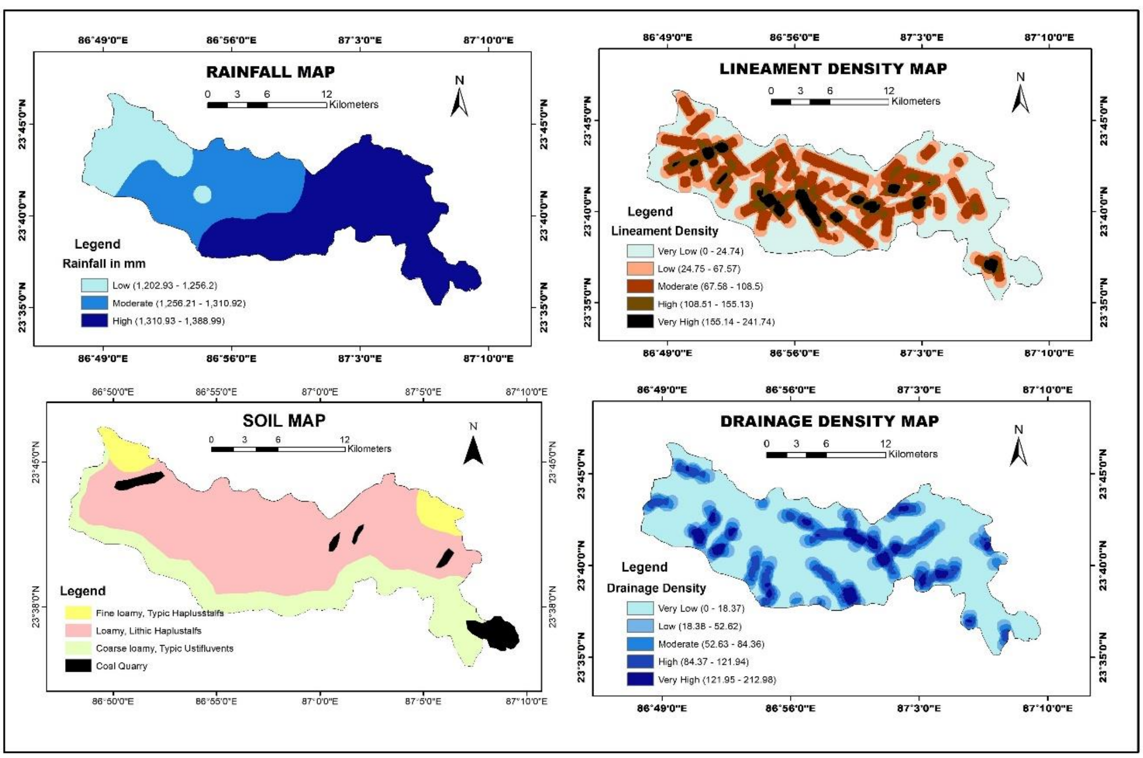

Fig.5.5: Rainfall Distribution map, Soil texture map, Lineament density map and Drainage density map

5.3.8 Suitable Location for Surface rainwater harvesting structure

Using the Analytical Hierarchy Process (AHP) method, a suitability map for surface rainwater harvesting (RWH) in the AMC region has been developed based on various weighted factors. The map categorizes the region into five distinct zones of suitability: very high suitable zone, high suitable zone, moderately suitable zone, low suitable zone, and extremely low suitable zone. The analysis reveals that 32.10% of AMC is classified as an extremely low suitable zone, while 30.25% of the area falls under the low suitable category. A moderate suitability for RWH is observed in 22.91% of the region. In contrast, only 10.62% of AMC is identified as highly suitable, and a mere 4.12% of the area is categorized as very highly suitable for surface RWH.

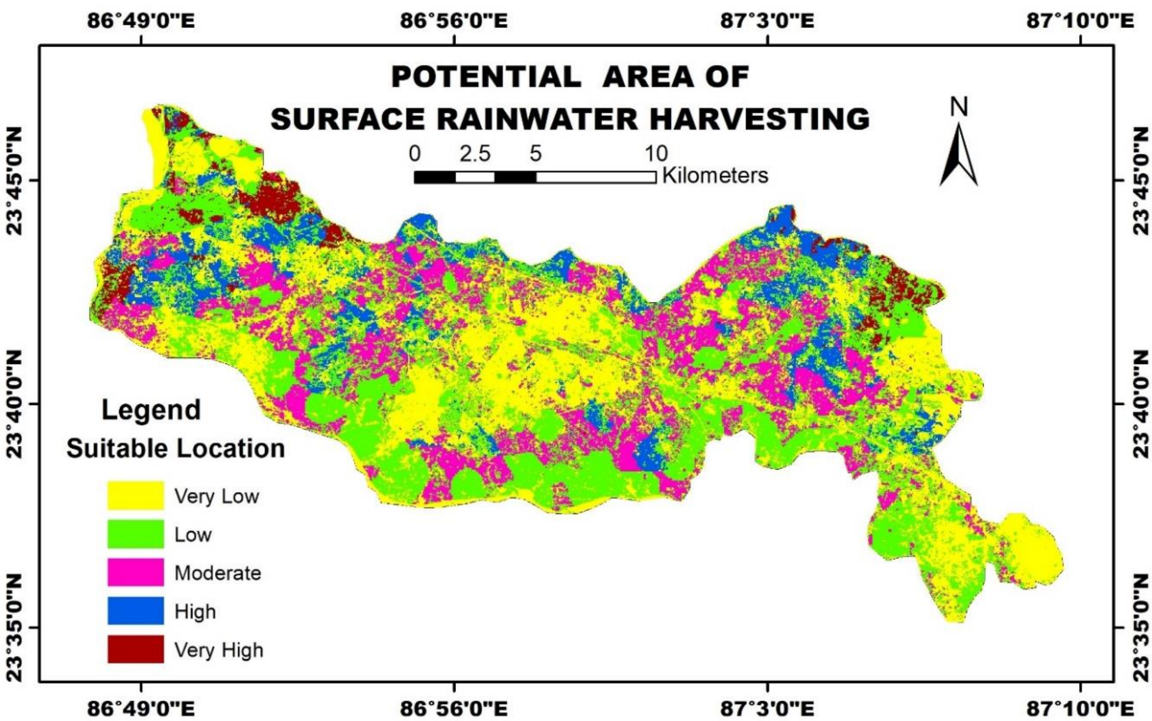

Fig.5.6: Suitable areas of Surface RWH

The very high and high suitable zones are generally dispersed throughout the region, primarily located in areas characterized by low slopes and natural depressions, which enhance the potential for water retention. The most suitable areas for RWH are concentrated in the south eastern and north-western parts of AMC, with additional pockets of highly suitable land found in the central east-west axis of the region. These findings highlight the importance of terrain features such as slope and depressions in determining optimal sites for surface RWH, with the most favourable zones providing the highest potential for rainwater capture and storage (Fig. 5.6).

5.3.9 Validation and Characterization

Table 5.3: Validation of Suitable location

Validation	Latitude	Longitude	Locality	Suitability
V1	23°44′36‴N	86°51′45″E	Borira	High
V2	23°44′09‴N	86°50′12″E	Kulti	Not suitable
V3	23°42′32‴N	86°48′36″E	Sanctoria	High
V4	23°42′36‴N	86°51′07″E	Bamandiah	High
V5	23°43′18‴N	86°50′10″E	Kulti	High
V6	23°42′01‴N	86°54′08″E	Mithani	High
V7	23°39′40‴N	86°59′03″E	Mohishila	High
V8	23°41′07″N	87°04′18″E	Kedulia	Very high
V9	23°41′47″N	87°05′16″E	Damodarpur	Very high
V10	23°42′36‴N	87°06′02″E	Jamuria	Moderately
V11	23°43′21‴N	86°04′11″E	Jamuria	Very high
V12	23°38′47″N	86°00′11″E	Damra	High
V13	23°41′45‴N	86°01′58″E	Girmint	Very high
V14	23°43′03‴N	86°58′25″E	Asansol	Moderately
V15	23°39′09‴N	86°55′11″E	Burnpur	High
V16	23°43′52‴N	86°53′18″E	Sitarampur	High
V17	23°44′11‴N	86°55′14″E	Talberia	Very high
V18	23°40′20‴N	86°52′56″E	Aluthia	Moderately
V19	23°42′11″N	86°59′56″E	Kalla	Very high
V20	23°42′56‴N	86°52′14″E	Neamatpur	High

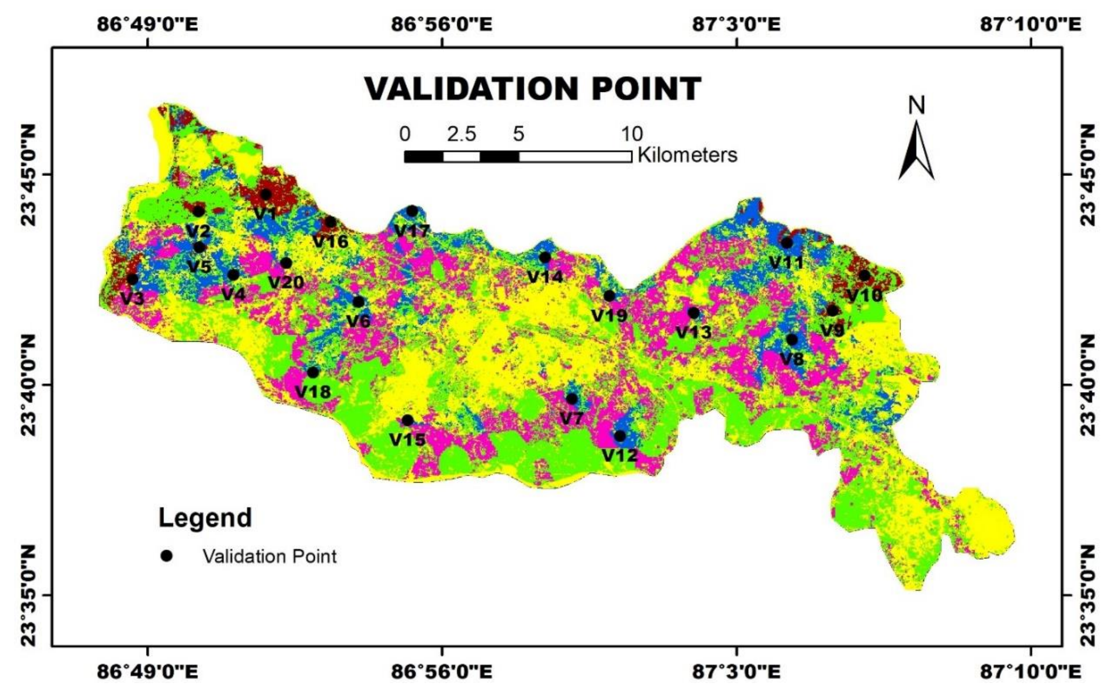

Fig.5.7: Location of Validation Point

Validation point 1: This point is located at Borira locality and highly suitable for surface RWH. It is a naturally downslope region surrounded by agricultural field. The distance from nearest settlement is 0.68km. This area is highly suitable for the construction of large surface RWH structure as well as have the potentiality to act as a natural reservoir with minor construction.

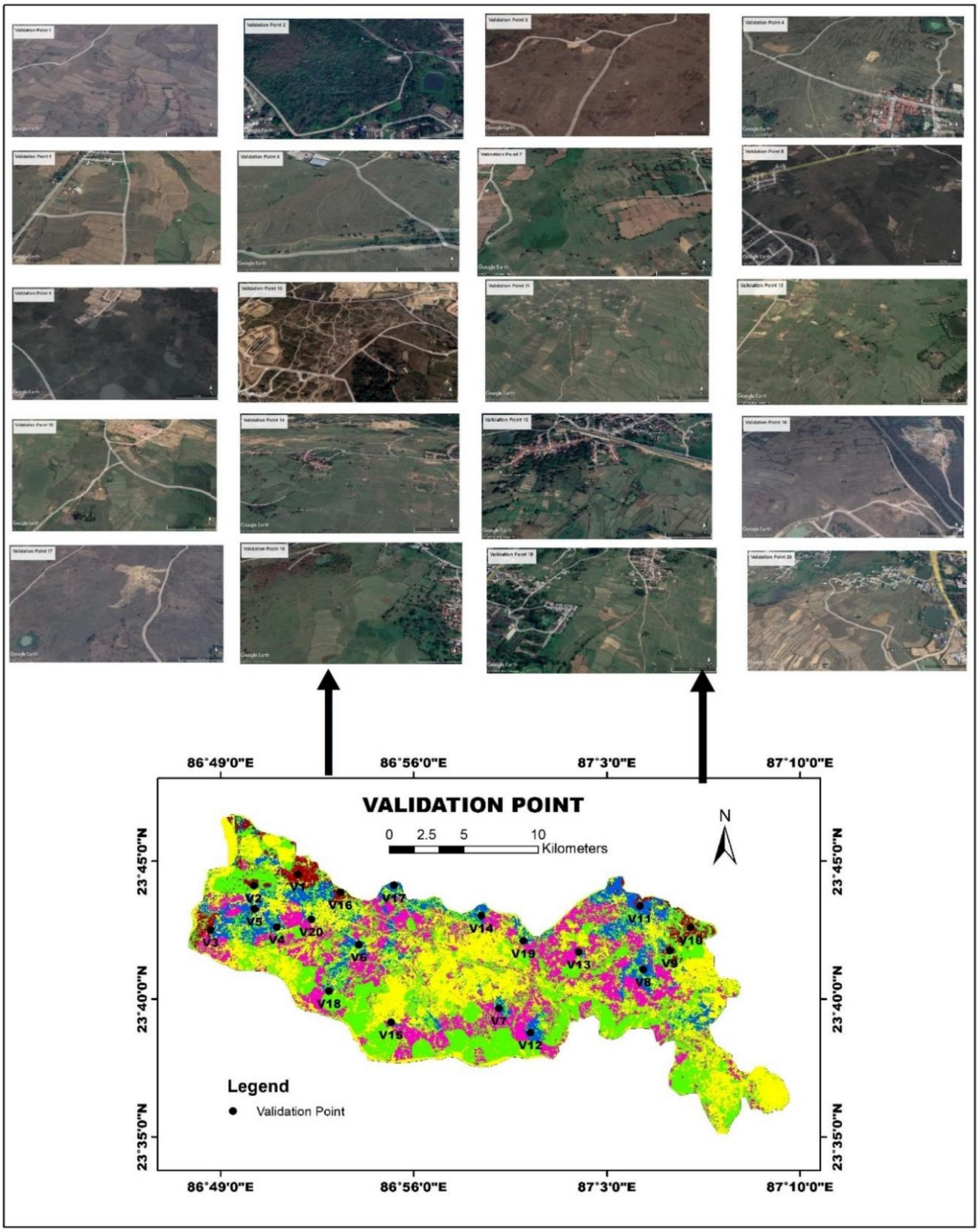

Fig.5.8: Integration of validation point with Google earth

Validation point 2: This is located at Kulti locality and not suitable for surface RWH as it is covered by vegetation having comparatively high slope.

Validation point 3: This is the Santoria area and also suitable for surface RWH. The distance from nearest settlement is 0.48 km and have low slope. This is also surrounded by agricultural land and small settlement unit. If necessary construction for surface RWH is done, then it may fulfil the demand of non-potable water of the local people during crisis period.

Validation point 4 and 5: This two point are very near to the settlement (0.13km). Being part of road side area and surrounded by settlement it is very useful for constructing small size surface RWH structure. If it is possible to maintain regular basis definitely it will help to reduce the pressure on main source of water.

Validation point 6: This point is located at Mithani area and have the qualities to act as a good natural reservoir. This area is also naturally down slope area surrounded by settlement and suitable mainly for small size construction.

Validation point 7, 8, 11, 12: Being a part of down slope region all these points has the potentiality of surface RWH. All these areas are suitable for large construction mainly for fulfilling the agricultural need as nearest settlement distance is more than 2 km from each points.

Validation point 9, 10: Point nine is located near Damodarpur and ten is Jamuria locality. Point nine is natural downslope region and surrounded by agricultural land have the high potentiality for surface RWH but point ten have comparatively high slope and not suitable surface RWH.

Validation point 13, 14: Point thirteen is located near Girmint and have very high potentiality for surface RWH. This is a naturally down slope area and suitable for large construction. But point fourteen has comparatively low potentiality because of high slope and dense settlement.

Validation point 15, 16, 17,18,19,20: The above mention five locations have potentiality of both small and large structure for using either domestic or agricultural purposes. All these points are located at down slope region, so all points have the quality of being natural reservoir. All these points have nearest settlement unit (within 1km) as well as agricultural land. These areas are highly suitable for installing both manmade and natural surface RWH structure.

5.3.10 Water Harvesting Capacities of Selected Mining Pits

The table (Table 5.4) below provides a detailed overview of the water harvesting capacities of six open cast mining pits located in various localities. Each pit's capacity is calculated based on its area and average depth, resulting in a total water storage capacity for all pits combined. The water harvesting capacity of six open cast mining pits varies based on their area, average depth, and location. Below is a detailed description of each pit's capacity.

Table 5.4: Detail of Proposed Surface rainwater harvesting sites

Sl. No.	Locality	Latitude	Longitude	Area in m^2	Average Depth in metre	Water Storage Capacity(Million Gallon)
1	Borira	23°44′56″N	86°51′23″E	1725541	27.50	10772.67
2	Ramnagar	23°45′01″N	86°50′06″E	374608	24.75	2449.28
3	Poidih	23°41′44″N	86°52′20″E	283554	10.58	792.52
4	Blue Factory	23°42′55″N	86°59′34″E	555737	11.20	1644.27
5	Girmint	23°42′21″N	87°02′26″E	257322	9.48	644.42
6	Raniganj	23°36′26″N	87°08′46″E	187149	8.75	432.59
Total Water Storage Capacity						**16735.75**

Source: Calculated by the Author

Borira opencast mining pit: The **Borira Pit,** located at latitude 23°44′56″N and longitude 86°51′23″E, has an area of 1,725,541 m² and an average depth of 27.50 meters. This pit boasts the largest water storage capacity among the six, holding approximately 10,772.67 million gallons of water due to its substantial area and depth.

Ramnagar opencast mining pit: The **Ramnagar Pit** is situated at latitude 23°45′01″N and longitude 86°50′06″E, covering an area of 374,608 m² with an average depth of 24.75 meters. It is the second-largest in terms of water storage capacity, able to store about 2,449.28 million gallons of water.

Poidih opencast mining pit: The **Poidih Pit,** located at latitude 23°41′44″N and longitude 86°52′20″E, spans an area of 283,554 m² and has an average depth of 10.58 meters. With a water storage capacity of 792.52 million gallons, it has a moderate capacity compared to other pits, reflecting its smaller area and depth.

Blue Factory opencast mining pit: The **Blue Factory Pit** is positioned at latitude 23°42′55″N and longitude 86°59′34″E, covering an area of 555,737 m² with an average depth of 11.20 meters. This pit has a significant water storage capacity of 1,644.27 million gallons, attributed to its large area.

Girmint opencast mining pit: The **Girmint Pit,** located at latitude 23°42′21″N and longitude 87°02′26″E, has an area of 257,322 m² and an average depth of 9.48 meters. It has a smaller water storage capacity of 644.42 million gallons, reflecting its modest area and depth.

Raniganj opencast mining pit: The **Raniganj Pit** is situated at latitude 23°36′26″N and longitude 87°08′46″E, with an area of 187,149 m² and an average depth of 8.75 meters. It has the smallest water storage capacity of 432.59 million gallons, due to its relatively smaller area and depth.

The combined water storage capacity of all six pits is 16,735.75 million gallons. This substantial capacity highlights the potential of these pits for water harvesting, which can be crucial for local water management and supply, especially in areas prone to water scarcity.

Fig.5.9: Google Earth View of selected Open Cast Mining Pits

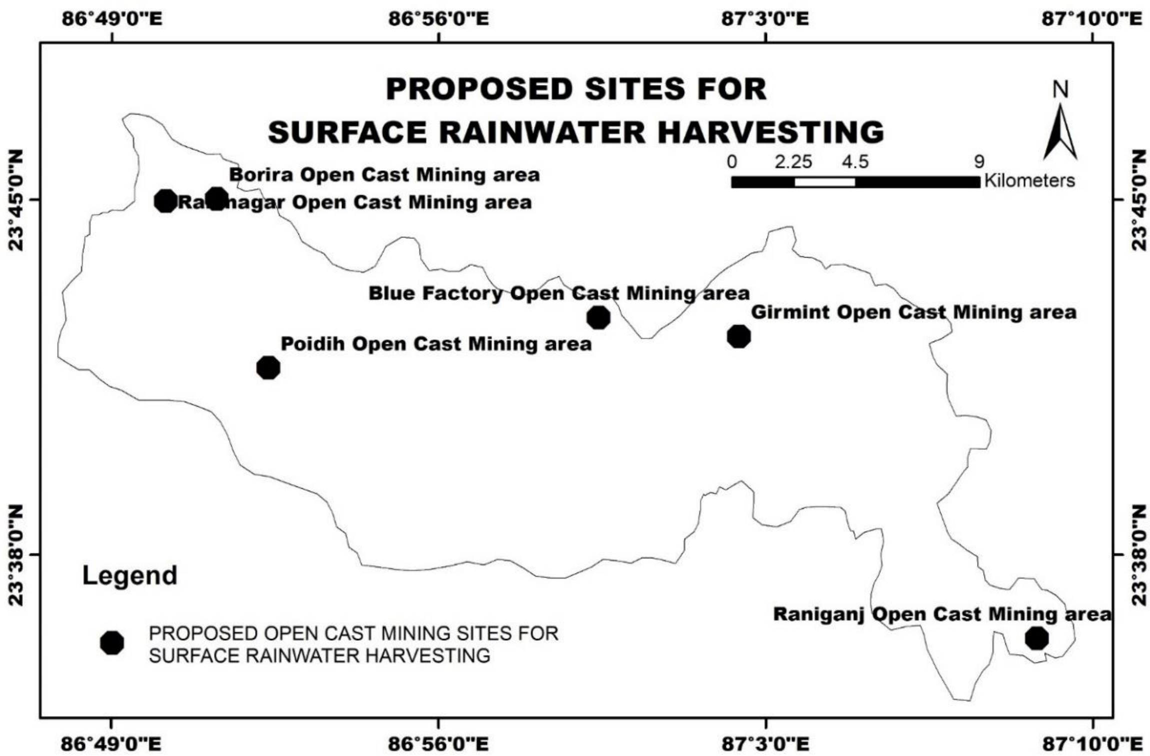

Fig.5.10: Locational detail of six selected opencast mining pits

5.3.11 Mining Pit Channels

Mining pit channels are the result of systematic excavation and removal of overlying soil and rock layers to expose mineral deposits, primarily coal. These channels vary in size and shape, ranging from small, shallow pits to vast, expansive excavations spanning several hectares. It is clear from the location map of mining pit and pit channels , all the open cast mining pits are surrounded by many mining pit channels. In this study, although the volumetric capacities of mining pit channels have not been considered for surface rainwater harvesting, connecting these pit channels to the nearest open cast mining pit will undoubtedly enhance the surface runoff capacity. This increased capacity will ultimately lead to more efficient surface rainwater harvesting, significantly augmenting the overall water storage potential of the mining pits.

In open cast mining, interconnecting mining pit channels can be a strategic method to manage surface runoff. This approach involves linking multiple pits and channels to create a network that can efficiently direct and manage water flow. The process aims to increase surface runoff, reducing water accumulation in mining pits and minimizing the environmental impact of mining activities. Interconnecting mining pit channels in open cast mining aims to improve water management, minimize erosion, and reduce environmental impact.

This involves a detailed site assessment, including topographic surveys and hydrological evaluations, followed by designing channels to handle runoff efficiently. The excavation and construction phase ensures minimal environmental disturbance while establishing connections between pits through openings or culverts. Water diversion structures like weirs and spillways are installed for controlled water flow, and erosion control measures, such as geotextiles and revegetation, are implemented to stabilize the soil. Regular monitoring and maintenance of the system are crucial to ensure optimal functionality and address any issues like debris accumulation or water contamination. The benefits include enhanced water management, reduced environmental impact, improved operational efficiency, and sustainable site management. However, challenges such as engineering complexity, environmental considerations, and significant initial and ongoing costs must be addressed. Through meticulous planning and implementation, interconnected pit channels can significantly enhance the management of surface runoff in open cast mining.

5.4. Conclusion

RWH is the best cost effective technology to meet the demand of non-potable water in water scarce region. In the present study area five different zones of suitability for surface RWH system have been identified, but after validation and characterization of these zone it is found that only two zones having very high and high potentiality of surface RWH are practically suitable for constructing any kind of natural and artificial surface RWH structure. Others three zones i.e. moderate, low and very low potential zones are totally unsuitable for surface RWH structure because of typical geo hydrological setting of these areas. The utilization of opencast mining pits and mining pit channels for surface rainwater harvesting in the Asansol Municipal Corporation area presents a substantial opportunity to enhance local water resources. Detailed analysis shows that the six identified mining pits possess a combined water storage capacity of 16,735.75 million gallons, highlighting their potential as significant reservoirs.

This study explores the feasibility and effectiveness of utilizing open cast mining pits and channels for rainwater harvesting in the Asansol urban area. It begins with a comprehensive assessment of abandoned mining sites to identify suitable locations for rainwater harvesting infrastructure. From previous experiences of surface RWH system, it is proved that regular maintenance is key to the success of any kind of rainwater harvesting systems which is the important barrier of constructing surface RWH structure along with willingness of the public. Although the selecting areas are suitable for meeting the demand of agricultural as well as domestic to some extent but roof top rainwater harvesting may be the best solution for meeting the non-potable household demand of the AMC. By integrating mining pit channels with the nearest open cast mining pits, the surface runoff capacity can be significantly increased. This integration would improve the efficiency of surface rainwater harvesting, allowing for the capture and storage of more rainwater. Such an approach not only addresses water scarcity issues but also promotes sustainable water management practices. It leverages existing infrastructure to create a reliable water supply system, mitigating the effects of seasonal variations in rainfall.

In conclusion, the strategic use of open cast mining pits and their channels for rainwater harvesting can play a pivotal role in ensuring water security for the Asansol Municipal Corporation, contributing to the sustainable development of the region. For successful implementation, it is crucial to conduct comprehensive hydrological and engineering studies to design effective channel-pit integration systems. Regular maintenance of these systems is also essential to ensure their efficiency and longevity. Additionally, community involvement and awareness programs can enhance the acceptance and success of these initiatives.

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CHAPTER-6

POTENTIALITY OF ROOFTOP RAINWATER HARVESTING IN ASANSOL MUNICIPAL CORPORATION

Abstract

Asansol Municipal Corporation (AMC) faces growing challenges in managing water resources due to increasing population and environmental changes. Rooftop rainwater harvesting (RRWH) emerges as a promising solution to enhance urban water sustainability. This chapter explores the potential of RRWH systems within AMC, focusing on their capacity to address water scarcity, support groundwater recharge, and reduce reliance on conventional water sources. The research evaluates the feasibility of RRWH by analysing local meteorological data, including average rainfall and distribution patterns, and assessing the suitability of rooftops in residential, commercial, and institutional buildings. The potential benefits of RRWH are multifaceted. Firstly, RRWH systems can significantly decrease the burden on municipal water supplies by providing an alternative source of water for non-potable uses such as landscaping, toilet flushing, and cooling. Secondly, by capturing and storing rainwater, RRWH can contribute to groundwater recharge, thereby supporting the long-term sustainability of local aquifers. Additionally, RRWH can mitigate the effects of urban flooding and reduce storm water runoff, which often leads to waterlogging and pollution. The study further examines the practical aspects of implementing RRWH, including system design, maintenance requirements, and cost considerations by cost analysis. It assesses the economic viability of RRWH by comparing initial investment costs and operational expenses. The research identifies key factors influencing the success of RRWH projects, such as community awareness, regulatory support, and integration with existing water management frameworks. In conclusion, the study underscores the significant potential of RRWH in AMC as a sustainable water management strategy. By providing a detailed analysis of its cost and implementation considerations, the research offers valuable insights for policymakers and urban planners to promote RRWH as a feasible solution for enhancing water resilience and sustainability in Asansol.

6.1 Introduction

Traditionally, a city's water supply system has been planned by assessing water supply security. However, incorporating non-traditional water sources and accounting for climate change impacts now makes this assessment more complex. When modelling urban water supply systems, including non-traditional water sources adds to the complexity, and the uncertainty introduced by climate change impacts further complicates the evaluation of urban water supply security (Paton et al., 2014). Urban areas worldwide face numerous challenges related to water scarcity, storm water management, and environmental sustainability. Increasing water scarcity and the gradual decline in water quality from point and non-point sources of pollution are creating a significant threat to sustainable human development (Jha et al., 2014). In response to these challenges, roof top rainwater harvesting has emerged as a promising solution to augment water resources, mitigate storm water runoff, and promote sustainable water management practices in urban environments. In regions with severe water scarcity, rooftop rainwater harvesting (RRWH) can provide a self-sufficient and independent domestic water supply (Shadeed & Alawna, 2021). Roof top rainwater harvesting involves the collection, storage, and utilization of rainwater that falls on rooftops for various non-potable uses such as irrigation, toilet flushing, and cleaning. The process typically begins with the installation of gutters and downspouts to channel rainwater from the roof surface to storage tanks or cisterns. Filtration systems and first flush diverters are employed to remove debris and contaminants, ensuring the quality of harvested rainwater. Depending on the application, harvested rainwater may undergo additional treatment, such as disinfection, before use. Rooftop Rainwater Harvesting (RTRWH) has been demonstrated as the most cost-effective and environmentally friendly method (Anchan & Shiva Prasad, 2021). In various regions around the globe, rooftop and rainwater harvesting have been implemented to address the shortcomings of traditional water supply systems in meeting the population's needs (Liaw & Tsai, 2004). Rainwater harvesting systems (RWHS) have shown greater efficiency in meeting demands when the Demand-Roof Area ratios are smaller (Lopes et al., 2017). Rainwater harvesting is regarded as a viable method to decrease water demand and serves as a crucial alternative resource for domestic and irrigation water supply (Assayed et al., 2013). The benefits of rainwater harvesting (RWH) in decreasing surface runoff and mitigating flood risks in urban areas were highlighted, along with its effect on groundwater recharge (Nachshon et al., 2016). By comparing the annual harvestable rainwater with irrigation needs, it was possible to determine the proportion of gardens that could be fully self-sufficient in water, as well as the number of gardens whose water needs could be partially met with rainwater (Lupia et al., 2017).

Highly urbanized cities continually face challenges in establishing a sustainable urban water system (An et al., 2015). Urban areas are highly vulnerable systems due to significant environmental pressures, large ecological footprints, and a heavy reliance on water from distant sources (Angrill et al., 2011). Asansol Municipal Corporation (AMC), a rapidly growing urban centre in West Bengal, India, faces significant challenges in managing its water resources due to its burgeoning population, industrial activities, and variable climate conditions. Rapid population growth and human activities, combined with the impacts of global environmental change, have greatly heightened the vulnerability of human systems to fluctuations in water quantity and quality (Nazemi & Madani, 2018). The rising demand for water, coupled with the impacts of climate change and infrastructural limitations, has underscored the urgent need for innovative solutions to enhance water sustainability and resilience. Rooftop rainwater harvesting (RWH) emerges as a viable strategy to address these challenges, offering a sustainable approach to water management that can complement traditional water supply systems. Although the potential for replacing the city's water supply is low, rainwater harvesting (RWH) from large institutions can significantly contribute to providing potable water to areas experiencing severe water shortages (Adugna et al., 2018).

Rooftop rainwater harvesting involves the collection and storage of rainwater from rooftops, which is then used for various purposes, including potable water supply, irrigation, and industrial applications. This method harnesses the natural precipitation falling on buildings to supplement local water supplies, reduce the burden on municipal systems, and contribute to groundwater recharge. In the context of AMC, where water scarcity is prevalent, RWH offers several advantages that align with the city's need for sustainable water solutions. AMC's rapid urbanization has led to increased water demand, placing significant stress on existing water supply infrastructure. The city's dependence on surface water sources, such as rivers and reservoirs, is further strained by pollution, over-extraction, and seasonal variations in water availability. RRWH provides an alternative source of water that can be particularly beneficial during periods of water scarcity. By capturing and utilizing rainwater from rooftops, AMC can reduce its reliance on conventional water sources, thereby mitigating the impact of water shortages on residents and businesses. Groundwater is a crucial resource for AMC, serving as a significant component of the city's water supply. However, excessive groundwater extraction and inadequate recharge have led to declining water tables and reduced aquifer levels. RRWH can play a critical role in enhancing groundwater recharge by directing collected rainwater into recharge wells or infiltration pits. This process helps replenish aquifers and supports the long-term sustainability of groundwater resources, ensuring a more reliable and resilient water supply for the future. Urban flooding is a recurring problem in AMC, exacerbated by inadequate drainage systems, rapid runoff from impervious surfaces, and heavy rainfall events. RRWH can contribute to flood mitigation by capturing rainwater at its source, thereby reducing the volume of runoff that flows into storm water drains and water bodies. Storm water runoff from urban areas often carries pollutants such as sediments, oils, and chemicals, which can degrade water quality in rivers and lakes. RRWH systems can help mitigate this issue by intercepting and filtering rainwater before it enters the storm water network. The implementation of RRWH systems offers both economic and environmental benefits. Economically, RWH can lead to cost savings on water bills for households and businesses by providing an alternative source of water for non-potable uses. Environmentally, RWH helps conserve water resources, reduce energy consumption associated with water supply and treatment, and decrease the carbon footprint of water management activities. For RRWH to be effective in AMC, several factors need to be considered, including system design, maintenance requirements, and community engagement. The feasibility of RRWH depends on the availability of suitable rooftops, the quality of collected rainwater, and the capacity of storage and filtration systems. Engaging with local communities, raising awareness about the benefits of RRWH, and providing technical and financial support are essential for successful implementation. Additionally, integrating RWH with existing water management policies and infrastructure can enhance its effectiveness and sustainability.

Despite its numerous benefits, roof top rainwater harvesting faces several challenges, including initial costs, space limitations, maintenance requirements, and water quality concerns. The upfront investment required for equipment and infrastructure may deter some homeowners or businesses from adopting rainwater harvesting systems, particularly in urban areas with limited space and regulatory barriers. Moreover, ensuring the proper maintenance and treatment of harvested rainwater is essential to prevent contamination and safeguard public health.

Therefore, it can be said that roof top rainwater harvesting offers a sustainable and cost-effective solution for addressing water scarcity and storm water management challenges in urban environments. By harnessing the natural resource of rainwater, cities can reduce their dependence on traditional water sources, improve water quality, and enhance overall resilience to climate change impacts. However, successful implementation of roof top rainwater harvesting requires careful planning, public awareness, supportive policies, and ongoing collaboration between stakeholders. Future research and innovation in rainwater harvesting technologies and practices are essential to maximize its potential benefits and promote widespread adoption in urban areas worldwide.

Considering the immense importance of rooftop rainwater harvesting in water resource management the present chapter has been designed to investigate the potentiality of rooftop rainwater harvesting in AMC. This chapter will provide the answer of obvious research questions including- What quantity of water can be harvested through rooftop rainwater harvesting? Can this harvested water fulfill the demand for non-potable water uses? In the end of the work, a comparative cost analysis has been made for answering the essential question- Which rooftop rainwater harvesting model would be optimal for sustainable water resource management?

6.2 Database and Methodology

6.2.1 Rainfall Pattern Analysis

In this study, 30 years of rainfall data (1992 to 2022) for the Asansol Municipal Corporation was collected from the Irrigation and Waterways Department, Durgapur Subdivision, West Bengal, to analyse the rainfall pattern. To understand the rainfall trend and pattern, basic statistical measures such as mean, median, standard deviation, and Mann-Kendall test were applied. The Mann-Kendall test is a non-parametric statistical test widely used for detecting trends in time series data. It is particularly useful in environmental science, hydrology, and climatology to identify trends in data sets over time, such as changes in temperature, precipitation, river discharge, and other environmental variables. The test is robust to missing values and can handle non-normally distributed data, making it versatile for various applications. Additionally, the rainfall data was plotted using line diagrams.

6.2.2 Average Household Population

The average household population was calculated using the 2011 census data for Asansol Municipal Corporation (AMC). By dividing the total population of each ward by the total number of households in that ward, the average household population for AMC was determined.

6.2.3 Selection of Household

In this study, a multistage and purposive sampling method was employed to select households. Initially, 15 wards were purposively chosen from the 'A' category wards comprising four municipalities proportionately. Subsequently, within each of these selected wards, twenty households were purposively selected for measuring roof areas (Fig 7.2). Category ‘A’ wards are typically characterized by advanced urban development, featuring a high concentration of concrete structures and high-rise buildings. These areas are particularly suitable for rooftop rainwater harvesting due to the abundance of large, flat surfaces available on buildings, which can efficiently collect and store rainwater (See Chapter-2).

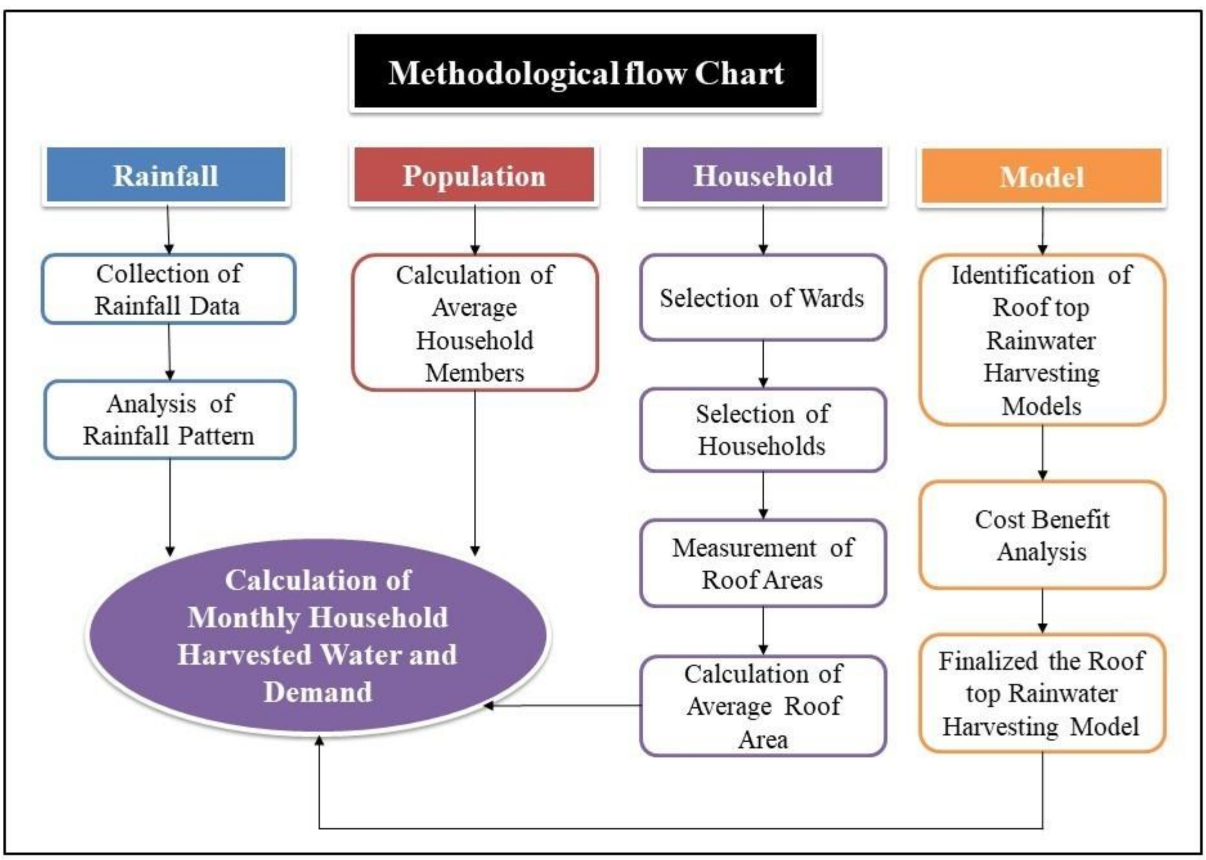

Fig.6.1: Methodological flow chart

6.2.4 Measurement of Roof Area

Google Earth Pro was utilized to measure roof areas using high-resolution images. The measurement tool in Google Earth Pro was employed to carefully measure the roof areas of each selected household. Google Earth had been used for calculating area by various researchers in the world. The surface area of Sana'a City has been calculated using data from Google Earth (Taher, 2014). The average roof area value of the twenty households was then used to calculate potential rainwater harvesting. The detail calculation procedures for average roof area are given below for the Ward no.49 (Fig 6.3). The average roof area for other wards have been calculated in similar way.

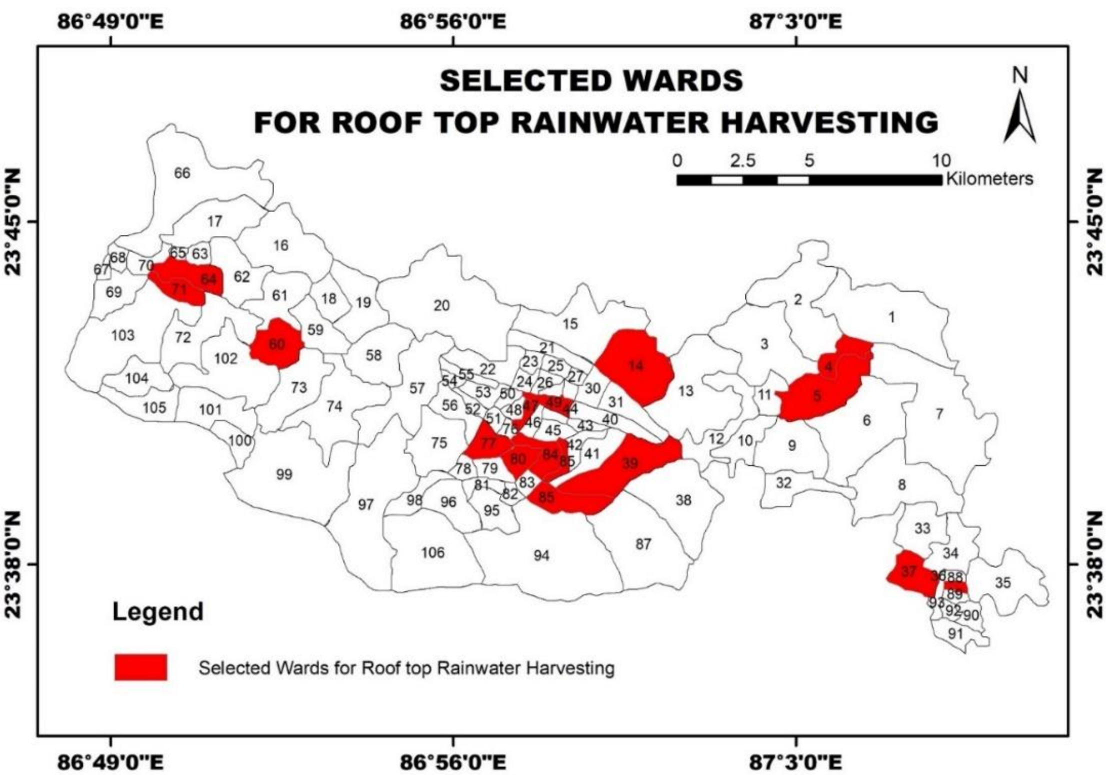

Fig.6.2: Selected Wards for Roof top rainwater harvesting

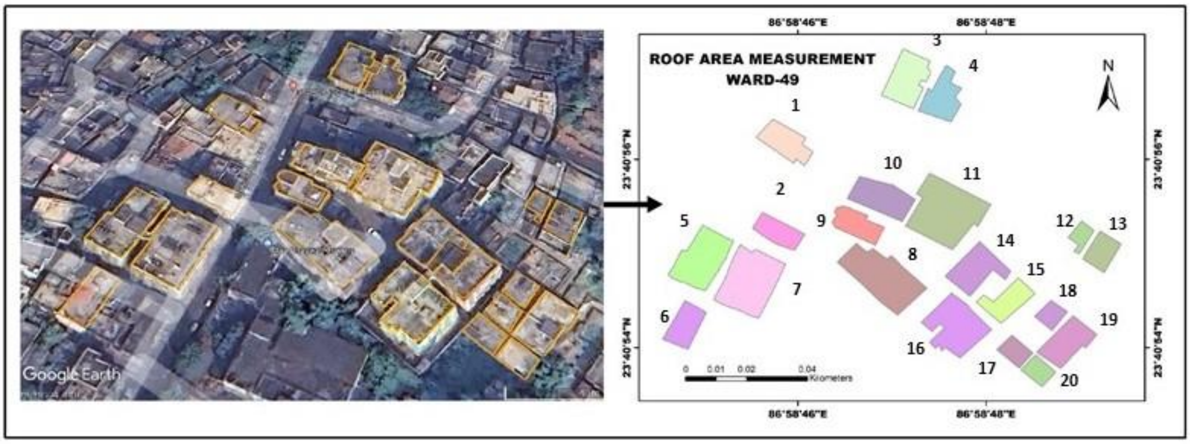

Fig.6.3: Measurement of Roof areas

6.2.5 Estimation of Monthly non-potable water demand

The average household population of AMC is 6. According to the Indian Standard Code of Basic Requirements for Water Supply (IS 1172:1993), the daily per capita non-potable water requirement is 45 litre. Therefore, the daily household non-potable water requirement is 270 litre (45 litre x 6 people). Consequently, the monthly household non-potable water requirement is 8,100 litre, or 8.10 m^3 (270 litre x 30 days).

6.2.6 Estimation of Monthly Rainwater Harvesting per household

The volume of rainwater that could be harvested per household per month was determined by adapting equation expressed in Ghisi et al. (2006). The equation is as:

$$VR = \frac{R \times HRA \times RC}{1000}$$

where,

VR monthly volume of rainwater per household (in cubic meters), *R* monthly rainfall depth in mm, *HRA* household roof area in m^2, *RC* runoff coefficient (unit less).

Table 6.1: Calculation of Average Roof Area

Ward No.	Household No.	Roof Area in m2	Average Roof Area in m^2
49 (Ward no. 49 has been selected for showing the methodology for measurement of roof area)	1	85.56	98.53
	2	70.23	
	3	102.40	
	4	102.19	
	5	111.48	
	6	70.23	
	7	148.64	
	8	130.65	
	9	83.61	
	10	90.24	
	11	150.12	
	12	75.03	
	13	92.90	
	14	95.24	
	15	92.90	
	16	130.06	
	17	69.68	
	18	69.68	
	19	130.06	
	20	69.77	

Source: Calculated by the Author

6.2.7 Selection of Best Model

A comparative cost analysis was conducted to select a suitable rooftop rainwater harvesting model for sustainable water resource management in AMC. Based on the analysis results, a gravity-fed rooftop rainwater harvesting system consisting of a plastic tank and PVC pipes was recommended for AMC.

6.3 Result and Discussion

6.3.1 Rainfall pattern of AMC

Thirty years monthly rainfall data (1992-2021) of AMC collected from Irrigation and Waterways Department, Durgapur Subdivision have been analysed in order to understand the general rainfall pattern, average monthly and annual rainfall and wet and dry months of the year under investigation.

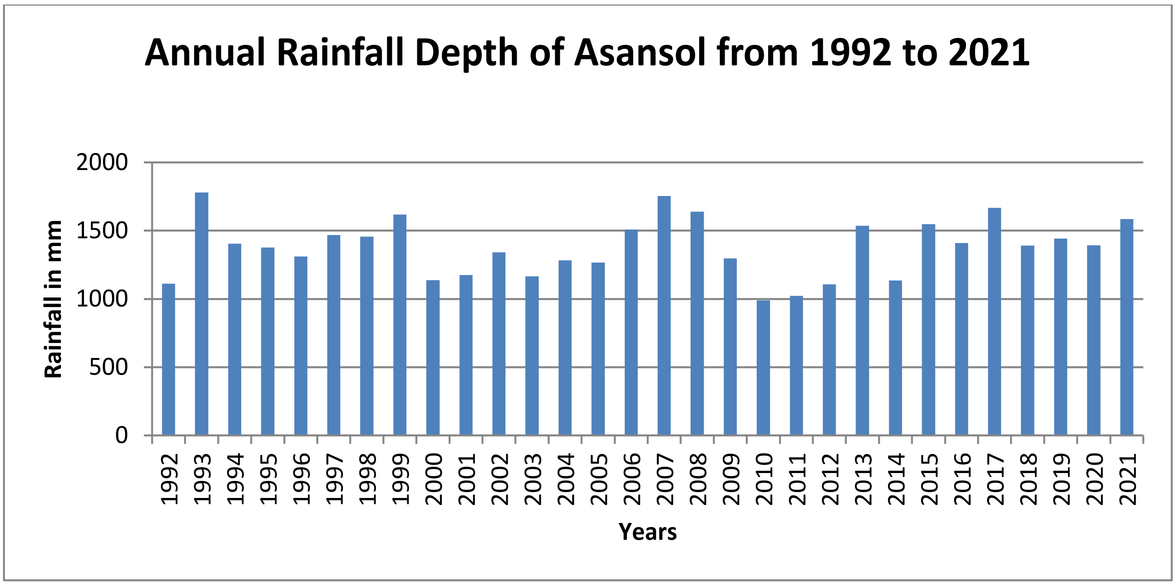

Fig.6.4: Annual Rainfall depth of AMC

With an average annual rainfall of 1376.87 mm, Asansol experiences a significant amount of rainfall. The standard deviation of 212.13 mm indicates a moderate level of variability in rainfall. There are noticeable fluctuations from the average rainfall amount, but these fluctuations are not extremely high. The standard error of 38.73 mm suggests that the average rainfall of 1376.87 mm is a reasonably precise estimate of the true mean rainfall for Asansol. The variance of 45,000 mm confirms that there is a reasonable spread in the rainfall data, supporting the observation of moderate variability from the standard deviation.

Table 6.2: Descriptive Statistics and Mann-Kendall Test

Rainfall	Descriptive Statistics				Mann-Kendall Test		
	N	Mean	Std. Error	SD	Z	P-Value	Tau
	30	1376.87	38.73	212.13	0.49	0.61	0.06

A 4-year monthly rainfall dataset, specifically from the years 1995, 2005, 2015 and 2021, has been plotted against their respective months to illustrate the nature of the rainfall distribution in the study area (Fig 6.5). The diagram (Fig 6.6) and the result of Mann-Kendall test clearly indicate that there is no significant positive or negative trend in rainfall within the Asansol Municipal Corporation (AMC) region as the P-value is 0.61 which is >0.05 (Table 6.2). A steady rainfall is required for Rainwater harvesting for any areas in the world which is observed in AMC.

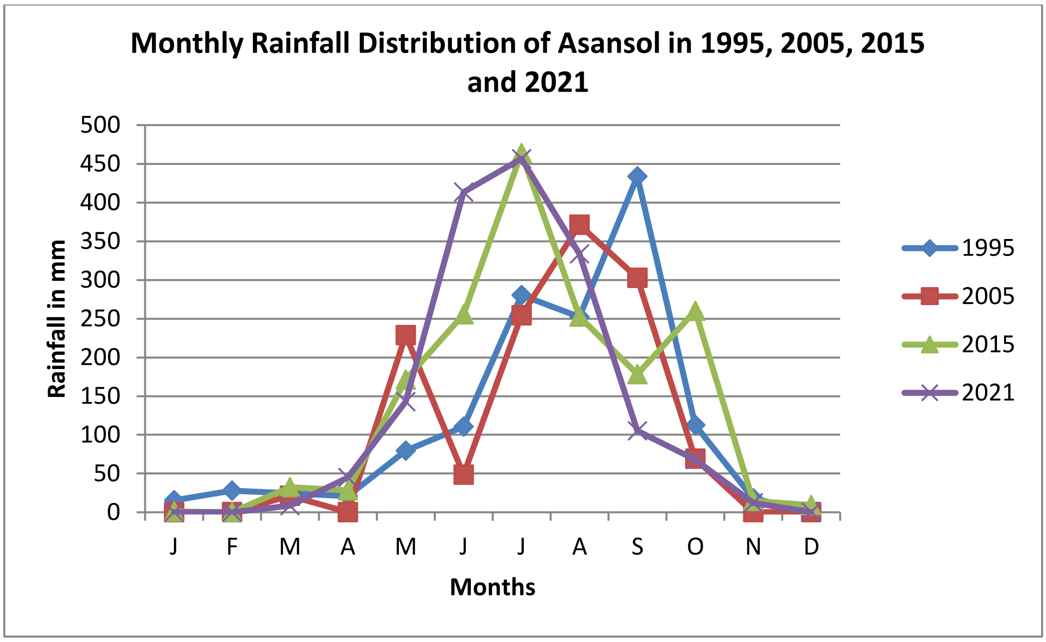

Fig.6.5: Monthly Rainfall Distribution Pattern of AMC

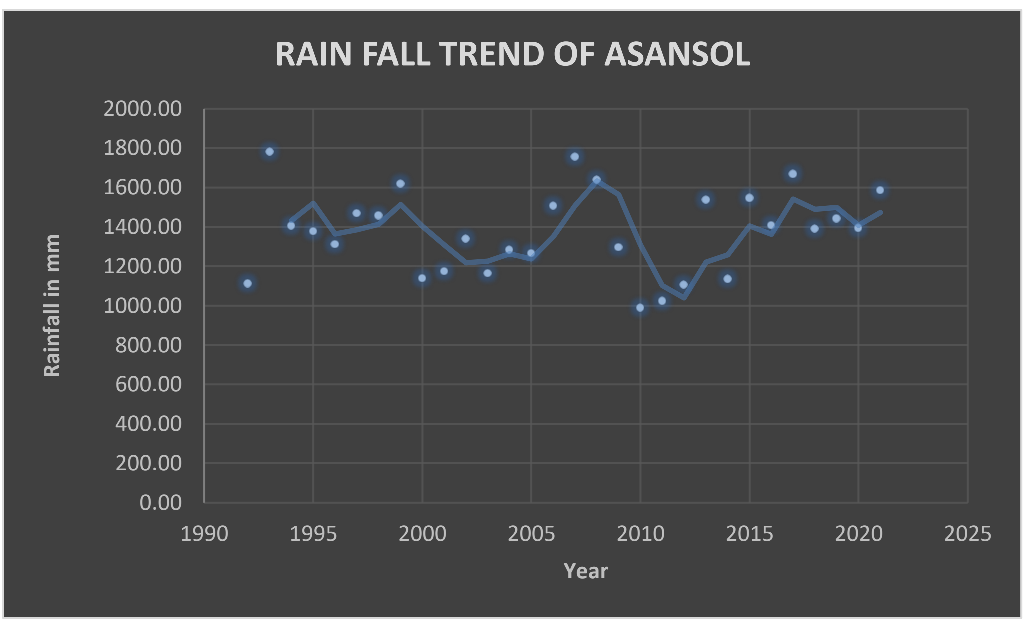

Fig.6.6: Rainfall trend of AMC

6.3.2 Rainwater Harvesting and Demand

Monthly rainwater harvesting capacity and non-potable water demand statistics are given below in tabulated form (Table 6.3)-

Table 6.3: Monthly Household harvested rainwater and demand

Month	Monthly Average Rainfall(mm)	Volume of Harvested Rainwater(m^3/month)	Monthly Water Demand(m^3)	Monthly Balance(m^3)
January	10.34	0.87	8.10	-7.23
February	17.30	1.45	8.10	-6.65
March	24.30	2.04	8.10	-6.06
April	42.38	3.55	8.10	-4.55
May	102.41	8.58	8.10	0.48
June	215.27	18.03	8.10	9.93
July	314.83	26.37	8.10	18.27
August	298.22	24.98	8.10	16.88
September	230.06	19.27	8.10	11.17
October	108.57	9.09	8.10	0.99
November	8.78	0.74	8.10	-7.36
December	4.40	0.37	8.10	-7.73

Source: Calculated by the Author

January: With an average rainfall of 10.34 mm, the volume of harvested rainwater is 0.87 m^3, which falls short of the monthly water demand of 8.10 m^3. This results in a monthly balance of -7.23 m^3, indicating a significant deficit.

February: The average rainfall is 17.30 mm, leading to a harvested rainwater volume of 1.45 m^3. However, the monthly water demand of 8.10 m^3 is not met, resulting in a balance of -6.65 m^3, showing a deficit.

March: The month experiences an average rainfall of 24.30 mm, yielding 2.04 m^3 of harvested rainwater. This is insufficient to meet the 8.10 m^3 water demand, resulting in a deficit with a monthly balance of -6.06 m^3.

April: With 42.38 mm of average rainfall, the harvested rainwater volume reaches 3.55 m^3. Despite this, it does not meet the monthly water demand of 8.10 m^3, resulting in a balance of -4.55 m^3, indicating a deficit.

May: The average rainfall is 102.41 mm, resulting in a harvested rainwater volume of 8.58 m^3, which just meets the monthly water demand of 8.10 m^3. This leads to a slight surplus with a monthly balance of 0.48 m^3.

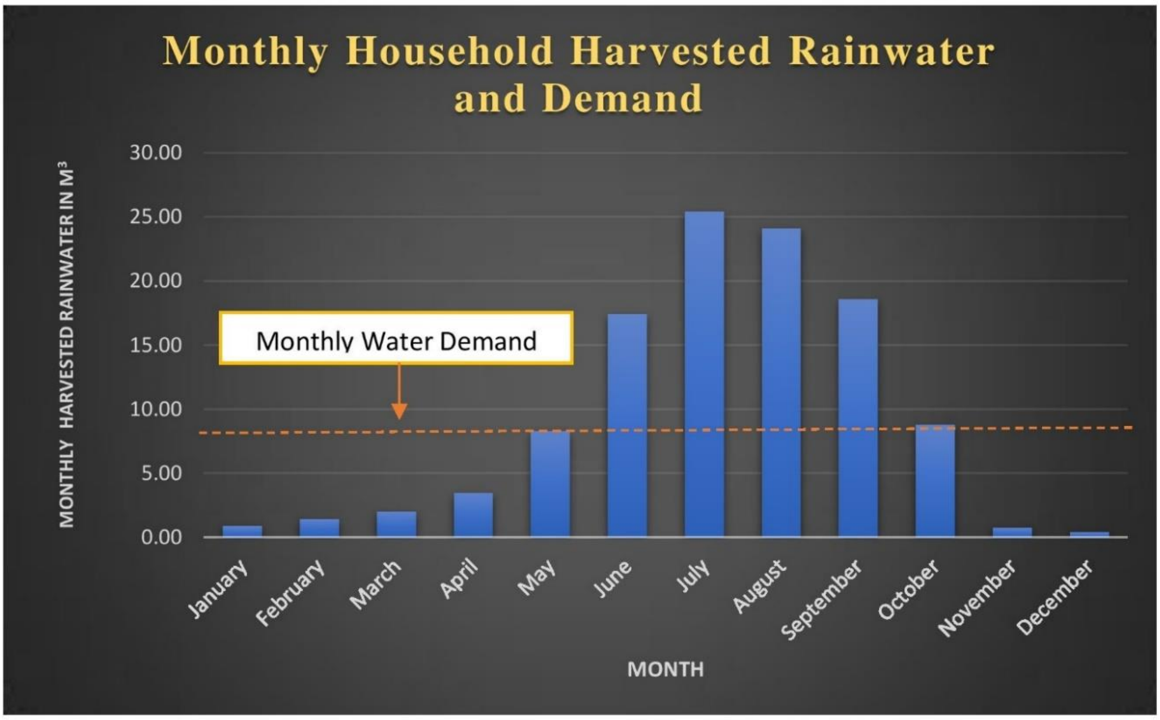

Fig.6.7: Monthly Household Harvested Rainwater and Demand (Non-potable)

June: With an average rainfall of 215.27 mm, the volume of harvested rainwater is 18.03 m^3, which significantly exceeds the monthly water demand of 8.10 m^3. This results in a surplus with a monthly balance of 9.93 m^3.

July: The month sees an average rainfall of 314.83 mm, leading to a harvested rainwater volume of 26.37 m^3. This sufficiently meets and exceeds the 8.10 m^3 water demand, resulting in a significant surplus with a balance of 18.27 m^3.

August: An average rainfall of 298.22 mm results in 24.98 m^3 of harvested rainwater. This meets the monthly water demand of 8.10 m^3, resulting in a surplus with a balance of 16.88 m^3.

September: The average rainfall is 230.06 mm, yielding a harvested rainwater volume of 19.27 m^3. This is more than enough to meet the monthly water demand of 8.10 m^3, resulting in a significant surplus with a balance of 11.17 m^3.

October: With an average rainfall of 108.57 mm, the harvested rainwater volume is 9.09 m^3, which just meets the monthly water demand of 8.10 m^3. This results in a slight surplus with a monthly balance of 0.99 m^3.

November: The month experiences an average rainfall of 8.78 mm, leading to a harvested rainwater volume of 0.74 m³. This is insufficient to meet the monthly water demand of 8.10 m³, resulting in a deficit with a balance of -7.36 m³.

December: With an average rainfall of 4.40 mm, the volume of harvested rainwater is 0.37 m³, which falls short of the monthly water demand of 8.10 m³. This results in a significant deficit with a monthly balance of -7.73 m³.

The months experiencing a water deficit, where the harvested rainwater is insufficient to meet the demand, are January, February, March, April, November, and December. Conversely, the months with a water surplus, where the harvested rainwater exceeds the demand, are May, June, July, August, September, and October.

The overall trend shows that during the rainy months (May to October), the harvested rainwater exceeds the monthly water demand, resulting in surpluses. However, during the dry months (January to April, November, December), the harvested rainwater is insufficient to meet the monthly water demand, resulting in deficits. To address the deficits, water storage solutions by tank size calculation might be necessary to ensure a consistent water supply throughout the year.

The mean of total rainwater harvesting capacity has been calculated to be 115.34 m^3 per household per year while the total non-potable household water demand per household amounts to 97.2 m^3. The surplus water can be effectively utilized for direct groundwater recharge, which will contribute to replenishing the local aquifers. In doing so, it will enhance the groundwater quality within the jurisdiction of the Asansol Municipal Corporation, supporting sustainable water management practices in the region.

The following table provides a summary of the annual rainwater harvesting capacity and non-potable household water demand for various wards within the Asansol Municipal Corporation. This data highlights the significant potentiality of rooftop rainwater harvesting as an effective solution to meet non-potable water needs for households. By implementing this approach, the pressure on the city's primary water sources can be greatly reduced, contributing to a more sustainable and efficient water management system for Asansol.

Table 6.4: Yearly Household harvested rainwater for non-potable demand

Ward No.	Average Roof area in (m^2)	Volume of Rainwater that can be (m^3/yearly)	Yearly Non-potable Water Demand(m^3)	Yearly Balance(m^3)
4	98.65	115.46	97.20	18.26
5	99.52	116.46	97.20	19.26
14	99.20	116.10	97.20	18.90
37	100.15	117.21	97.20	20.01
39	103.25	120.84	97.20	23.64
44	102.50	119.95	97.20	22.75
60	100.60	117.73	97.20	20.53
64	99.68	116.66	97.20	19.46
71	101.25	118.50	97.20	21.30
77	103.20	120.78	97.20	23.58
80	102.50	119.95	97.20	22.75
84	100.36	117.45	97.20	20.25
85	102.30	119.72	97.20	22.52
88	100.38	117.48	97.20	20.28

Source: Calculated by the Author

6.3.3 Rooftop Rainwater Harvesting Model

It is necessary to select best rooftop model for rainwater harvesting depending on local socio-economic conditions and weather. After detail cost benefit analysis a gravity fed rooftop rainwater harvesting model composed by Plastic tank with PVC pipes has been suggested for AMC. The simplified image of proposed rainwater harvesting model is given below along with descriptions of different components.

6.3.3.1 Components of RRWH Model

Collection Surface(Roof): The first component is the surface area of the roof where rainwater will be collected. This can be any roof structures, such as a house, garage, or shed.

Gutters and Downspouts: Gutters are installed along the edges of the roof to collect rainwater and channel it towards downspouts. Downspouts are vertical pipes that direct water from the gutters to the collection system.

Leaf Guards and Filters: To prevent debris such as leaves, twigs, and dirt from entering the collection system, leaf guards and filters can be installed at the entry points of gutters or downspouts.

First Flush Diverter: This is a device that helps in the physical purification of rainwater before entering the storage tank. The first flush typically contains the most pollutants collected from the roof surface.

Storage Tank: Rainwater collected from the roof is stored in a tank for later use. Tanks can be made of various materials like plastic, concrete, or metal and can be placed above or below ground.

Overflow System*:* An overflow system is necessary to prevent the tank from overflowing during heavy rainfall. Excess water can be directed to a soakaway pit, drainage system, or another storage tank if available.

Pump and Distribution System (Optional)*:* If the harvested rainwater is to be used for purposes requiring pressurized water, such indoor use, a pump and distribution system may be installed. This system pumps water from the storage tank to the desired location through pipes.

Water Treatment (Optional)*:* Depending on the end-use of harvested rainwater, treatment may be required. This can include filtration, disinfection, or other purification methods to ensure water quality meets standards for its intended use.

Usage Points: Harvested rainwater can be used for various purposes including , toilet flushing, laundry, car washing, gardening, cleaning and even drinking (with appropriate treatment).

Monitoring and Maintenance*:* Regular inspection and maintenance of the system are essential to ensure its proper functioning. This includes checking for leaks, cleaning filters, and ensuring the integrity of the storage tank.

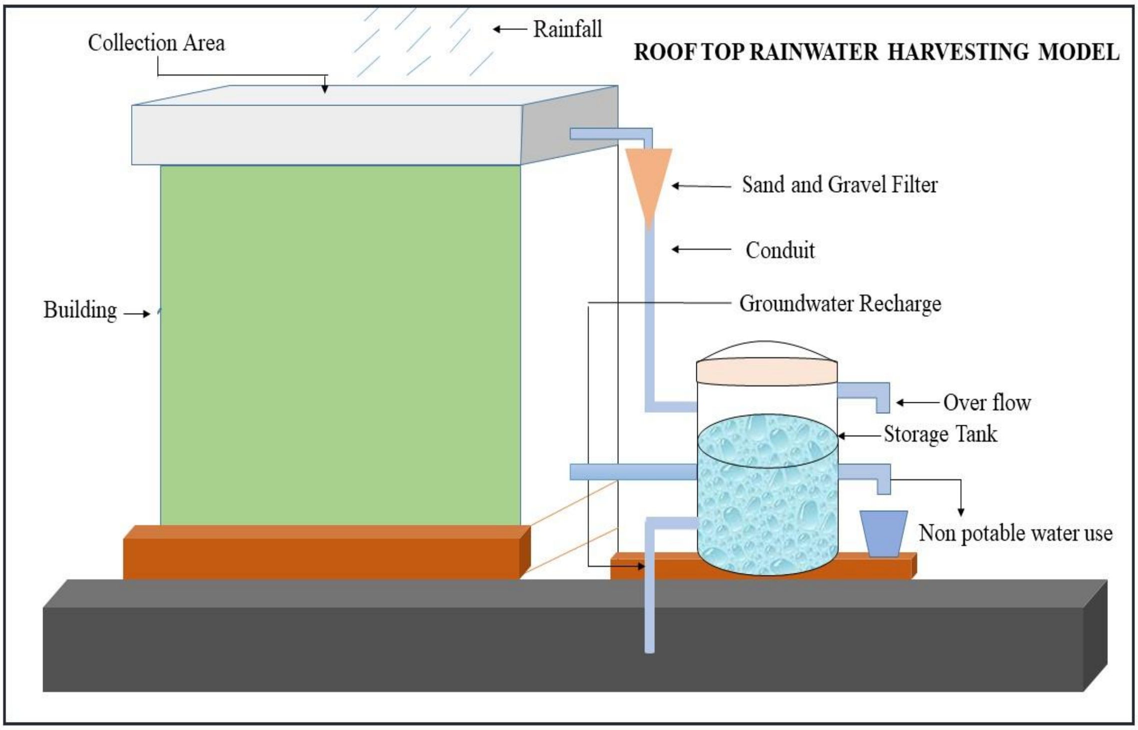

Fig.6.8: Rooftop Rainwater Harvesting Model

6.3.4 Cost Analysis

Following are the detail of cost analysis of Plastic tank with PVC pipes vs Concrete tank with iron pipes(1000 litre capacity) made on the basis of information provided by Samriddhi Construction, Asansol (January,2024) (Table 6.4).

Initial Cost*:* The Plastic Tank with PVC Pipes has a significantly lower initial cost (Rs. 79000 or $950) compared to the Concrete Tank with Iron Pipes (Rs. 116500 or $1400). This makes it more accessible for those with limited initial capital.

Durability and Longevity: The Concrete Tank with Iron Pipes offers higher durability and longevity compared to the Plastic Tank with PVC Pipes. This suggests that over the long term, the concrete tank is likely to require fewer replacements and repairs.

Maintenance*:* The Plastic Tank with PVC Pipes has lower maintenance costs compared to the Concrete Tank with Iron Pipes. This could be beneficial for those who prefer lower ongoing maintenance efforts and expenses.

Environmental Impact: The Plastic Tank with PVC Pipes has a lower environmental impact than the Concrete Tank with Iron Pipes. This could be an important consideration for those looking to minimize their environmental footprint.

Table 6.5: Cost analysis of Gravity-fed Roof top Rainwater Harvesting System with 1000 litre capacity

Aspect	Plastic Tank with PVC Pipes	Concrete Tank with Iron Pipes
Storage Tank Cost	Rs. 41500 ($500)	Rs. 66500 ($800)
Piping Cost	Rs. 4200 ($50)	Rs. 8300 ($100)
Foundation/Base Cost	Rs. 8300 ($100)	Rs. 8300 ($100)
Installation Labour Cost	Rs. 16600 ($200)	Rs. 25000 ($300)
Overflow and Drainage System Cost	Rs. 4200 ($50)	Rs. 4200 ($50)
Miscellaneous Costs	Rs. 4200 ($50)	Rs. 4200 ($50)
Total Estimated Cost	Rs. 79000 ($950)	Rs. 116500($1400)
Initial Cost	Low	High
Durability	Medium	High
Longevity	Medium	High
Maintenance	Lower	Medium
Aesthetic Appeal	Good	Good
Environmental Impact	Lower	Higher
Functionality	Suitable for smaller properties or those with lower water demands.	Suitable for larger properties or those with higher water demands.
Long-term Costs	Potential for higher long-term costs due to potential replacement or repair needs.	Potential for moderate long-term costs due to potential durability and longevity.

Source: Prepared based on Samriddhi Construction, Asansol, 2024

Functionality: The Plastic Tank with PVC Pipes is suitable for smaller properties or those with lower water demands, whereas the Concrete Tank with Iron Pipes is more suitable for larger properties or those with higher water demands. This indicates that the choice of tank may depend on the scale of water usage and the size of the property.

Long-term Costs: The Plastic Tank with PVC Pipes may incur higher long-term costs due to the potential need for replacements or repairs. In contrast, the Concrete Tank with Iron Pipes may have moderate long-term costs due to its higher durability and longevity.

Choosing between a Plastic Tank with PVC Pipes and a Concrete Tank with Iron Pipes depends on various factors including initial cost, long-term cost, property size, water demand, and environmental considerations.

For smaller properties or those with lower water demands, the Plastic Tank with PVC Pipes might be more cost-effective initially but could incur higher long-term costs.

For larger properties or those with higher water demands, the Concrete Tank with Iron Pipes, although more expensive initially, might be more economical in the long run due to its durability and longevity.

6.4 Conclusion

The analysis of monthly rainfall and water demand in Asansol Municipal Corporation demonstrates that rooftop rainwater harvesting can significantly contribute to meeting the water needs of the area. During the rainy season (May to October), there is a substantial surplus of harvested rainwater, indicating a strong potential for utilizing rainwater to meet water demands during these months. This surplus can be stored and used during the drier months (January to April, November, and December), which experience deficits.

The analysis of rainwater harvesting potential of within the Asansol Municipal Corporation reveals that with a total harvesting capacity of 115.34 m^3 and a non-potable household water demand of 97.2 m^3, there is a surplus of 18.14 m^3 per household per year that can be used for direct groundwater recharge. This excess not only contributes to aquifer replenishment but also improves groundwater quality. The data from various wards further emphasize that rooftop rainwater harvesting is a viable solution to meet household non-potable water needs. By implementing this system, the city can significantly reduce its reliance on primary water sources, promoting sustainable water management and alleviating pressure on its water supply infrastructure. The rainy season yields a considerable amount of harvestable rainwater, with monthly surpluses per household per month ranging from 0.48 m^3 to 18.27 m^3. During the dry months, the harvested rainwater is insufficient, resulting in deficits ranging from -4.55 m^3 to -7.73 m^3.

Implementing an efficient rooftop rainwater harvesting system, such as plastic tanks with PVC pipes, can be beneficial due to their lower initial cost, despite lower longevity. For smaller properties or those with lower water demands, plastic tanks with PVC pipes may offer a cost-effective solution, though they may incur higher long-term maintenance costs. For larger properties or those with higher water demands, the Concrete Tank with Iron Pipes, although more expensive initially, might be more economical in the long run due to its durability and longevity.

Rooftop rainwater harvesting is environmentally friendly and can reduce the dependency on conventional water sources, thereby alleviating pressure on local water resources. Lower environmental impact systems, like plastic tanks with PVC pipes, should be considered for properties where environmental sustainability is a priority. Investing in durable and high-capacity storage systems will ensure a reliable water supply throughout the year, making the community more resilient to seasonal variations and potential water shortages. In conclusion, the potential for rooftop rainwater harvesting in Asansol Municipal Corporation is promising. With strategic planning and investment in suitable infrastructure, it can provide a sustainable and supplementary water source, reduce dependency on municipal water supply, and enhance water security for the community.

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SUMMARY & CONCLUSION

In this chapter, an attempt has been made to present the conclusions of this comprehensive study on the water resource potential of the Asansol Municipal Corporation in West Bengal, with a focus on sustainable management practices. The chapter is systematically divided to provide a holistic overview of the major findings and observations derived from the research along with addressing the sustainable development goal 6(SDG 6). This includes an assessment of the current water resources, challenges faced in their management, and the implications for sustainability. Following these insights, this chapter offer a set of targeted suggestions aimed at enhancing the sustainable management of water resources in the region. Additionally, this chapter outlines future directions for research and policy development, ensuring a long-term, sustainable approach to water resource management in Asansol.

7.1 Critical Observations

All observations have been made based on field surveys, secondary information gathered from reliable sources about the Asansol Municipal Corporation, and an analysis of the overall results in the context of current conditions.

- ❖ There has been significant water loss in the Asansol Municipal Corporation (AMC) area due to frequent leaks in the water distribution pipelines. This issue is especially prevalent in the extended regions of AMC, such as Jamuria, Kulti, and Raniganj. The construction and management of the pipeline system in these areas are flawed, leading to continuous water wastage and inefficiencies in supply.
- ❖ The city of Asansol is experiencing significant environmental changes, with a decrease in vegetation cover and surface water bodies alongside a rise in built-up areas and land surface temperature. This trend highlights the ongoing urbanization and environmental degradation occurring in the region. The decline in vegetation cover is concerning as it leads to reduced biodiversity, increased soil erosion, and diminished ecosystem services. Similarly, the loss of surface water bodies negatively affects water availability, habitat quality, and overall ecological balance

in Asansol. Conversely, the expansion of built-up areas contributes to the urban heat island effect, exacerbating land surface temperature rise.

- There is a noticeable inconsistency in the daily water supply across different parts of AMC, both in terms of frequency and timing. While some areas, particularly in the core Asansol region, receive water twice a day, with each supply lasting around an hour, other regions, like Jamuria, only receive water once a day, with the duration ranging from 30 minutes to an hour. This uneven distribution has led to dissatisfaction among residents, particularly in the extended regions where supply is less frequent and unreliable.
- The introduction of rooftop rainwater harvesting systems for non-potable uses has received mixed reactions from the residents of AMC. While some people are eager to install these systems due to their potential benefits in water conservation, others are hesitant. Their reluctance stems from concerns about the initial installation cost, the space required, and ongoing maintenance. Additionally, some are worried about the quality and safety of rainwater for certain uses, contributing to their unwillingness to adopt the system.
- To meet their domestic water needs, many residents of AMC have resorted to purchasing packaged water. Wealthier households tend to buy branded packaged drinking water, ensuring a higher quality of supply. In contrast, lower-income groups often purchase water from local vendors at a lower price, usually delivered in drums. This disparity in access highlights the socio-economic differences in how residents manage their water supply.
- The gap between water demand and supply becomes most pronounced during the summer months when the region experiences higher temperatures and increased water consumption. Many residents face frequent water shortages during this time, leading to difficulties in meeting their daily domestic water needs. This seasonal shortfall exacerbates the challenges posed by the existing issues of water distribution and management in AMC.
- The city of Asansol is facing a critical challenge in providing adequate water supply to its rapidly growing population. The disparity between demand and availability is stark, highlighting the urgent need for comprehensive solutions to address this issue. The current water supply infrastructure is strained and unable to keep pace with the burgeoning population, leading to significant hardships for residents. It is

evident that immediate action is required to upgrade and expand the water supply system in Asansol.

- ❖ The city of Asansol faces a pressing challenge with its insufficient surface and groundwater resources to meet the escalating demands of its rapidly growing population. The inadequacy of surface and ground water availability in Asansol highlights the vulnerability of its water supply infrastructure and the necessity for sustainable solutions.
- ❖ A cost analysis comparing rooftop rainwater harvesting models indicates that the gravity-fed plastic tank with PVC pipes system is more efficient than the concrete tank with iron pipes system. This analysis takes into account various factors including initial investment costs, maintenance expenses, durability, and water yield efficiency. The gravity-fed plastic tank with PVC pipes system offers several advantages over the concrete tank with iron pipes system. Firstly, the initial investment costs for the plastic tank system are generally lower compared to the concrete tank system due to the cheaper materials involved. Additionally, plastic tanks are lightweight and easier to install, reducing labour costs and time. Moreover, PVC pipes are durable, corrosion-resistant, and require minimal maintenance, resulting in lower long-term operational costs. The gravity-fed design of the system ensures efficient water flow without the need for additional pumping mechanisms, further reducing energy consumption and operational expenses.

7.2 Major Findings

The findings are derived from the detailed calculations and analyses conducted and presented in the preceding chapters. These chapters provided a thorough examination of the data, applying various analytical methods to assess and interpret the information. The results reflect the insights gained from these comprehensive calculations and analyses, offering a well-rounded understanding of the study's subject matter.

- ❖ The Asansol Municipal Corporation (AMC) wards can be classified into four distinct categories based on their predominant land use and land cover patterns: A, B, C, and D. Category ‘A’ wards are primarily dominated by built-up areas, with over 50% of their land covered by such development. Category ‘B’ wards are characterized mainly by industrial activities, occupying more than 50% of the area. Category ‘C’ wards are predominantly agricultural, with over 50% of the land used for farming. Lastly, Category ‘D’ wards are mainly focused on coal mining, with more than 50% of the area dedicated to mining activities. Out of the 106 wards in AMC, 77 fall under Category A, 20 under Category C, 6 under Category D, and 3 under Category B.

- ❖ The population of the Asansol Municipal Corporation (AMC) has been steadily increasing over the years. According to predictions, the total population of AMC is expected to reach 2,704,763 by 2051, compared to 1,243,414 in 2011.
- ❖ Currently, the Asansol Municipal Corporation (AMC) has the capacity to supply 45.58 million gallons of water per day. However, the total domestic water requirement is 60.85 million gallons per day, resulting in a significant and growing gap between demand and supply. Based on the projected population growth, this gap is expected to increase to 35 million gallons per day in the future (2051).
- ❖ The sectoral water demand in the Asansol Municipal Corporation (AMC) reveals that 22,210 million gallons per year are needed for domestic use, 56,726 million gallons per year for agriculture, and 233,888 million gallons per year for industrial purposes. This indicates that the industrial sector is the largest consumer of water in AMC.
- ❖ Surface water bodies and vegetation in the Asansol Municipal Corporation (AMC) have been steadily decreasing over time, while land surface temperature and built-up areas have been increasing. In 1990, there were 17.32 km² of surface water bodies and 48.54 km² of vegetation. By 2020, these had decreased to just 4.58 km² of surface water bodies and 20.25 km² of vegetation. Conversely, the area under settlement has significantly expanded, from 25.59 km² in 1990 to 77.29 km² in 2020.
- ❖ According to the results of the AHP and FR models, only 5% to 10% of the Asansol Municipal Corporation (AMC) area falls within zones of very high groundwater potential, and 10% to 15% is classified as high groundwater potential zones. Approximately 30% of the area is covered by moderate groundwater potential zones, while about 65% falls under low to very low groundwater potential zones. The findings from the FR model are more accurate than those from the AHP model.
- ❖ Approximately 15% of the area under the Asansol Municipal Corporation (AMC) has been identified as suitable for surface rainwater harvesting. Most of these areas are naturally downslope, making them suitable for constructing both man-made and natural surface rainwater harvesting structure. There is variation in the spatial extent

of these suitable locations, which affects the size of the rainwater harvesting construction units.

- ❖ Open cast mining pits offer substantial potential for surface rainwater harvesting if managed effectively. The six selected open cast mining pits have a combined capacity to harvest 16,735.8 million gallons of water. There is significant variation in the rainwater harvesting potential depending on the size and depth of the pits. Interconnecting the pit channels between these pits could enhance surface water collection by increasing runoff.
- ❖ The yearly variability of rainfall in Asansol Municipal Corporation (AMC) is very low which is ideal for rainwater harvesting. However, effectively utilizing rooftop rainwater harvesting technology can alleviate pressure on primary water sources by substituting non-potable water uses. The greatest potential for water harvesting occurs during the months of June, July, August, and September, while limited harvesting opportunities are available in January, February, March, and December. For AMC, a gravity-fed plastic tank with PVC pipes is the most suitable rainwater harvesting model.

7.3 Addressing the Sustainable Development Goal 6(SDG 6)

Water is essential for life, livelihoods, and sustainable development. In 2010, the United Nations recognized access to sufficient drinking water and sanitation as a fundamental human right (Guppy et al., 2019). Effective and integrated water management plays a critical role in advancing many of the 17 Sustainable Development Goals (SDGs), particularly SDG 6, which focuses on ensuring the availability and sustainable management of water and sanitation for everyone. The Sustainable Development Goals (SDGs) place a stronger emphasis on environmental issues compared to the Millennium Development Goals. SDG 6, which addresses water, adopts a broader perspective by acknowledging the importance of conservation alongside drinking water and sanitation (Lele, 2017). However, from a normative standpoint, SDG 6 remains focused on adequacy and sustainability, with less emphasis on the goal of justice—an important gap. Intergenerational justice is crucial in addressing many environmental challenges, particularly water, which is a shared, multi-use resource that flows in only one direction.

According to Sustainable Development Goal 6 (SDG 6), it is crucial to ensure the availability and sustainable management of clean, safe, and affordable drinking water for all. However, a significant gap between water demand and supply has been observed, which contradicts the objectives of SDG 6. Based on the 2011 census, the domestic water demand in Asansol Municipal Corporation (AMC) exceeds supply by approximately 5,573.55 million gallons annually. This shortfall is expected to grow substantially, reaching 12,775 million gallons per year by 2051, given the projected population growth.

The study suggests that rooftop rainwater harvesting presents a viable solution for addressing the non-potable water needs of the population. As of 2011, rooftop rainwater harvesting could potentially provide 5,394.7 million gallons of water annually. However, the future potential for rooftop rainwater harvesting is uncertain due to a lack of detailed information on future building infrastructure and capacity for such systems in 2051. Nevertheless, based on the 2011 population, it is feasible to significantly reduce the water supply gap through the widespread adoption of rooftop rainwater harvesting systems in AMC. Furthermore, the study highlights an additional opportunity to enhance water availability by utilizing the existing opencast coal mining pits in the region. These pits, when properly repurposed for surface rainwater harvesting, could yield approximately 16,735 million gallons of water per year.

In light of these findings, it becomes evident that the combined strategies of rooftop rainwater harvesting and surface rainwater harvesting in opencast mining pits could play a crucial role in ensuring water security in AMC, both now and in the future. Specifically, by 2051, the projected domestic water supply gap of 12,775 million gallons per year could be effectively bridged through the efficient use of surface rainwater harvesting in the available mining pits. Thus, with proper planning and the implementation of these sustainable water management techniques, AMC can not only meet the growing water demand but also align itself with the objectives of SDG 6, creating a more sustainable and resilient water resource system for the region.

7.4 Suggestions and Recommendations

The following suggestions and recommendations have been made based on the critical observations and findings of the work-

- ❖ To address water loss due to leakage from faulty pipelines, it is essential to conduct a comprehensive audit of the existing water distribution network, particularly in areas like Jamuria, Kulti, and Raniganj, to identify and repair critical leakage points. Upgrading the infrastructure with durable materials and advanced construction techniques can significantly reduce future leaks. Implementing smart meters and sensors will enable early detection of leaks and minimize wastage. Additionally, launching a public awareness campaign can encourage residents to report water leaks or wastage, with incentives offered for identifying such issues. Setting up a dedicated helpline or mobile app would streamline the reporting process and enhance community participation in maintaining the water supply system.

- ❖ To address inconsistent water supply and distribution timings, a more efficient and equitable water distribution schedule should be designed for all parts of the Asansol Municipal Corporation (AMC). This would ensure that areas like Jamuria receive a more consistent water supply, similar to the core Asansol region. Promoting the installation of personal and community water storage systems will allow households to store water for later use, helping them manage supply variations. Additionally, recalibrating the water distribution network to reduce discrepancies between localities, including optimizing water pressure systems and scheduling water releases, will further improve the reliability of the overall supply system.
- ❖ To address the mixed reactions to rooftop rainwater harvesting, government subsidies or low-interest loans could be introduced to reduce the initial installation costs, making the systems more affordable, particularly for lower-income households. Public education campaigns highlighting the long-term cost savings and the role of rainwater harvesting in reducing water shortages, especially during summer, would encourage broader adoption. Providing guidelines or certification to ensure that these systems meet quality standards for non-potable uses, along with training local technicians to offer affordable maintenance services, would further alleviate concerns regarding quality and upkeep.
- ❖ To reduce reliance on packaged water for domestic use, AMC should strengthen its water purification systems to ensure safe, potable water reaches all households, thereby decreasing the need for packaged alternatives. Establishing affordable community water filtration kiosks or stations would offer a low-cost option for residents, especially lower-income groups, to access safe drinking water. Additionally, enforcing strict regulations on local water suppliers who provide non-branded water in drums, along with regular inspections and quality control, would ensure the safety of water supplied for domestic use, mitigating potential health risks.
- ❖ To address seasonal water shortages and the demand-supply gap, water conservation programmes should be implemented, encouraging households to adopt water-efficient appliances and practices, particularly during peak summer

months. Increasing water storage capacity by building additional reservoirs or storage facilities would allow for stockpiling water during periods of lower demand, such as the monsoon season, ensuring sufficient supply during the summer. Expanding groundwater recharge projects through large-scale rainwater harvesting in public areas would help replenish aquifers and provide a backup water source. Additionally, exploring alternative water sources, such as treated wastewater for non-potable uses in public institutions and industries, could free up more potable water for domestic needs.

- The implementation of rooftop rainwater harvesting presents a promising solution to address the non-potable water demands of Asansol City. By harnessing rainwater through rooftop harvesting, Asansol can significantly reduce its reliance on traditional water sources for non-potable needs, thereby alleviating pressure on surface water reservoirs and groundwater reserves. This approach offers several benefits, including reducing the strain on existing water supply infrastructure, mitigating the risk of water shortages during dry seasons, and promoting sustainable water management practices. Moreover, rooftop rainwater harvesting is a cost-effective and eco-friendly solution that can be easily integrated into both existing and new construction projects throughout the city. Community awareness and participation are crucial for the successful implementation of this initiative, necessitating public education campaigns and incentives to encourage widespread adoption. With careful planning, investment, and community engagement, Asansol can harness this abundant resource to enhance its water security and sustainability for future generations.
- Surface rainwater harvesting utilizing open cast mining pits and pit channels presents a promising opportunity to address water scarcity challenges in Asansol. This approach involves repurposing abandoned or underutilized mining pits as reservoirs for rainwater collection and storage, as well as creating channels to facilitate runoff capture and distribution. The utilization of open cast mining pits for rainwater harvesting offers several advantages. These pits provide large, pre-existing depressions that can efficiently collect rainwater, reducing the need for additional excavation or construction. Moreover, the depth of these pits allows for significant water storage capacity, making them ideal reservoirs for capturing runoff during periods of heavy rainfall. By creating pit channels connecting these reservoirs to surrounding areas, rainwater can be directed to where it is needed

most. This can help replenish groundwater resources, support agricultural activities, and mitigate flooding in low-lying areas. Additionally, the creation of pit channels can enhance water infiltration into the soil, promoting groundwater recharge and enhancing overall water resilience in the region. Community engagement and participation are crucial for the successful implementation of surface rainwater harvesting utilizing open cast mining pits and pit channels. Local stakeholders, including government agencies, mining companies, and community organizations, must collaborate to identify suitable sites, design effective water management strategies, and ensure sustainable use of rainwater resources. Overall, surface rainwater harvesting utilizing open cast mining pits and pit channels holds great potential to enhance water security and resilience in Asansol. By coupling this innovative approach, the city can effectively utilize its natural resources to address water scarcity challenges and promote sustainable development for future generations.

7.5 Future Direction of Research

Asansol Municipal Corporation (AMC) faces increasing challenges related to water scarcity and sustainable urban development. Addressing these challenges requires innovative solutions and strategic planning. Two key areas of future research for AMC include the development of effective water marketing strategies and exploring sustainable methods to utilize nearby water sources, such as the Maithon Dam, to mitigate the ongoing water crisis. By focusing on water marketing, AMC can investigate pricing models, distribution efficiency, and demand management to optimize water use. Simultaneously, studying the potential of reservoirs like Maithon Dam could offer practical solutions for water storage, transfer, and distribution, reducing dependency on over-exploited groundwater sources and enhancing long-term water security for the region.

7.6 Conclusion

Roof top rainwater harvesting and surface rainwater harvesting present promising solutions to address water scarcity issues in Asansol City. However, several challenges hinder their effective implementation and utilization. These challenges range from technical and infrastructural limitations to socio-economic and environmental considerations. One of the primary challenges facing roof top rainwater harvesting in Asansol is the lack of awareness and understanding among residents about its benefits and implementation. Many individuals may not be familiar with the concept or may perceive it as complex or impractical. This underscores the importance of community education and outreach programs to promote awareness and encourage adoption of rainwater harvesting practices. Technical constraints also pose obstacles to roof top rainwater harvesting in Asansol. Some buildings may lack suitable roof structures or may require retrofitting to install rainwater collection systems. Additionally, inadequate maintenance of existing infrastructure can lead to inefficiencies or system failures, diminishing the effectiveness of rainwater harvesting initiatives. Surface rainwater harvesting faces similar challenges in Asansol, particularly regarding the availability of suitable sites for collection and storage.

Urbanization and land-use changes have altered the landscape, reducing natural water catchment areas and increasing surface runoff. Identifying and securing appropriate locations for surface rainwater harvesting infrastructure is essential but may be complicated by competing land-use priorities and regulatory considerations. Furthermore, both rooftop and surface rainwater harvesting initiatives may encounter challenges related to water quality and contamination. In urban areas like Asansol, pollutants from industrial activities, vehicle emissions, and improper waste disposal can compromise the quality of collected rainwater, rendering it unsuitable uses without appropriate treatment. Ensuring water quality standards and implementing effective filtration and purification measures are essential for safeguarding public health and promoting the safe use of harvested rainwater. Socio-economic factors also influence the success of rainwater harvesting initiatives in Asansol. Economic constraints may limit households' ability to invest in rainwater harvesting infrastructure or maintain systems over time. Incentive programs, subsidies, or financing options may be necessary to make rainwater harvesting more accessible and affordable for low-income communities.

Moreover, cultural and behavioural factors can affect the adoption of rainwater harvesting practices. Traditional water management practices and attitudes toward water use may need to be addressed to promote behavioural change and encourage sustainable water conservation habits. Environmental considerations are paramount in rainwater harvesting initiatives, particularly in a region like Asansol facing ecological challenges such as deforestation, soil erosion, and habitat degradation. Implementing rainwater harvesting projects in harmony with ecosystem restoration efforts can enhance environmental sustainability and resilience while addressing water scarcity issues. In addition, while rooftop and surface rainwater harvesting hold significant potential to alleviate water scarcity in Asansol City, they are not without challenges. Addressing these challenges requires a holistic approach that integrates technical innovation, community engagement, policy support, and environmental stewardship. By overcoming these obstacles, Asansol can harness the full benefits of rainwater harvesting to enhance water security, promote sustainable development, and build resilience in the face of future water challenges.

In conclusion future research endeavours in water resource management for Asansol City should adopt a multidisciplinary approach, incorporating scientific, technological, socio-economic, and policy perspectives. Collaboration between researchers, policymakers, stakeholders, and local communities is essential to translate research findings into actionable strategies and initiatives for enhancing water security, resilience, and sustainability in Asansol City and beyond.

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APPENDIX

Questionnaire for Pilot Survey

Evaluating Water Resource Potential of Asansol Municipal Corporation in West Bengal towards its sustainable management

Name of the Respondent :

Address :

1. Type of family

a) Nuclear b) Joint c) Extended

2. a) Number of adult males in the household..................

b) Number of adult females in the household...............

c) Number of males children.......................................

d) Number of females children...............................

3. How many members of the household are employed?.................

4. What is the monthly household income?

a) <5000 b) 5000-15000 c) 15000-25000 d) 25000-35000 e) 35000-45000 f)>45000

5.Education level :

Level	Male	Female
Primary		
Secondary		
Higher Secondary		
Graduate		
Post Graduate		
Other technical training		

6.Occupational Pattern

Types of occupation	Male	Female
Business		
Service		
Workers		
others		

8. Which of the following sources of drinking water are available in your locality?(Multiple responses are possible)

a) Bore well/hand pump b) Public tap c) Community well d) Household water supply(piped) e) Others

9. Which of the following sources of drinking water does your household use?(Multiple responses are possible)

a) Bore well/hand pump b) Public tap c) Community well d) Household water supply(piped) e) Others

10. What is your main sources of water? Single response

a) Bore well/hand pump b) Public tap c) Community well d) Household water supply(piped) e) Others

11. What is the frequency of water supply?

a) 24 hour supply b) More than once a day c) Once a day d) Once a two days e) Once in three days f) Other

12. Is this frequency sufficient for your needs? Yes /No

13. How often would you like to get water?

a) More than once a day b) Once a day c) Other

14. Is the quantity of water that you receive (from your main source of water) adequate?

a) Yes b) No

15. Is water available (from your main source) throughout the year? a) Yes b) No

16. Which months do you face scarcity? multiple response

17. Generally, how does the water smell? a) No smell b) Foul smell

18.Do you pay for water? a) Yes b) No

19. How much do you pay for a month?

20. Have you made a complaint related to your drinking water service in the past one year?

21. To whom did you complain?

22. What was the result of the complaint?

23. Overall, are you satisfied with your drinking water service? a) Satisfied b) Dissatisfied

24. What is the extent of your satisfaction? a) Complete b) Partial

25. What are the reasons for your dissatisfaction? (list up to five)

26. Pattern of Municipal water supply per day

Time	Hours
Morning	
Afternoon	
Evening	

27.What changes do you observed on the water resources in the past 10 to 15 years?

28.Have you ever experienced of any water harvesting techniques? If yes then details.

a)Yes b)No

29.Mention the present water storage system in your house...

No of tanks	Materials	Capacity of tank

30. How many liters of water do you need in order to sufficiently meet your household needs? Give the specification.

Potable	Liters/Person/Day	Non Potable	Liters/Person/Day
Drinking		Toilet flushing	
Cooking		Car washing	
Personal Bathing		Gardening	
Others		Laundry/Washing clothes	
		Room cleaning	
		Others	

31. Details of Building

Nature	Roof materials	No.of floors	Roof area in m^2	Others information

32. Do you ever think for any kind of alternative sources of water?

33. Do you have any perception about rain water harvesting?

34. If feasible do you interested to install any kind of rainwater harvesting system? If not then why?

Rainfall distribution of Asansol(1992-2021)

YEAR	JAN	FEB	MAR	APRIL	MAY	JUNE	JULY	AUGUST	SEP	OCT	NOV	DEC
1992	13.383	10.242	1.89	12.549	65.873	250.109	342.564	184.654	174.291	56.616	0.165	0.019
1993	4.139	1.799	69.68	90.181	91.378	367.17	305.56	351.347	357.444	131.942	8.637	0
1994	15.405	47.388	62.798	62.73	86.786	185.558	301.43	352.716	125.559	160.747	3.511	0.019
1995	15.625	27.697	24.518	20.887	79.374	110.661	280.418	252.478	433.79	112.615	17.912	0.256
1996	6.575	18.058	9.6	46.178	37.804	260.359	170.342	470.701	140.425	150.812	0.007	0
1997	25.492	15.986	45.47	73.195	113.099	66.063	373.504	389.86	279.587	62.421	10.354	13.637
1998	21.884	68.821	33.34	46.259	88.646	187.497	215.791	232.488	245.808	291.23	25.06	0
1999	4.326	3.643	0.871	0.84	138.91	203.407	268.837	441.381	467.478	75.551	11.711	0
2000	3.392	49.019	3.026	73.899	131.694	216.932	171.927	244.964	196.247	38.334	6.502	1.511
2001	0.582	6.203	65.453	33.375	120.012	235.742	187.553	253.724	113.066	149.703	9.023	0
2002	22.606	13.203	9.864	69.369	56.344	215.979	258.872	364.907	232.112	86.453	10.733	0
2003	11.2	16.3	29.2	49.2	95.6	140.5	211.3	294.5	198.3	81.3	35.2	2.3
2004	7.5	0	24.3	53.1	92.8	227.4	181.6	309.7	240.2	142.3	0	3.3
2005	30.6	24.4	46.4	46.4	51.4	171.1	310.4	199.4	133.2	242.2	0	9.6
2006	0	0	5.7	72.2	113.1	174.6	517	282.6	305.9	26.3	9.2	0
2007	0	48.4	40.6	27	71.7	245.9	497.1	288.6	451.4	50.5	33.6	0
2008	23.1	13.3	21.3	37.3	125.2	375.5	420.1	297.9	268.3	56.3	0	0
2009	0	0	21.3	0.3	228.8	48.6	254.4	371.3	302.7	69	0.2	0
2010	0	8.2	10	13.1	110	223.2	190.8	122.8	209.1	49.9	8.3	43.8
2011	9.5	11.36	5.8	40.6	85.6	190.2	235.6	289.6	99.35	45.5	6.9	3.2
2012	31.1	7.8	3.2	63.3	39.4	133.9	424.5	277.9	14.6	57.2	37.5	15.6
2013	6.8	17.5	4.6	41.5	175.1	210.2	145.5	341.1	250.7	342.5	0	0
2014	1.1	35.1	32	0.7	74.6	233.9	280.6	256.5	195.3	23.9	0	0.7
2015	8.5	10.1	29.4	76.3	64.2	338.1	587.3	285.8	111.8	34.1	0	0.9
2016	13.5	29.3	15	0	120	182.5	263.9	463.5	274.5	44.3	1.9	0
2017	1.2	0	32.6	28.3	171.2	255.8	464.1	252.9	178.2	260.1	14.5	9.1
2018	2.3	4.3	2	89.4	86.2	201.4	528.6	217.9	232.2	7.4	0	17.6
2019	0	30	8.6	33.2	116.6	138.4	259.6	243.4	365.2	235.8	0	10.6
2020	30.4	1	62	25	98.2	253.8	339.2	278.4	200	104.2	0.6	0
2021	0	0	8.5	45	142.6	413.6	456.6	333.6	105.2	67.8	12	0

Roof Area Measurement

Nature of Building	Roof Materials	Roof area in m^2
Concrete	Cemented	69.77
Concrete	Cemented	130.064
Concrete	Cemented	111.483
Concrete	Cemented	69.677
Concrete	Cemented	102.1933
Concrete	Cemented	92.903
Concrete	Cemented	83.61
Concrete	Cemented	92.903
Concrete	Cemented	69.677
Concrete	Cemented	148.644
Concrete	Cemented	150.123
Concrete	Cemented	70.23
Concrete	Cemented	90.24
Concrete	Cemented	102.4
Concrete	Cemented	130.064
Concrete	Cemented	75.03
Concrete	Cemented	95.24
Concrete	Cemented	70.23
Concrete	Cemented	85.56
Concrete	Cemented	130.65
Concrete	Cemented	148.644
Concrete	Cemented	92.3
Concrete	Cemented	85.25
Concrete	Cemented	90.23
Concrete	Cemented	102.5
Concrete	Cemented	130.064
Concrete	Cemented	102.1933
Concrete	Cemented	102.2
Concrete	Cemented	75.35
Concrete	Cemented	92.03
Concrete	Cemented	85.35
Concrete	Cemented	130.19
Concrete	Cemented	120.35
Concrete	Cemented	148.5
Concrete	Cemented	69.677
Concrete	Cemented	75.25
Concrete	Cemented	102.03
Concrete	Cemented	112.3
Concrete	Cemented	110.03

Concrete	Cemented	69.677
Concrete	Cemented	92.903
Concrete	Cemented	11.483
Concrete	Cemented	92.903
Concrete	Cemented	60.387
Concrete	Cemented	69.677
Concrete	Cemented	102.1933
Concrete	Cemented	130.064
Concrete	Cemented	111.483
Concrete	Cemented	83.61
Concrete	Cemented	83.61
Concrete	Cemented	83.61
Concrete	Cemented	102.1933
Concrete	Cemented	102.1933
Concrete	Cemented	130.064
Concrete	Cemented	148.644
Concrete	Cemented	92.903
Concrete	Cemented	111.483
Concrete	Cemented	109.35
Concrete	Cemented	112.03
Concrete	Cemented	125.35
Concrete	Cemented	130.02
Concrete	Cemented	60.387
Concrete	Cemented	60.387
Concrete	Cemented	111.483
Concrete	Cemented	102.1933
Concrete	Cemented	83.61
Concrete	Cemented	69.677
Concrete	Cemented	69.677
Concrete	Cemented	83.61
Concrete	Cemented	111.483
Concrete	Cemented	111.483
Concrete	Cemented	130.064
Concrete	Cemented	69.677
Concrete	Cemented	60.387
Concrete	Cemented	69.677
Concrete	Cemented	92.903
Concrete	Cemented	92.903
Concrete	Cemented	83.61
Concrete	Cemented	83.61
Concrete	Cemented	92.903
Concrete	Cemented	111.483
Concrete	Cemented	111.483
Concrete	Cemented	69.677

Concrete	Cemented	85.36
Concrete	Cemented	69.677
Concrete	Cemented	92.903
Concrete	Cemented	92.903
Concrete	Cemented	102.1933
Concrete	Cemented	111.483
Concrete	Cemented	69.677
Concrete	Cemented	83.61
Concrete	Cemented	69.677
Concrete	Cemented	102.1933
Concrete	Cemented	111.483
Concrete	Cemented	130.064
Concrete	Cemented	69.677
Concrete	Cemented	92.903
Concrete	Cemented	102.1933
Concrete	Cemented	69.677
Concrete	Cemented	135.2
Concrete	Cemented	79.85
Concrete	Cemented	214.54
Concrete	Cemented	210.1
Concrete	Cemented	96.32
Concrete	Cemented	75.2
Concrete	Cemented	58.36
Concrete	Cemented	55.24
Concrete	Cemented	125.53
Concrete	Cemented	56.39
Concrete	Cemented	67.27
Concrete	Cemented	55.23
Concrete	Cemented	63.21
Concrete	Cemented	202.25
Concrete	Cemented	110.32
Concrete	Cemented	112.25
Concrete	Cemented	55.35
Concrete	Cemented	47.23
Concrete	Cemented	58.36
Concrete	Cemented	66.54
Concrete	Cemented	88.2
Concrete	Cemented	74.23
Concrete	Cemented	99.35
Concrete	Cemented	65.32
Concrete	Cemented	65.2
Concrete	Cemented	65.35
Concrete	Cemented	115.25
Concrete	Cemented	64.32

Concrete	Cemented	85.35
Concrete	Cemented	88.36
Concrete	Cemented	102.35
Concrete	Cemented	111.23

Concrete	Cemented	85.36
Concrete	Cemented	195.65
Concrete	Cemented	65.32
Concrete	Cemented	97.25
Concrete	Cemented	110.25
Concrete	Cemented	98.36
Concrete	Cemented	65.32
Concrete	Cemented	97.65
Concrete	Cemented	67.25
Concrete	Cemented	115.58
Concrete	Cemented	68.98
Concrete	Cemented	98.36
Concrete	Cemented	106.35
Concrete	Cemented	102.36
Concrete	Cemented	65.35
Concrete	Cemented	185.36
Concrete	Cemented	67.35
Concrete	Cemented	55.25

Plate 1: GPS Reading of a Mining Pit

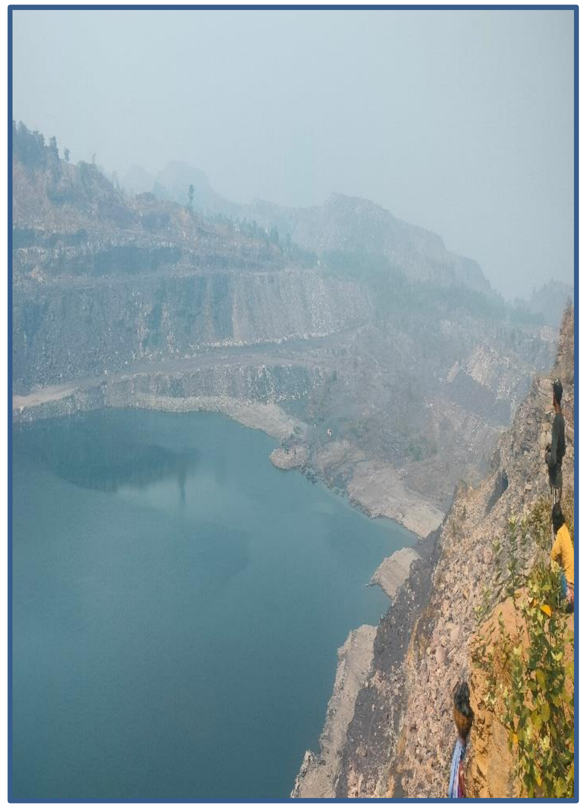

Plate 3: Image of Opencast Mining Pit

Plate 2: Measurement of a Mining Pit

Plate 4: Interaction with local people