Final Report

AN EXPERIMENTAL ASSESSMENT OF LOW-COST AUGER HOLE TECHNIQUE FOR ACCELERATING GROUNDWATER RECHARGE


A joint field-oriented research study of

National Institute of Hydrology
Central India Hydrology Regional Centre, Bhopal
&
M.P. Water and Land Management Institute, Bhopal

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PREFACE

Groundwater is a crucial resource for meeting domestic and agricultural demands in India. However, excessive extraction has led to a severe decline in groundwater levels, particularly in regions where natural recharge from rainfall is inadequate. This growing concern necessitates innovative conservation strategies to ensure sustainable water management. Artificial groundwater recharge, especially through the Auger Hole Technique, has emerged as an effective method to enhance groundwater replenishment in urban sprawls and rural zones. By facilitating rapid infiltration, this technique significantly improves recharge rates compared to natural percolation. This study, conducted at the Water and Land Management Institute (WALMI) Bhopal, evaluates the effectiveness of the Auger Hole Technique in addressing groundwater depletion in areas characterized by clayey soil, structural plateaus, and highly variable rainfall patterns.

The experimental findings revealed that infiltration rates increased by 25 to 40 times after stabilizing auger holes, showcasing the technique's potential to enhance groundwater recharge significantly. The study underscores the importance of adopting this simple, cost-effective, and scalable solution for sustainable water management, particularly in urban sprawls, rural areas, and agricultural fields. By utilizing locally available materials, the Auger Hole Technique not only optimizes groundwater recharge but also promotes community involvement in water conservation. Its application can help combat water scarcity, reduce urban flooding, and support sustainable urban water management. This research study, conducted collaboratively by the National Institute of Hydrology (NIH), Central India Hydrology Regional Centre (CIHRC) Bhopal, and Water and Water Management Institute (WALMI) Bhopal highlights the critical role of innovative groundwater recharge methods in ensuring water security. The study team comprised of Prof. Vivek Bhatt of WALMI Bhopal, Dr. R. V. Galkate, Scientist-F, and Dr. R.K. Jaiswal of NIH, CIHRC, Bhopal.

Date: 18/02/2025 **Director, NIH**

Place: Bhopal

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1.0 INTRODUCTION

Groundwater is a critical resource in India, serving as the backbone of agricultural, industrial, and domestic water supply in the country. Accounting for over 62% of the irrigation water and 85% of rural drinking water needs, it supports livelihoods and food security for millions of people (Ray, 2019; Dave, 2019). India is the largest user of groundwater in the world, extracting about 260 billion cubic meters annually. However, over-extraction of groundwater has led to a sharp decline in water tables, with groundwater levels dropping significantly (Singh, 2017). Sustainable management of this resource is essential to meet the growing demand of a growing population and mitigate the impacts of water scarcity and climate change. Enhanced conservation, groundwater recharge initiatives, and stricter regulation are key to preserving this vital resource for future generations.

India has witnessed a fast increase in Urban population. It is estimated that by 2030, around 40% of the country's population is expected to reside in urban areas. With rising economic standards and the consequent improvement in living standards, there has been a significant expansion of urban landscapes. The urban areas witness higher runoff due to changes in land cover from open to impervious due to construction, which includes buildings, pavements, and roads. Developmental and construction activities have changed natural drainage patterns in urban areas, disturbing recharge. In non-urban areas also, there have been changes in land cover and drainage patterns due to deforestation and infrastructural development activities. This has resulted in flash floods and fast decreasing groundwater availability however, urban developmental activities cannot be ceased owing to economical and commercial perspectives.

The decline of groundwater levels has become a major problem in India due to its over-exploited to meet increasing domestic and agricultural water demands. This situation has been worsening due to the widening gap between the amount recharged through rainfall and the amount withdrawn (Dangar et al., 2021). Rainfall alone is not sufficient to recharge groundwater satisfactorily. Therefore, artificial recharge is one of the important activities to conserve rainwater both on the ground and underground. In many parts of the country, especially in the arid and semi-arid regions, due to the vagaries of monsoon and scarcity of surface water, dependence on groundwater resources has led to increased groundwater depletion tremendously in recent years (Bouwer, 2001). The amount of natural recharge is insufficient to meet the increasing demand for groundwater resources. On the other hand, rapid urbanization and land-use changes have decreased the infiltration rate into the soil and have diminished the rate of natural recharging of aquifers by rainfall. These factors have contributed to lowering the water table so much that many dug wells and tube wells giving previously sufficient yield are decreasing now in their yield and ultimately drying up. The situation becomes more precarious during summer when most of the yield of dug wells and shallow tube wells either reduces considerably or dries up. This can severely impact both urban and rural areas.

Artificial recharge is the process by which the groundwater recharge is augmented at a rate much higher than those under the natural condition of percolation. A variety of methods are employed in India to recharge groundwater, combining traditional and modern techniques suited to its diverse climatic and geological conditions. Rainwater harvesting is one of the most prevalent approaches, including rooftop rainwater harvesting, where rainwater is collected from roofs and directed into recharge pits, wells, or underground reservoirs, and surface runoff harvesting, which diverts rainwater into recharge structures like ponds or percolation pits. The rooftop water harvesting structures in rural and urban areas proved to be effective to recharge groundwater. To effectively harvest rainwater, it is necessary to catch the rain when it falls and where it falls. Percolation pits and trenches, often filled with porous materials like gravel and sand, are widely used to enhance infiltration. Small check dams and nala bunds constructed across streams or rivers temporarily hold water, allowing it to percolate into aquifers. Injection wells are employed in urban areas with declining groundwater levels to directly inject water into deeper aquifers, while recharge shafts and modified dug wells channel water into underground aquifers effectively. Farm ponds and traditional water tanks such as Kunds and Ahars store rainwater, promoting gradual infiltration. Contour bunding and trenches are built along natural land contours to slow runoff and encourage water absorption. Gabion structures made of wire mesh and stones are used to reduce water velocity and facilitate recharge. Subsurface dykes, and underground impermeable barriers, obstruct groundwater flow to raise water tables upstream. Additionally, the revival of traditional systems like step wells (Baolis), Johads (earthen dams), and Zings (high-altitude ponds) has gained importance in modern groundwater management. These methods collectively help mitigate water scarcity, replenish aquifers, and promote sustainable groundwater use across the country.

Groundwater plays a pivotal role in Madhya Pradesh, supporting agriculture, drinking water, and industrial activities across the state. As a predominantly agrarian region, nearly 70% of the state's agricultural activities depend on groundwater, making it a lifeline for millions of farmers. Madhya Pradesh is among the top groundwater-extracting states in India, with an annual extraction of approximately 33 billion cubic meters, contributing significantly to the country's food security (Gupta, 2014). However, over-extraction in areas like Malwa and Bundelkhand has led to alarming declines in water tables, with some regions witnessing a drop of 1 to 2 meters per year (Surjibhai et al., 2024). Despite receiving abundant rainfall in certain areas, poor recharge practices and excessive reliance on groundwater have created water stress in many parts of the state. To ensure long-term sustainability, it is crucial to adopt measures such as rainwater harvesting, watershed development, and community-based groundwater management practices.

Madhya Pradesh, with an agriculture-dominated economy, heavily relies on groundwater for irrigation. Excessive extraction, particularly for water-intensive crops like wheat and paddy, has led to significant declines in groundwater levels. The lack of regulation in groundwater usage further exacerbates the problem, threatening the sustainability of agricultural practices in the state (Shah et al., 2014; Patle & Sharma, 2023). Rapid urbanization in cities such as Bhopal and Indore has increased groundwater demand for industrial and domestic use. Unchecked urban sprawl coupled with insufficient rainwater harvesting systems has contributed to the depletion of aquifers, making urban water security a pressing concern (Shah, 2016; Kumar, 2004; Raju, 2015). Madhya Pradesh experiences erratic rainfall patterns, leading to inadequate recharge of groundwater aquifers. Despite heavy monsoon rainfall in some regions, poor water management practices result in surface runoff rather than aquifer replenishment, worsening water scarcity in summer (Patel et al., 2020). Alongside quantity concerns, groundwater quality in parts of Madhya Pradesh has deteriorated due to contamination from industrial effluents and agricultural runoff. Studies indicate elevated nitrate and salinity levels, which could render groundwater unsafe for consumption in many regions (Taloor et al., 2024). The Government of India has implemented several watershed management programs to improve groundwater recharge, enhance water conservation, and promote sustainable agricultural practices. These programs integrate various techniques to address water scarcity and ensure the optimal use of resources. These programs include Integrated Watershed Management Programme (IWMP), Pradhan Mantri Krishi Sinchayee Yojana (PMKSY), Mahatma Gandhi National Rural Employment Guarantee Act (MGNREGA), Atal Bhujal Yojana (ABHY), Jal Shakti Abhiyan (JSA), Neeranchal National Watershed Project, Model Watershed Projects by NABARD, etc. These programs combine community participation, modern technology, and traditional knowledge to enhance groundwater recharge and ensure the sustainable use of water resources across India. However, experts emphasize the need for community-based water management, stricter regulation of groundwater use, and investments in artificial recharge projects to ensure sustainable usage. For further details, refer to studies and policy discussions from sources like the Geological Society of India and government conference updates on water crisis strategies (Singh et al, 2017).

In this context, physical, topographical, and hydrological limitations along with economic growth drive demand for decentralized water conservation to ensure and extend water availability on a sustainable basis. There is an urgent need to reverse the trend of falling groundwater levels due to the following reasons:

- To maintain baseflow in surface water bodies to ensure perennial flows.
- Ensure adequate water availability for the growing population and its increasing living standards.
- Limited and shrinking land availability for the creation of new surface water sources.
- To ensure source sustainability of a large number of water supply schemes, both in rural as well as urban areas.

Thus, maintaining groundwater levels is the key to perennially of surface water sources, ensuring water availability to the masses in diverse areas. Despite huge efforts by the government for groundwater recharge, to gain more effective results in a short time, it seems now imperative to promote efforts at the individual level contributing to groundwater recharge. Thus, there is an urgent need to develop and test technologies to be adopted at a mass scale that can be constructed even at the individual level. Most of the prevalent techniques of groundwater recharge are costly and time-consuming, however, we are proposing an economical and scalable technology that can be used to recharge point locations like wells, rural watersheds as well as urban areas through the construction of Auger Holes with locally available filter media. The present study aims to test and evaluate the effectiveness of the new Auger Hole Technique for the artificial recharge of groundwater through experimental studies. This project may be able to present a scalable technology of auger hole recharge through designing the spacing, depth, filter media, and their impact on groundwater regime in rural and urban areas. This technique may help to augment groundwater recharge and improve water quality due to dilution of polluted groundwater. It will help to enhance meet the growing water demand in rural as well as urban areas. As groundwater has been the main source of water to meet irrigation and domestic water demand in the country, the proposed Auger Hole Technique may likely be one of the simple and effective techniques to improve groundwater recharge and fulfill the increasing demand. The proposed Auger Hole Technique is very simple, less expensive, and requires less space, low maintenance, and less manpower. This technique may help to recharge groundwater resources and to meet challenges like droughts, water scarcity, and water shortage.

The major problem with surface storage for recharge is the loss of land covered with water and the ecological, environmental, and social problems thereafter. These methods of recharging are expensive and not easily compatible; hence a simple, easy, and low-cost Auger Hole Technique has been proposed in this project proposal, which will be used to recharge groundwater and it will be less expensive and require less space. Auger Hole Technique of recharge can be effective in minimizing water loss due to evaporation compared with similar surface storage systems. Many environmental problems arising out of surface storage can be avoided using artificial recharge. There will be no loss of agricultural lands or forests by inundation as would occur behind a surface storage structure. This technique will help to inject the runoff water into the ground and will increase the groundwater table naturally.

This project proposal focuses on evaluating the Auger Hole Technique for its potential application in artificial rainwater harvesting. The study aims to design and determine optimal specifications for auger holes, including size, depth, and the selection of suitable local filter materials. Assess the improvement in infiltration rates achieved through the application of the Auger Hole technique and give recommendations for enhancing the technique's efficiency, utility, and adoptability in diverse settings of rural and urban areas. The research will also explore the appropriate dimensions and locally available materials to minimize costs, enhancing the technique's feasibility and adaptability within the community. The findings will contribute to the development of practical and sustainable solutions for water conservation and augmentation of groundwater recharge through rainwater harvesting. The specific objectives of the study are as below.

- Rainfall and groundwater level analysis of the study area
- To identify the appropriate procedure for the design and construction of Auger holes for its adoption
- Assessment of the impact of Auger hole techniques in the improvement in groundwater recharge rate
- Suggestions and recommendations

2.0 REVIEW OF LITERATURE

Artificial recharge is one of the oldest activities undertaken in India and the world to conserve rainwater both on the ground and underground to irrigate agriculture in arid and semi-arid regions. In the olden days, the recharge movement initiated by the local communities was aided and supported by kings; chieftains; philanthropists, and those who valued water and practiced conservation. There are numerous examples and stone inscriptions from as early as 600 A.D. citing that ancient kings and other benevolent persons considered the construction of *Ooranies*, as one of their bounden duties to collect rainwater and use it to recharge wells constructed within or outside *Ooranies* to serve as the drinking water source. Even today, thousands of such structures exist and are in use for multiple purposes in the southern coastal towns and villages of Tamilnadu where underground water is saline. The spread of Artificial Recharge Movement in India (ARMI) can be broadly classified under three phases and analyzed. The first phase relates to the period: before the Green Revolution when limited exploitation of groundwater was taking place i.e., before 1960; the second is the period between 1960 and 1990 where intense groundwater exploitation took place with signs of overexploitation, and the third is the period from 1990 to-date when water scarcity is increasing with alarming groundwater level decline in certain pockets of India. The first phase is the one when traditional water harvesting methods were given impetus through unorganized yet spontaneous movement by the local communities aided by kings and benevolent persons to meet the local requirements at the time of crisis. During this period, there was very little knowledge-based input from the government and non-government organizations, and the scientific community to assist in understanding and systematic ways of putting into practice artificial recharging and up-scaling. Yet, the local community used their intimate knowledge of the terrain, topography, and hydrogeology of the area to construct and operate successful artificial recharge structures, some of which have managed to survive even today.

Sharma (2021) carried out a groundwater assessment in Madhya Pradesh. According to his assessment, 24 groundwater blocks out of 313 have been categorized as "over-exploited," meaning groundwater extraction exceeds recharge levels This situation highlights the urgent need for sustainable water management practices, especially in agriculture-dominated areas where extraction is intense. Rahman et al., (2020).) carried out groundwater assessment studies showed that in Rajasthan, they observed that over 80 percent of the blocks are overexploited, dark or critical, closely followed by Punjab at 78.8 percent, Delhi at 77.8 percent, as well as Haryana, Tamil Nadu, and Karnataka at 58.4, 45.5 and 38.9 respectively, and Andhra Pradesh and Gujarat are above the national average in overexploitation.

Lata, (2019) in her paper described that the Uttar Pradesh (UP) government's experiment to recharge Excess River (flood) water via earthen canals has succeeded in raising the water table and bringing down the cultivation costs. The efforts of the Government of UP have opened up a new and practical way to conserve and rejuvenate falling groundwater reserves through the use of floodwater. The project- the Madhya Ganga Canal projects (MGCP), which occupies lower Ganga canal commands- was initiated in 1988. Sakthivadivel & Chawla, (2001) reported that, in 2000, the International Water Management Institute (IWMI) carried out a study on the Lakhaoti branch canal of the MGCP, to assess the impact of diversion of surplus Ganga water, during the Kharif season, on groundwater levels and cropping patterns. The Lakhaoti branch is spread over 205.6 thousand hectares and covers the districts of Ghaziabad, Bulandsher, and Aligarh in western UP. It is bounded by the drainage canals of the Kali and Nim rivers. The Government of Tamil Nadu has enacted a groundwater regulation act of the Chennai Metropolitan Area to overcome the grave situation it had faced due to the severe drinking water crisis.

Revered Shri Panduranga Shastri Athvale of the "Swadhyay Parivar" has introduced a movement in Gujarat called "Nirmal Neer" (clean water) intending to provide drinking water and support irrigation through effective rainwater harvesting. Under his inspiration, schemes such as recharging of wells and tube wells, diverting rainwater into the existing ponds, and construction and maintenance of check dams and ponds have been taken up by the villagers. In 1995, in Saurashtra region alone, people have adopted recharging of well schemes in 98,000 wells (Parthasarathi & Patel, 1997). The massive adoption of the scheme explicitly indicates the awareness of conservation and better utilization of rainwater.

The Act named *"The Chennai Metropolitan Area Groundwater (Regulation) Act, 27 of 1987"* came into force with effect in February 1988. The Act envisages i) registration of existing wells, ii) regulation of sinking new wells, iii) issue of license to extract groundwater for non-domestic purposes by the Revenue officials on payment of prescribed fees after getting technical clearance from Chennai Metropolitan Water Supply and Sewerage Board (CMWSSB). In different parts of India like Chhattisgarh, Himachal Pradesh, Andhra Pradesh, and other states practices to increase storage of groundwater as well as surface water by constructing watershed harvesting structures, recharge pits, and other methods like check dams, farm ponds, nalla treatment to restores and enhances the capacity, contour bunds, Gully plugging, nalla bunding, percolation tank, Continuous contour trench (CCT), Deep CCT, Earthen Structures, drainage line treatments, Widening and deepening of Nalla Bed, Cement Storage Tank, Compartment bunding, revival of the water supply system, bore well recharging, and Plantation, etc.

Chewang Norphel (2012) gave the concept of Artificial Glaciers at Ladakh in Jammu & Kashmir, in this a canal made to divert water from the main glacial stream to a small shaded catchment area away from the village to keep water frozen. Ice retaining walls were constructed on the sides in series to store frozen water. Vohra and Franklin, in their comprehensive report, mentioned that the

Baburao Anna Hazare used rainwater harvesting to fill the empty cracks located in impenetrable basalt rock found throughout the region. He used methods like nalla bunds, gully plugs, and contour trenches, and renovated an old percolation tank, shrubs, trees, and grass were planted along the hillsides all around the Ralegaon Siddhi village. Pokharkar, (2012) appraised the work carried out by Sri Popatrao Pawar, Sarpanch of a Panchayat in Maharashtra, who encouraged the techniques like Johad, earthen check dams, which have been traditionally used to store rainwater and recharge groundwater at Hiware Bazar village in Maharashtra.

The Government of India is undertaking various programs such as MGNREGA, Rural Development Program, Integrated Watershed Development Program (IWDP), NGO, and social corporate responsibilities, which are working to improve groundwater level and surface storage. This year, the Government of India launched a program called Jal Shakti Abhiyan from July 1 to November end. In this campaign, officials of the Government of India, groundwater experts, and scientists, worked closely with state and district officials in India's most water-stressed districts, according to the Central Ground Water Board (CGWB; 2017). Not only developed new water sources but also found and revived old structures hidden under the soil, wherever possible focusing on the rapid implementation of five target interventions to meet the increasing water requirements for various activities and also making people aware of recycling, reuse of water, water conservation and water resource management. Groundwater movement is being organized in India on a large scale so that the level of groundwater will be maintained in the future. Singh & Gupta (2017) evaluated the use of augur holes in Rajasthan, a semi-arid region. The researchers found that augur holes significantly increased groundwater recharge compared to conventional surface methods. The study highlighted the technique’s potential in areas with low natural recharge rates but also noted challenges related to maintaining hole permeability and preventing siltation.

Rao & Kumar, (2018) compared augur holes with recharge pits in various soil conditions. The study concluded that augur holes performed better in soils with low surface permeability, while recharge pits were more effective in areas with higher surface infiltration rates. The study underscores the importance of site-specific assessments for selecting appropriate recharge techniques. Verma & Singh, (2020) focused on the long-term performance of augur holes and associated maintenance issues. It reports that while augur holes can be effective, their performance tends to degrade over time due to clogging and siltation. The study highlights the need for regular maintenance and monitoring to ensure sustained effectiveness. Kumar & Sharma, (2021). Investigated the use of augur holes in urban environments. The findings suggest that while augur holes can be beneficial in urban areas with impervious surfaces, issues related to space constraints and urban pollution need to be carefully managed.

The review of literature and works carried out in the past has indicated that groundwater recharge works are important to solve drinking, irrigation, and other requirements like water for livestock which are the worst sufferers in the case of drought or low rainfall years. The occurrence of groundwater is often poor in rural areas and diminishing very sharply in urban areas due to the indiscriminate exploitation of confined aquifers. The techniques that are commonly used to recharge groundwater are costly, time taking and require a large workforce which is possible through the involvement of all sections of society which is not possible everywhere. The mass movement for recharge was successful in very limited areas due to not gaining momentum. The proposed project will help develop and demonstrate a noble Auger hole technique that can be applied for artificial groundwater recharge and improvement of water quality in rural as well as urban areas of India.

Wadwekar & Pandey, (2021) conducted a case study of Bhopal city to assess groundwater recharge potential through rainwater harvesting in urban environments. They observed that, in Bhopal city, the primary water requirement is now fulfilled by utilizing local and external resources. Despite having ample water bodies, is facing a water crisis. Extensive groundwater extraction over the years has led to resource depletion and degradation, and the water requirement is now fulfilled from the Narmada River. This paper analyses the existing status of groundwater in the city and identifies the probable reasons for the depletion through a Cause/Effect relationship. The study explores suitable recharge locations through GIS-based land suitability analysis and identifies techniques to improve the resource. Spatial planning interventions and policy measures are proposed to recharge and rejuvenate the groundwater resources through rainwater harvesting and improve the overall ecosystem health.

3.0 MATERIALS AND METHODOLOGY

3.1 Study Area

In the present study, the testing and evaluation of the effectiveness of the new Auger Hole Technique for artificial recharge of groundwater through experiments has been carried out in the premises of the Water and Land Management Institute (WALMI), Bhopal. WALMI is an autonomous institute of the Government of Madhya Pradesh to provides training and working on sustainable water and land management through training, research, and extension activities, promoting efficient resource utilization and agricultural productivity. The WALMI is situated on a flat hillock surrounded by a beautiful valley and steep slope land. The WALMI has developed a 33.08 ha farm where different agronomic, biological, and mechanical soil and water conservation and water harvesting structures including trenches, boulder bunds, gabion structures, farm ponds, afforestation, plantation, and beekeeping, organic manure for society education. Appropriate plants suitable for the region were selected and the Miyavaki tree plantation system was adopted for sustainable plant growth. The water and soil conservation activities have been implemented in a phased manner in the WALMI farm and it was imperative to evaluate the impact of these structures on the recharge of groundwater along with control of soil erosion and soil moisture maintenance. The base map of WALMI and the farm are presented in Figure 3.1.

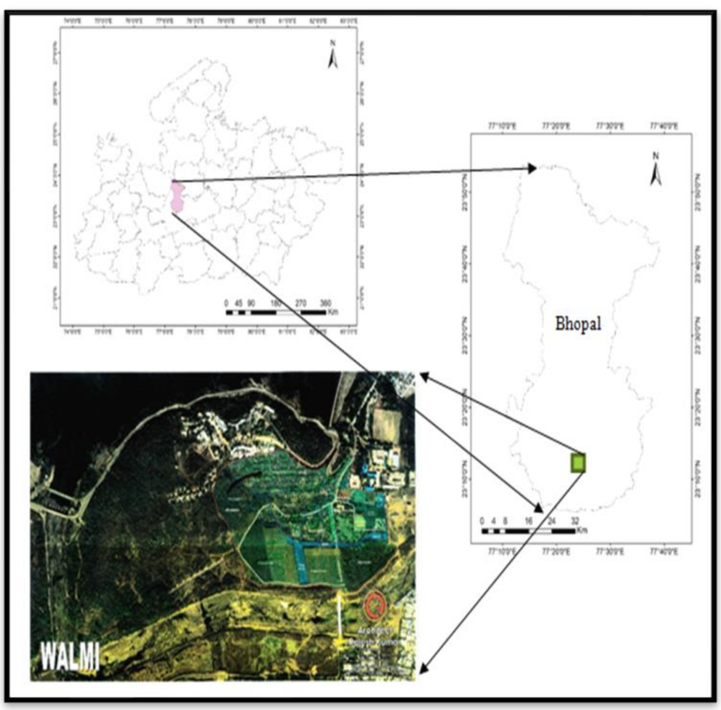

Figure 3.1: Location map of WALMI Campus

3.2 Data Used

In this study, the rainfall data of the Bhopal rain-gauge station of the India Meteorological Department (IMD) from 1980 to 2019 was used for statistical analysis. The long-term groundwater level data of four observation wells of Ground Water Survey, MPWRD, Bhopal falling near the WALMI campus was used for the analysis. Data collected from Infiltration tests conducted at the Auger hole sites was also used in the analysis.

3.3 Step-by-step procedure

The flow chart of the work and procedure adopted in the study is shown in Figure 3.2.

Figure 3.2: Flow chart of procedure adopted

3.4 Rainfall Data Analysis

Rainfall is the primary source of water for recharge and analyzing rainfall patterns helps in understanding how much water is available for infiltration and subsequent recharge of aquifers. Rainfall can be highly variable in terms of intensity, duration, and distribution. Understanding these patterns helps estimate the potential for recharge in different conditions, such as during droughts or heavy rainfall events. The long-term rainfall data of Bhopal station of the India Meteorological Department (IMD) from the year 1980 to 2019 has been collected to perform various statistical analyses including Average Annual Rainfall, Average Monsoon Rainfall, Average Non-Monsoon

Rainfall, Winter Rainfall, Number of Rainy days, Standard Deviation, Coefficient of Variance, and Rainfall Departure Analysis for dry and wet year probability, etc.

Trend analysis of rainfall is crucial in artificial groundwater recharge planning as it helps to predict water availability, identify patterns of drought or excessive rainfall, and guide sustainable water resource management. It enables planners to design effective recharge structures that align with changing climatic conditions. Accurate analysis supports long-term water security and ecosystem balance. Therefore, a trend analysis of annual, monsoon, and non-monsoon rainfall was conducted using the Mann-Kendall non-parametric test to assess the significance of rainfall patterns in the study area.

3.5 Groundwater Data Analysis

The analysis of groundwater level data provides insights into fluctuations caused by seasonal recharge and exploitation. During the pre-monsoon period, groundwater levels typically decline due to usage to meet water demands. Monsoon rains recharge the aquifers, bringing groundwater levels back to their original depths. However, post-monsoon, levels decrease again due to continued exploitation. This pattern of recharge and drawdown highlights the dynamic nature of groundwater resources. A long-term trend analysis of groundwater levels can reveal whether the groundwater situation in an area is improving or declining. Such an assessment is crucial for determining the recharge rates required to maintain sustainable groundwater levels. It also aids in identifying appropriate groundwater recharge measures. Factors like soil type and land use significantly influence the balance between rainfall infiltration and surface runoff. Analyzing these factors alongside rainfall data provides more accurate estimates of recharge potential. Understanding the interplay between rainfall and groundwater recharge can guide effective water management practices. Measures such as artificial recharge techniques like, auger holes, recharge pits, rainwater harvesting, and sustainable land use practices can enhance groundwater replenishment.

In the present study, pre-monsoon and post-monsoon groundwater level data from 1984 to 2024 were statistically analyzed. The data was obtained from four observation wells maintained by the State Ground Water Survey of the Water Resources Department, Madhya Pradesh, located near the WALMI Campus in Bhopal. A trend analysis was conducted to identify rising or declining patterns in groundwater levels at various significance levels using the non-parametric Mann-Kendall test. The results of this analysis offer valuable insights for planning sustainable groundwater recharge strategies through rainwater harvesting in the study area.

3.6 Land Use Land Cover

Land use and land cover (LULC) information is crucial for planning artificial groundwater recharge as it influences infiltration, runoff, and recharge potential. Vegetative cover, soil type, and impervious surfaces affect how much rainfall percolates into aquifers. Identifying suitable recharge zones, such as barren lands or low-lying areas, depends on accurate LULC data. It helps optimize artificial recharge structures like recharge pits and trenches. Integrating LULC with hydrological data ensures effective and sustainable groundwater management. For this analysis, the land use and land cover (LULC) map of the study area was obtained from the Bhuvan Portal of ISRO's National Remote Sensing Centre (NRSC) and is presented below in Figure 3.3.

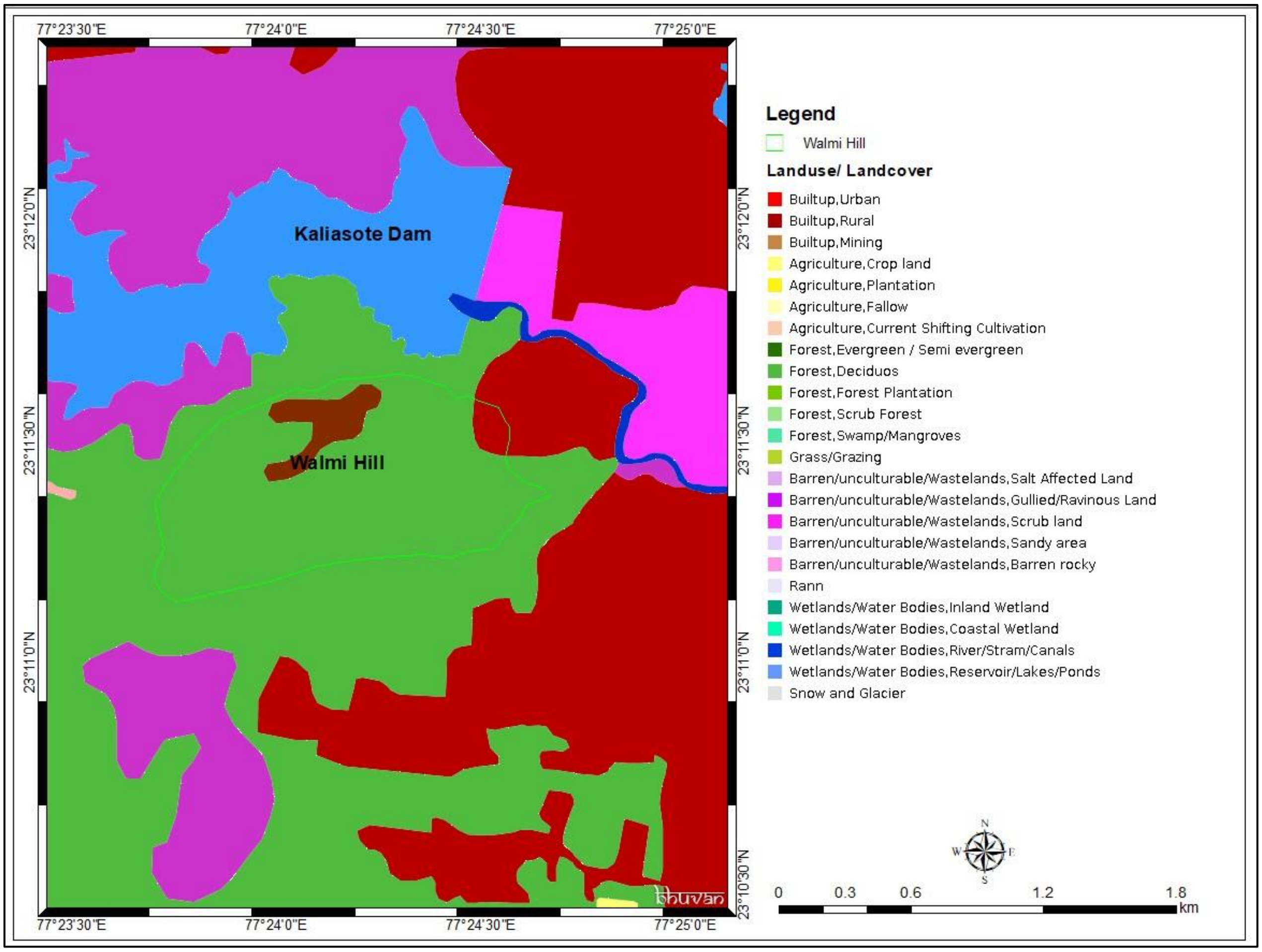

Figure 3.3: Land use / Land cover Map

The LULC map shown in Figure 3.3 reveals that the majority of the study area falls under the plantation category, with a smaller portion consisting of built-up areas located at the top of the WALMI hill.

3.7 Geomorphology

Geomorphology plays a vital role in artificial groundwater recharge by determining the terrain, landforms, and subsurface characteristics that influence water infiltration and storage. Features like valleys, plateaus, and floodplains guide the selection of suitable recharge zones. The permeability and porosity of geomorphic units, such as alluvial plains or fractured rocks, affect recharge efficiency. Understanding geomorphology helps in designing effective recharge structures tailored to local conditions. It ensures sustainable groundwater replenishment by aligning recharge strategies with natural geological settings. The geomorphology map of the study area, obtained from the Bhuvan Portal of ISRO-NRSC, is presented below in Figure 3.4.

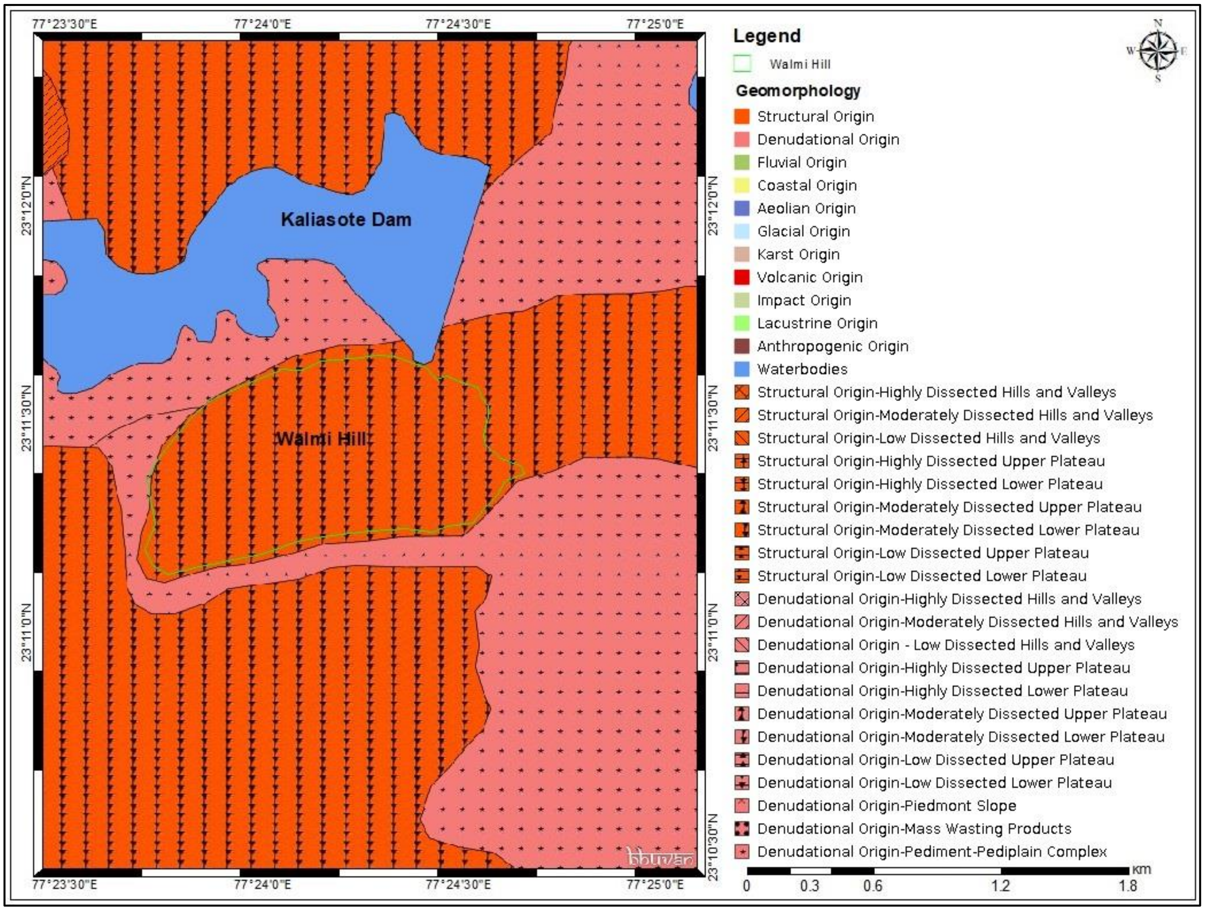

Figure 3.4: Geomorphology Map

The geomorphology map in Figure 3.4 shows that the study area is characterized by a structural origin, specifically a highly dissected lower plateau. Surrounding this plateau are geomorphic features of denudational origin, identified as a pediment-Pedi-plain complex. A prominent waterbody is located nearby, created by the Kaliasote Dam on the Kaliyasot River.

3.8 Soil Type and Soil Loss

Soil and water are two important natural resources containing mineral particles and organic constituents separated into horizons of numerous depths and oil acts as a storehouse for plant nutrients, an environment for microorganisms, and a reservoir with sufficient water holding capacity for plant growth. The soil erosion mainly affects the damage of the topsoil profile, which is the best productive zone with a depth of 20 to 30 cm. Increased soil erosion contributes to nutrient loss, decreasing agricultural yield. The destruction of the agricultural lands started from rain splash erosion to sheet erosion, rills, gullies, and lastly bank erosion that caused huge losses to farmers and society as a whole. In WALMI campus the soil the soil loss was estimated using the Universal Soil Loss Equation and soil loss was observed ranging from 1.5 t/ha/yr to 180 t/ha/yr with an average value of 45.6 t/ha/yr. The water harvesting intervention helps to improve the groundwater recharge and reduce the runoff which may consequently help to reduce the soil loss. The soil type in the study area is mainly clay type (NIH Report, 2022).

3.9 Designing Auger Hole Specifications

In the present study, ten Auger holes are planned for construction in the WALMI campus. The design parameters, including diameter, depth, and filtration media, have been optimized to ensure simplicity, efficiency, and rapid implementation. The dimensions of the Auger holes were determined based on the capabilities of locally available tractor-mounted auger digging equipment, commonly accessible in most regions. The filtration media were selected from locally sourced materials, such as boulders, bricks, charcoal, and coarse river sand, to minimize costs and ensure sustainable resource utilization. The design of the Auger holes emphasizes ease of construction, allowing local artisans or workers to execute the project using readily available tools and materials. Additionally, the size and placement of the Auger holes are carefully planned to avoid interfering with the functional utility of urban or rural spaces. A key consideration was to keep construction costs low and economically justified, enhancing the feasibility of large-scale adoption. These design criteria aim to promote the widespread acceptance of the Auger hole technique as an effective artificial groundwater recharge structure suitable for both rural and urban sprawls. The Specifications for the Auger holes designed are given in Table 3.1 and the experimental setup and design of augur hole structure is shown in Figure 3.5.

Table 3.1: Specifications for the Auger holes designed

Design parameter	**Details**
Total Number of Auger holes	10
Locations	Garden, open areas, natural depressions, and surface flow paths
Diameter	1 ft
Depth	10 ft

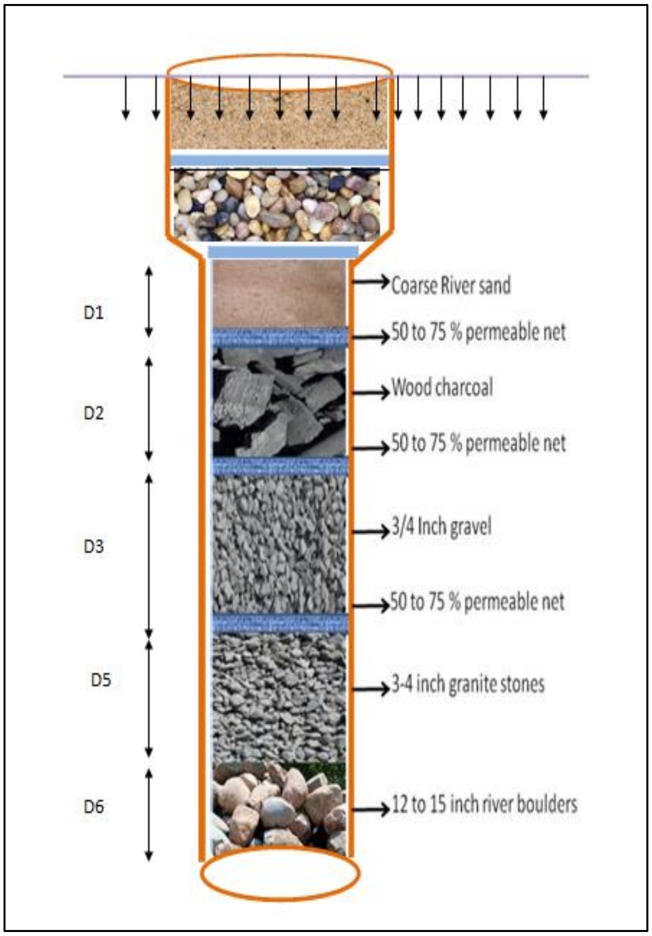

Figure 3.5: Proposed Auger Hole and its filtration media

Auger hole structure has been designed with the following considerations:

- To take up recharge activities on a mass scale
- Recharge activities to be initiated by the common man. He may not have technical knowledge, but his recharge contributions are important.
- No specific site selection issues.
- To permit recharge in paved areas also.
- It should be simple to construct
- It should be cheap
- Easy to construct
- Should use locally available material
- Effects of mistakes and errors in site selection and construction should remain localized.
- No need for any highly specialized knowledge or skill for construction.

Underlying design principle:

- Permeability in the horizontal direction is two to three times more than that in the vertical direction in naturally stratified
- Pressure increases with water head (depth of water in this case)

Site Selection:

- Normally all sites wherever drilling by auger is to be done are suitable for construction of auger hole. Depending on the strata, the drilling depth may vary.
- Owing to the high infiltration rate, these structures are more suitable in streams or at places of water stagnation.
- Usually, the recharged water gets purified by a natural soil medium before joining the groundwater. However, an auger hole should not be constructed within the vicinity of 10 m from any groundwater abstraction structure. It should not be constructed at sites where the water contains high concentrations of dissolved toxic impurities which may pollute groundwater in the long run viz. in close vicinity of sewer lines, industrial effluent points, etc.
- Thus, auger holes can be constructed almost on all sites where there is soil or soft strata of a minimum 2m depth.
- It can be constructed in lawns, plains, vacant plots, stormwater drains, paved areas in urban landscapes wherever is water stagnation, forests, farms, etc.

3.10 Locations of test sites for construction of Auger Holes

The latitude and longitude of the locations of augur holes in the WALMI campus are given in Table 3.2. Google map image showing the location of Augur holes and soil test sites in the WALMI campus is shown in Figure 3.6.

Table 3.2: Locations of augur holes in the WALMI campus

Sl. No.	Latitude	Longitude
1	23.192219°	77.403381°
2	23.192551°	77.403480°
3	23.192801°	77.403478°
4	23.192960°	77.403707°
5	23.193274°	77.404031°
6	23.193198°	77.404178°
7	23.192865°	77.403960°
8	23.192865°	77.403605°
9	23.192691°	77.403367°
10	23.192026°	77.402332°

Figure 3.6: Google map image showing location of Augur holes and soil tests in WALMI campus

3.11 Construction of Auger Holes

Ten Auger holes were constructed in the WALMI campus at various locations as discussed above. The construction was carried out in March 2021 i.e. in the pre-monsoon season. The photographs of the construction of Auger holes in the WALMI campus, Bhopal are shown in Figure AA below.

3.12 Design of Auger hole and filtration media

Photographs of the construction of Auger holes in the WALMI campus, Bhopal are shown in Figure 3.7. The depth of the Auger hole is generally designed based on the soil type and geological conditions. In hard rock regions, it is typically kept at 8 to 10 feet. Once the Auger hole is dug, its depth is measured using a measuring tape and recorded as "D" for further calculations. The depth to be filled with filter media is then determined following the simple procedure outlined below in sequence.

- Measure the depth of the Auger Hole: D ft and fill as per the following details
- 1st Layer (Bottom) - boulder (6 to 8 inch size): thickness x = D – 4 ft
- 2nd Layer - Broken Bricks (brick bet): 1 ft
- 3rd Layer - Gravel (Gitti, 25 mm): 1 ft
- 4th Layer - Charcoal: 3 inch
- 5th Layer - Marble/Coarse Sand/ 6mm gravel: 9 inch
- 6th Layer - Sand: 6 inch
- 7th Layer – Marble/Coarse Sand/ 6mm gravel: 6 inch

Figure 3.7: Photographs of construction of Auger holes in WALMI campus, Bhopal

3.13 Assessment of improvement in infiltration rate due to Auger hole

Increased infiltration allows rainwater and surface water to penetrate deeper into the soil, replenishing underground aquifers more effectively. Reducing surface runoff and enhancing water percolation ensures that a larger volume of water reaches the groundwater table. This process accelerates groundwater recharge, helping to restore depleted aquifers and improve water availability. Enhanced infiltration also minimizes water loss through evaporation and supports sustainable water management.

In this study, the assessment of improvement in infiltration rate due to Augur holes is quantified by applying infiltration tests at the sites where augur holes were constructed, in two-time domains for the same season, one of which is before the construction of the augur hole, and the second is after one year i.e. stabilization of augur holes. The infiltration tests were conducted on the selected four sites out of 10 augur holes sites by using the double ring infiltrometer.

3.13.1 Double-Ring Infiltrometer

The double-ring infiltrometer is a widely used method to measure soil infiltration, or how fast water enters the soil. It is particularly useful for assessing infiltration rates in agricultural fields, construction sites, or natural landscapes. The technique involves two concentric rings (a smaller inner ring and a larger outer ring) driven into the soil, with water applied to both rings as shown in Figure 3.8. The infiltration rate is measured primarily in the inner ring, while the outer ring minimizes lateral water movement.

Figure 3.8: Double-Ring Infiltrometer

3.13.2 Ring Placement:

Two concentric rings are placed on the soil surface. The inner ring typically ranges from 30 to 60 cm in diameter, while the outer ring is larger, often about 60 to 90 cm. The rings are driven into the soil to a uniform depth (usually 10–15 cm) using a mallet or a driving plate. The goal is to ensure that there is no significant gap between the soil and the rings to prevent leakage.

3.13.3 Water Application:

Water is added to both the inner and outer rings simultaneously. The outer ring reduces horizontal water movement, helping the inner ring focus on vertical infiltration. The depth of the water applied is measured, and it is important to maintain a constant head of water (typically between 2 and 12 cm) throughout the experiment to maintain uniform pressure.

3.13.4 Infiltration Measurement:

The drop in water level inside the inner ring is measured over time. This is typically done at regular intervals (e.g., every 1, 5, 10, 15, 30 minutes, depending on soil type). The rate at which the water level decreases in the inner ring represents the soil's infiltration rate. The cumulative infiltration (total volume of water infiltrated over a given time) is recorded along with the time elapsed. Typically, measurements are taken until a steady-state infiltration rate is achieved, meaning the rate becomes constant over time. The infiltration rate (often in mm/hr or cm/hr) is calculated from the volume of water infiltrated, ring diameter, and time. The photographs showing the infiltration test are shown in Figure 3.9.

Figure 3.9: Photographs showing infiltration test

After analyzing the infiltration rates before and after the construction of Auger holes, along with evaluating their cost-effectiveness and utility, recommendations were formulated to promote the widespread adoption of the Auger hole technique as an efficient artificial groundwater recharge structure for both rural and urban sprawls.

4.0 RESULTS AND DISCUSSION

4.1 Rainfall Analysis

Rainfall is a critical factor influencing surface water availability and groundwater recharge. In the present study, the rainfall analysis was carried out for long-term rainfall data of the Bhopal monitoring station of the India Meteorological Department (IMD) from the year 1980 to 2019 and statistics have been calculated as shown the Table 4.1 and monthly rainfall distribution in Bhopal station is shown in Figure 4.1.

Table 4.1: Rainfall statistics of Bhopal station

Time step	Average (mm)	Std Dev (mm)	Coefficient of Variation (%)	Mann Kendall Z statistic value	Sen's Slope
Annual	1150	290	0.25	0.12	0.09
Monsoon	1044	281	0.27	0.17	0.86
Non-Monsoon	107	80	0.75	-0.81	-1.01
Winter Rain	22	26	1.18	-0.67	-0.10
Pre-monsoon	30	39	1.31	0.47	0.10
Post Monsoon	55	68	1.24	-1.92	-0.96
Rainy Days	52	8	0.16	0.20	0.03

From the analysis, it can be seen that the average annual rainfall at Bhopal is 1150 mm with a Standard Deviation of 290 mm and a Coefficient of Variation of 0.25%. The average rainfall during monsoon season is found to be 1044 mm, with a Standard Deviation of 281 mm and 0.27% of Coefficient of Variation. The average rainfall during the non-monsoon season is found to be 107 mm, while the winter rainfall is 22 mm. The highest coefficient of variation of 1.31% is observed for the pre-monsoon period with an average rainfall of 30 mm, while the post-monsoon period has an average rainfall of 55 mm and the Coefficient of Variation is 1.24%. The average number of rainy days i.e. the day with rainfall equal to or more than 2.5 mm is found to be 52 days with a Standard Deviation of 8 days and a Coefficient of Variation of 0.16%, which is lowest among all the variables. The trend analysis indicated a non-significant rising trend in annual, monsoon, and pre-monsoon rainfall. The non-significant falling trend was seen in winter rainfall whereas a significant falling trend at a 95% significance level was seen in post-monsoon rainfall. From the analysis, it is seen that the seasonal as well as the annual rainfall at Bhopal shows very high variation and minimal trend in rainfall pattern highlighting the necessity for systematic water resource development and management in the area.

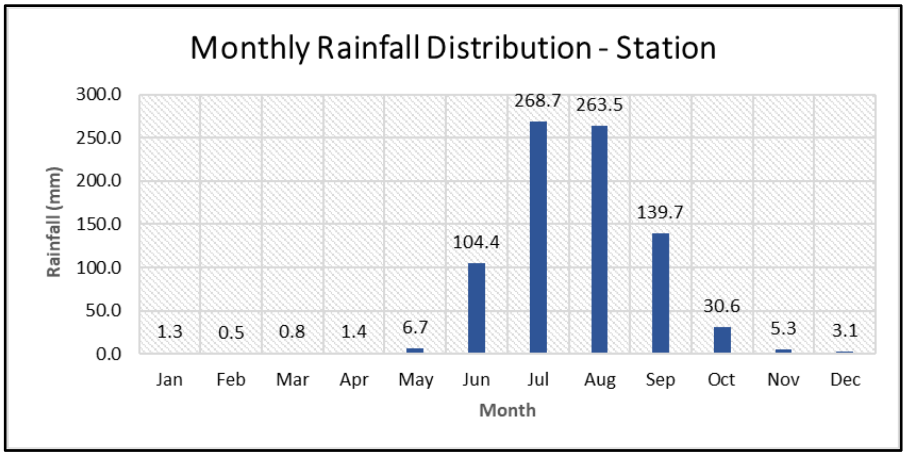

Figure 4.1: Monthly rainfall distribution at Bhopal station

The monthly rainfall distribution for the Bhopal weather monitoring station is given in Figure 2.4. From the monthly rainfall distribution, it has been observed that July month receives the maximum rainfall followed by August. The average monthly rainfall for July has been observed to be 268.7 mm. The second highest rainfall-receiving month is the month of August which received an average monthly rainfall of 263.5 mm. The month of September has received an average monthly rainfall of 139.7 mm and the least monthly average rainfall among the monsoon months has received during June. A considerable monthly average rainfall of 30.6 mm has also been received during October.

4.2 Rainfall Departure (RD) Analysis

Drought significantly reduces groundwater recharge by limiting the availability of surface water from rainfall, which is the primary source for replenishing aquifers. Prolonged dry periods decrease soil moisture, reducing the infiltration capacity and hindering water percolation into the groundwater table. With less surface water runoff, recharge structures also become less effective. Additionally, increased water extraction during droughts to meet demand further depletes groundwater levels. Over time, recurring droughts can exacerbate groundwater scarcity and threaten long-term water sustainability.

In the present study assessment of drought frequency has been carried out using rainfall departure analysis. The rainfall departure analysis is widely used for the determination of meteorological droughts, their, frequency, return period, and severity. In the present study, seasonal and annual rainfall departure analysis was carried out using long-term rainfall data from 1980 to 2019 of Bhopal station. As suggested by the India Meteorological Department, a year can be considered as a drought year when the annual rainfall deficit is more than 25% of its long-term normal rainfall (Appa Rao, 1986). Further, the meteorological drought can be classified according to its severity level. It is considered a Moderate drought when the annual rainfall deficit is between 25% to 50%, Severe drought when the annual rainfall deficit is between 50% to 75%, and Extreme drought when the annual rainfall deficit is more than 75%. The percentage departure of the annual rainfall time series has been calculated using Equation 1. The seasonal rainfall departure carried out using this equation for Bhopal station is shown in Figure 4.2. Drought frequency analysis based on annual and seasonal rainfall departure is shown in Table 4.2.

$$RD\ (\%) = \frac{P_i - P_m}{P_m} * 100 \qquad \textit{Equation 1}$$

Where,

RD is the percentage rainfall departure

Pi is the rainfall in the *ith* year

Pm is the long-term average rainfall for *m* years

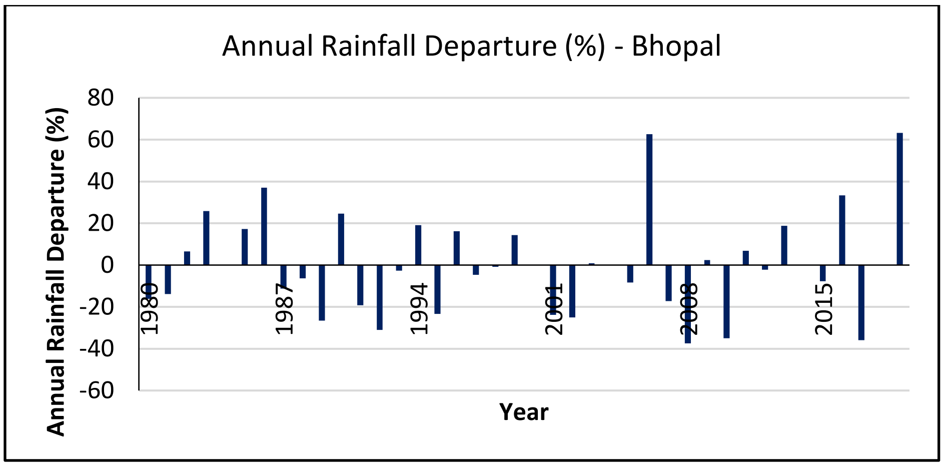

Figure 4.2: Seasonal rainfall departure (%) at Bhopal

Table 4.2: Drought frequency analysis of annual and seasonal rainfall at Bhopal

Drought Analysis	Drought Yrs	Highest Dep	Return Period (Yrs)	Frequency
On Annual RF Basis	5	-37	7	1 in 7-8 years
On Monsoon RF Basis	9	-43	4	1 in 4 years

In this study, the approach of probability analysis of rainfall has been applied to understand whether the station is drought-prone or not depending upon the probability of exceedance of 75% of average rainfall. A rainfall probability distribution graph at Bhopal station is shown in Figure 4.3 and drought status of is shown in Table 4.3.

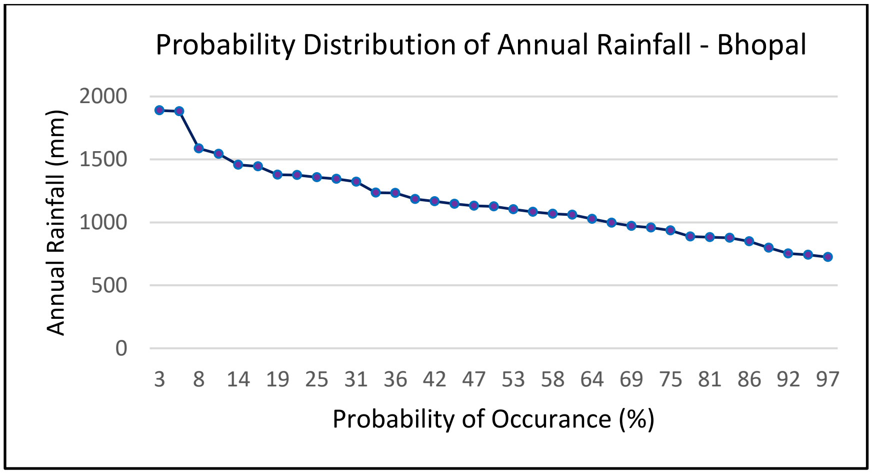

Figure 4.3: Probability distribution graph at Bhopal station

Table 4.3: Probability distribution analysis of rainfall

Rainfall	**75% of Mean (mm)**	**Prob of Occurrence (%)**	**Status**
Annual Rainfall	863	81	Not prone to Drought
Seasonal Rainfall	783	77	Drought Prone

The analysis of annual rainfall departures at Bhopal, as presented in Table 2.3, indicates a drought frequency of approximately one drought every 7 to 8 years. In contrast, the analysis of seasonal rainfall departures reveals a higher drought frequency, with one drought occurring approximately every 4 years. The probability distribution analysis of rainfall, shown in Table 2.4, suggests that Bhopal is drought-prone when assessed based on seasonal rainfall. However, when analyzed using annual rainfall data, the city is found to be less prone to drought. This discrepancy highlights a significant anomaly in drought occurrence depending on the chosen temporal scale of analysis. It underscores the urgent need to develop water resources and enhance groundwater recharge to meet water demands effectively during periods of scarcity.

4.3 Groundwater Data Analysis

Analyzing groundwater levels is essential for planning effective rainwater harvesting and artificial recharge structures. It helps to identify areas with severe depletion, guiding targeted interventions where recharge is most needed. Understanding seasonal and long-term groundwater trends enables the design of structures that align with local hydrogeological conditions. Such analysis also aids in optimizing the location, size, and type of recharge systems to maximize efficiency. It provides critical information for assessing water demands and planning sustainable groundwater management strategies. Ultimately, it ensures that rainwater harvesting and recharge efforts are both scientifically informed and impactful.

The WALMI Campus Bhopal has the nearest four Observation Wells (OW) located at Bawadia Kalan, Akbarpur, Chuna Bhatti, and Shahpura in Bhopal. The long-term groundwater level data of these four observation wells was used to assess the groundwater scenario in the study area. The location map of Observation Wells (OW) near the WALMI Campus in Bhopal area are shown in Figure 4.4.

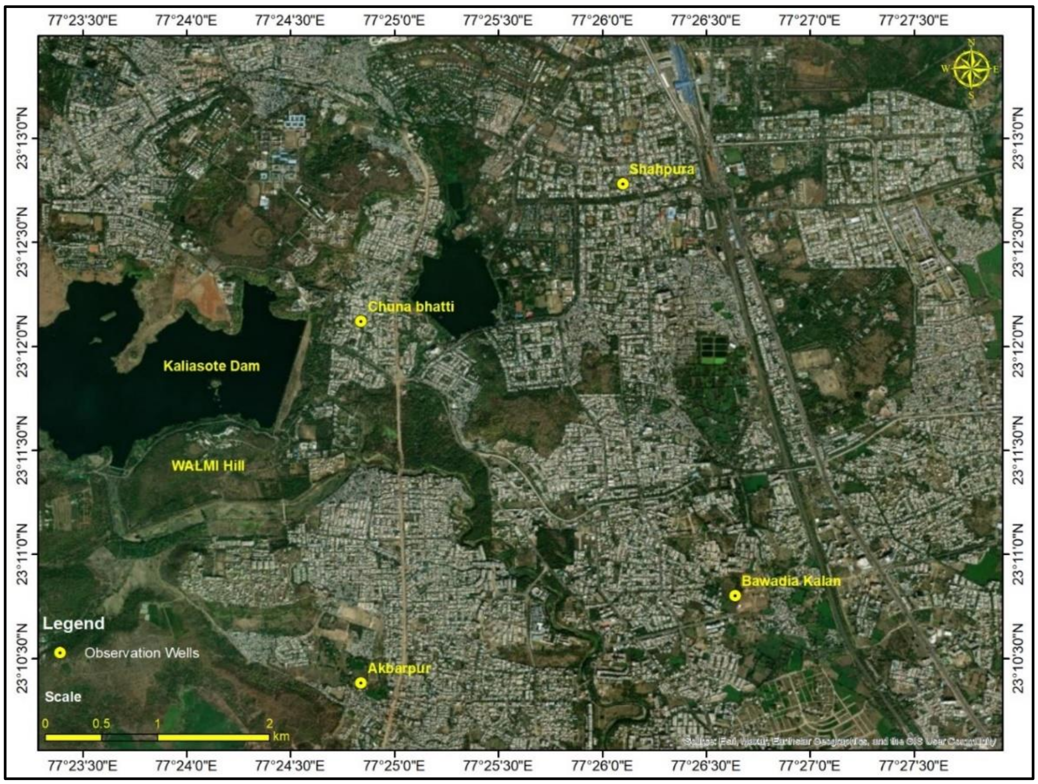

Figure 4.4: Location map of OB wells in Bhopal city near WALMI

The long-term groundwater level data has been analyzed for the four selected OB wells near WALMI campus in Bhopal as shown in Table 4.4.

Table 4.4: Average GW levels and fluctuation

Location Name	Well No.	Average GWL Pre Monsoon (BGL)	Average GWL Post Monsoon (BGL)	Average Fluctuation (m)	Fluctuation Range (m)	
					Minimum	Maximum
Bawadia Kalan	BPL022-OW	7.61	4.26	3.35	0.45	7.30
Akbarpur	BPL045A-OW2016	7.91	3.65	4.26	3.90	5.05
Chuna Bhatti	BPL076A-OW	8.75	5.44	3.31	1.55	7.50
Shahpura	BPL077-OW	3.51	2.39	1.12	0.10	2.35

The average groundwater level during the pre-monsoon season in the case of Bawadia Kalan OB well was found to be 7.61 m below the ground level (BGL) which on average gets raised during post-monsoon up to 4.26 m BGL. It was also observed that the average fluctuation in groundwater level between pre-monsoon and post-monsoon seasons in this well is 3.35 m with a minimum fluctuation of 0.45 m and a maximum fluctuation of 7.30 m during the observation period of 1984 to 2023. The observations obtained from the analysis of the groundwater levels of the selected OB wells are tabulated in Table 5. Similarly in the case of the OB well located at Akbarpur in Bhopal, the average groundwater level was found to be 7.91 m BGL during pre-monsoon while during post-monsoon it was raised to 3.65 m BGL. The average fluctuation was found to be 4.26 m with 3.90 m and 5.05 m of minimum and maximum fluctuations respectively. The OB well located at Chuna Bhatti in Bhopal has an average groundwater level of 8.75 m BGL during pre-monsoon and 5.44 m BGL during post-monsoon seasons with an average fluctuation of 3.31 m. The minimum fluctuation was observed to be 1.55 m and the maximum fluctuation was observed to be 7.50 m. the OB well located at Shahpura in Bhopal was observed to have an average groundwater level of 3.51 m BGL during the pre-monsoon season while on average it gets raised to 2.39 m BGL. The average fluctuation is 1.12 m. The fluctuation ranges from 0.10 m to 2.35 m as minimum and maximum fluctuation respectively.

The groundwater levels of the selected OB wells have also been observed to find out the trends in the groundwater table. The graph showing trends in the pre and post-monsoon season for the OB well located at Bawadia Kalan in Bhopal is shown in Figure 4.5. It can be seen that there is no trend in the post-monsoon groundwater level but there is a decreasing trend during the pre-monsoon season.

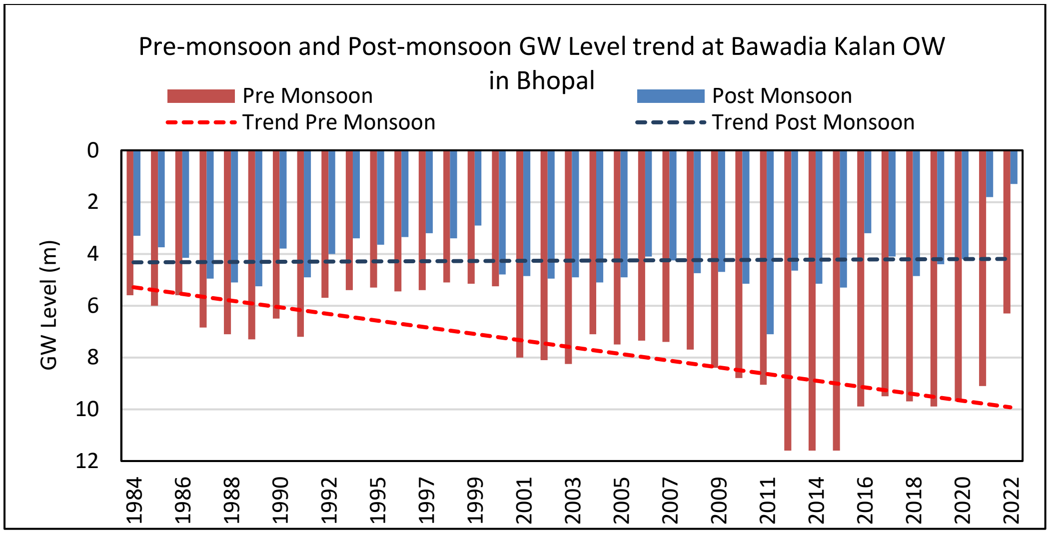

Figure 4.5: Pre-monsoon and Post-monsoon GW Level trend at Bawadia Kalan in Bhopal

The graph showing trends in the pre and post-monsoon season for the OB well located at Akbarpur in Bhopal is shown in Figure 4.6. From the graph, it can be seen that there is an increasing trend in groundwater levels in the case of both pre-monsoon and post-monsoon seasons.

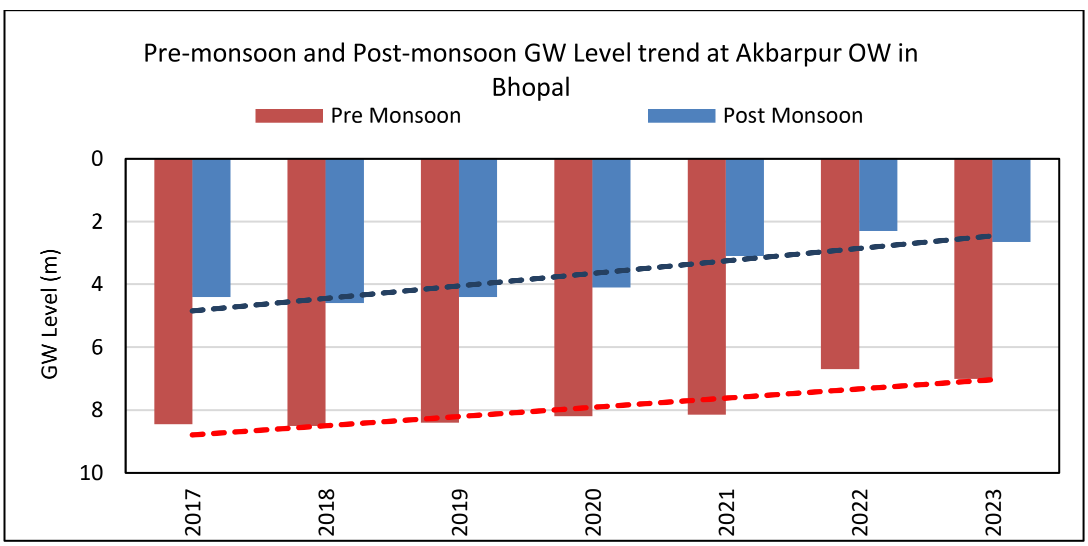

Figure 4.6: Pre-monsoon and Post-monsoon GW Level trend at Akbarpur in Bhopal

As in the case of Bawadia Kalan, the trend in the groundwater levels in the OB well located at Chuna Bhatti is also found to be decreasing during the pre-monsoon season but there is no significant trend during the post-monsoon season. The graph showing trends in the pre and post-monsoon season for the OB well located at Chuna Bhatti in Bhopal is shown in Figure 4.7.

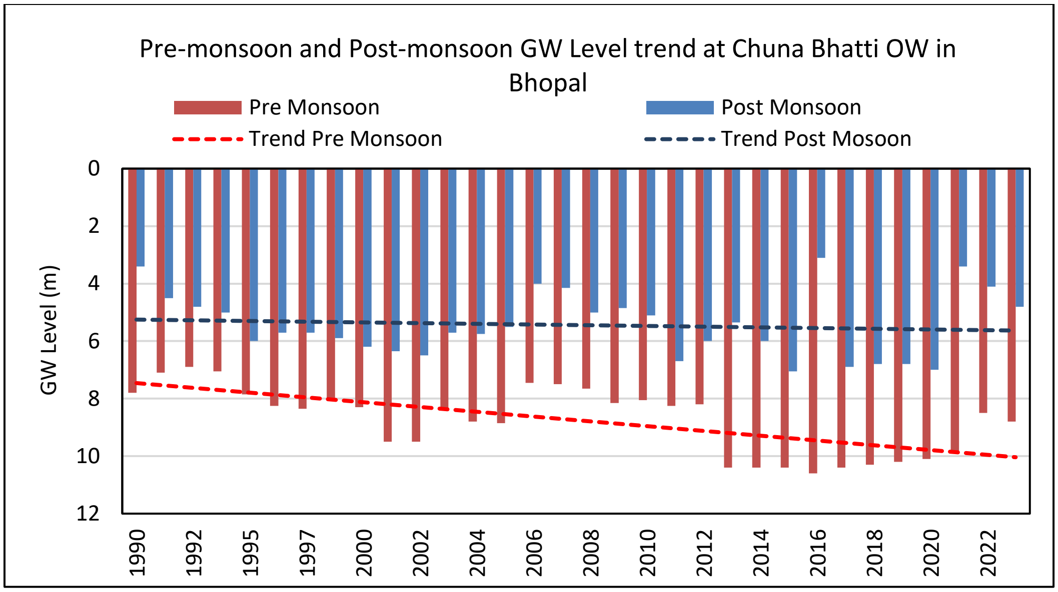

Figure 4.7: Pre-monsoon and Post-monsoon GW Level trend at Chuna Bhatti in Bhopal

The groundwater level trend in the OB well located at Shahpura in Bhopal is found to be increasing during the pre-monsoon season while a slightly increasing trend is also found during the post-monsoon season. The graph showing the trends during pre and post-monsoon season in the OB well located at Shahpura in Bhopal is shown in Figure 4.8.

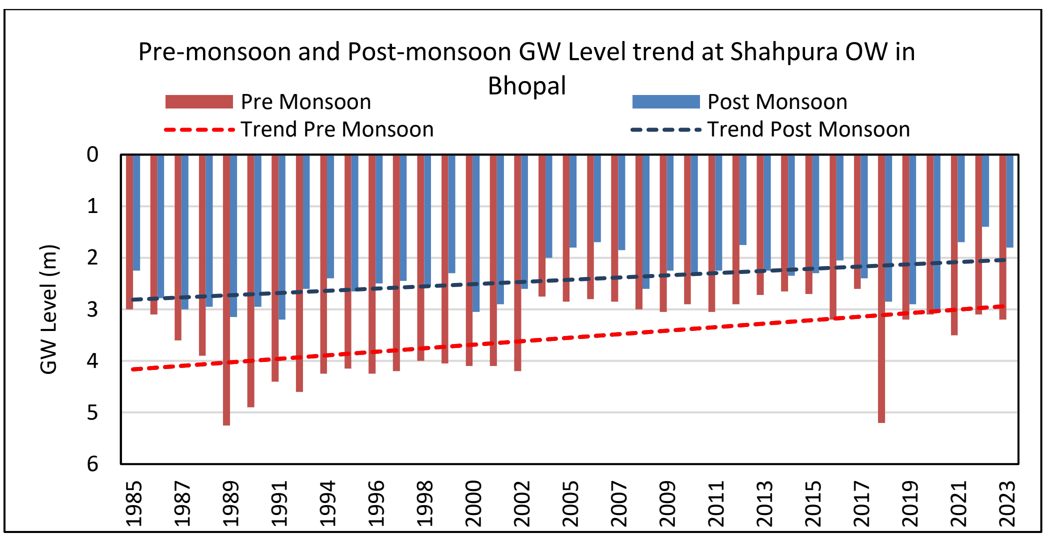

Figure 4.8: Pre-monsoon and Post-monsoon GW Level trend at Shahpura in Bhopal

The overall assessment of the groundwater level data analysis indicated a mixed trend of increasing or decreasing trend during pre-monsoon groundwater levels in nearby wells. Whereas an increasing trend was seen for the post-monsoon period in most of the wells located nearby. The trend analysis of groundwater level data of four observation wells falling in the study area and shown in Table 4.5.

Table 4.5: Trend analysis of groundwater level data of four observation wells in Bhopal

Observation Well Site	**Pre-monsoon GWL**			**Post-monsoon GWL**		
	Avg. GWL	MK-Z value	Trend	Avg. GWL	MK-Z value	Trend
Bawadia Kalan	7.60	4.52	Rising at 99% significance	4.30	0.44	Rising No significance
Akbarpura*	8.03		- -	3.65		
Chunabhatti	8.74	3.46	Rising at 99% significance	5.39	1.50	Rising No significance
Shahpura	3.55	-3.46	Declining at 99% significance	2.41	-2.12	Declining at 95% significance

*(*Long-term data not available for analysis)*

The trend analysis of groundwater level (GWL) data in Bhopal, conducted using the Mann-Kendall test, indicated a significant rising trend at the 99% confidence level at Bawadia Kalan for pre-monsoon season groundwater levels whereas the non-significant rising trend for the post-monsoon season. Thus, the analysis indicates significant rising trends in pre-monsoon groundwater levels at Bawadia Kalan and Chunabhatti, suggesting improved recharge or reduced extraction in these areas. In contrast, Shahpura shows a significant declining trend in both pre-monsoon and post-monsoon periods, pointing to potential groundwater depletion. These findings highlight the need for targeted water resource management strategies to address the varying groundwater trends within the Bhopal area.

4.4 Construction and Settlement of Auger hole

To scientifically validate the concept and refine the design specifications for Auger holes including size, depth, and the use of locally sourced filtration materials, construction was undertaken on the WALMI campus. A total of ten Auger holes were constructed in March 2021. Infiltration tests were conducted at four of these sites before the construction of Auger holes. Over a year, the Auger holes are settled and integrated naturally with the surrounding environment. After this period, once the Auger holes were fully established and functioning as groundwater recharge structures, infiltration tests were repeated at the same locations. These tests provided valuable data on the long-term performance and effectiveness of the Auger holes in facilitating groundwater recharge. Photographs Showing recharge through Auger hole during monsoon in the year 2022 are shown in Figure 4.9.

Figure 4.9: Recharge through Auger hole during monsoon (2022)

4.5 Assessment of improvement in infiltration rate due to Auger hole

For assessment of improvement in infiltration rate due to Auger hole, infiltration tests were conducted at four sites selected within the WALMI campus, Bhopal. These sites are designated as Site 1, Site 2, Site 3, and Site 4, and are located near the WALMI Hostel building, Car Parking area, and the Administration Building, respectively. Photographs showing infiltration tests at these four sites are shown in Figure 4.10. Infiltration tests were conducted before the construction of Auger holes and after the stabilization of these Auger holes after a year at the same sites. The infiltration curves representing the infiltration rate and cumulative infiltration with respect to time elapsed before the construction of the Augur hole and after stabilization at all four sites are shown in Figure 4.11.

Figure 4.10: Photographs showing infiltration tests at four sites in WALMI campus

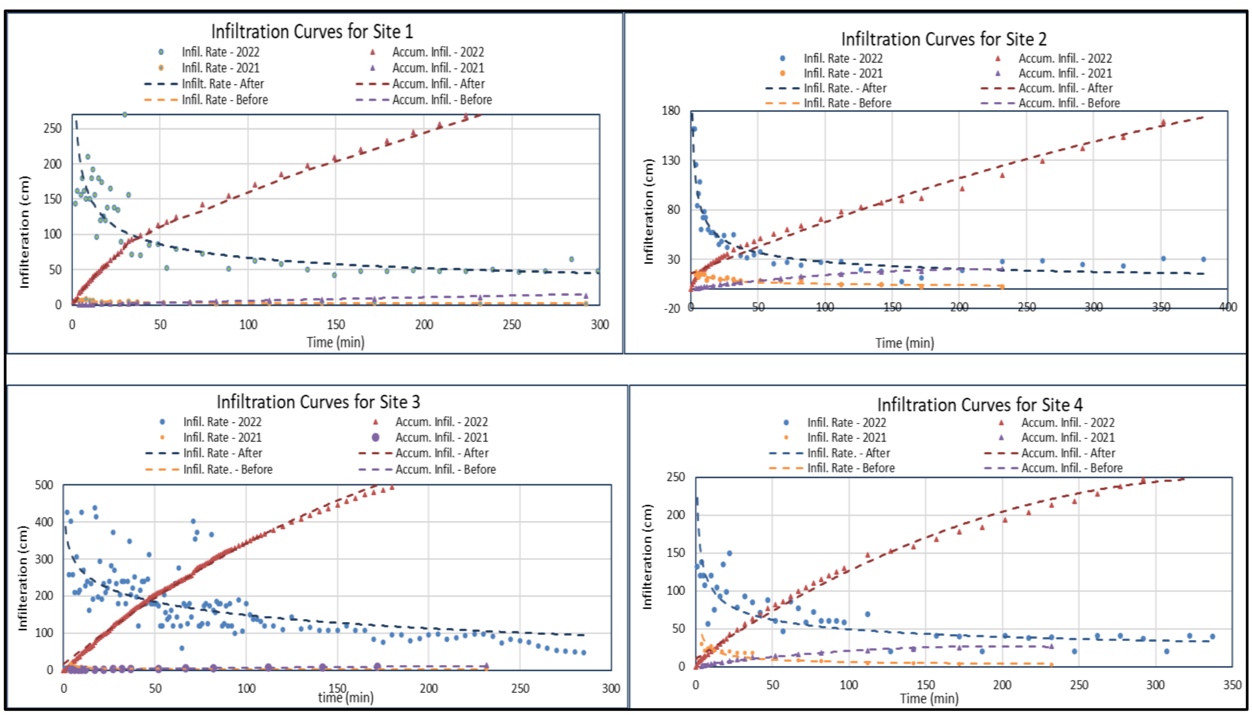

Figure 4.11: Improvement in infiltration rate and accumulated infiltration before and after construction of Auger hole at all four Sites

4.6 Improvement in Constant Rate of Infiltration:

After tabulating the infiltration rate and cumulative infiltration of all four sites, the constant infiltration rate for each of the four sites was assessed for both the cases before the construction of augur hole and after the stabilization of augur hole. The constant rate of infiltration (in cm/h) assessed is given below in Table 4.6.

Table 4.6: Improvement in Infiltration rate (cm/h) at all test sites.

Sites	Constant rate of Infiltration (cm/h)	
	Before Construction of Auger Hole	After Stabilization of Auger Hole
Site 1	2.1	47.6
Site 2	2.4	30.0
Site 3	2.4	48.1
Site 4	2.7	39.5

It can be observed that all four sites experienced a high improvement in the constant rate of infiltration after the stabilization of the augur hole. The site 1, which is located near the hostel had a constant rate of infiltration of 2.1 cm/h before the construction of the augur hole which had increased to 47.6 cm/h after the stabilization of the augur hole. In a similar manner, site 2 which is located near the car parking area, had an earlier constant infiltration rate of 2.4 cm/h which had been enhanced later to 30.0 cm/h. The site 3, located near the admin building, experienced the highest improvement among these four sites as it had an earlier constant rate of infiltration of 2.4 cm/h which had been enhanced after the stabilization of the augur hole to 48.1 cm/h. The site 4 is also located near the admin building, which had a constant rate of infiltration of 2.7 cm/h which had been increased to 39.5 cm/h after stabilization of the augur hole. From these results, it can be seen that the constant rate of infiltration had enhanced by a large amount at all four test sites. Thus, the infiltration rate was found to increase significantly due to the Auger hole after its stabilization which indicates the accelerated groundwater recharge as compared to the recharge from normal ground surface.

4.7 Improvement in Cumulative Infiltration

The cumulative infiltration is indicative of the total volume of water that can be recharged into the ground over the specified time. The Cumulative Infiltration (cm) before the construction of Auger holes and after the stabilization of these Auger holes after a year are given in Table 4.

Table 4.7: Cumulative Infiltration (cm) before and after construction of Auger hole

Time (hr)	**Cumulative Infiltration (cm) before and after construction of Auger hole**							
	Site 1		Site 2		Site 3		Site 4	
	Before	After	Before	After	Before	After	Before	After
0.5	2.4	85	6.2	40	2.7	130	10.5	57
1.0	3.5	124	11.0	55	4.4	230	17.8	93
2.0	6.4	185	16.4	82	6.5	356	27.7	153
3.0	9.1	232	23.1	92	9.1	402	40.7	184
4.0	11.1	282	28.2	115	11.1	430	51.5	218
5.0	13.0	333	32.2	142	13.2	458	-	-

Table 4.7 demonstrates a substantial increase in cumulative infiltration at all four sites due to the Auger hole. On comparison of cumulative infiltration after 5 hours of testing at all four sites, it was observed that the cumulative infiltration increased significantly from 13.0 to 333 cm at site 1 (by 25 times more), 32.2 to 142 cm at Site 2 (5 times more), 13.2 to 458 cm at Site 3 (40 times more) and 51.5 to 218 cm at Site 4 (4 times more). These results highlight the effectiveness of the auger hole technique in enhancing infiltration capacity and accelerating groundwater recharge.

4.8 Cost Estimate

The cost of the construction of the Auger hole, filter media material, and labor is worked out as below.

- Cost of hiring of tractor-mounted Auger machine per day: Rs 3000 to 3500
- Number of Auger holes to be dug per day: 20 to 25
- Labor cost per day: Rs 1000 to 1500

Thus, the approximate cost of construction of each Auger hole will be Rs 500 to 600

4.9 Adaptability

Based on the experimental setup of the Auger hole, including its design, construction, infiltration test results, cost-effectiveness, and overall experience, it is evident that Auger holes are one of the best, cost effective, and most accessible technologies for large-scale implementation. Constructed using locally available materials, they are highly effective in significantly enhancing groundwater recharge. This method can be easily adopted in both urban and rural areas for rainwater harvesting purposes. The auger hole method is a practical and affordable technique for enhancing rainwater harvesting and groundwater recharge. This method involves digging small, vertical holes using an auger, typically reaching permeable soil layers or aquifers. These holes allow rainwater or irrigation runoff to percolate directly into the ground, replenishing groundwater resources.

The auger hole method is a simple, cost-effective technique for rainwater harvesting and groundwater recharge, particularly suited for urban sprawls with limited space, where concrete surfaces hinder natural water percolation. In agricultural and rural settings, auger holes can be placed near fields to recharge wells and maintain soil moisture, reducing dependency on external water sources. Adding gravel or sand to the holes prevents clogging and ensures long-term efficiency. This method not only mitigates water scarcity but also improves water availability for crops, making it a sustainable solution for rural water management and agricultural productivity.

5.0 CONCLUSIONS

The overexploitation of groundwater in India to meet increasing domestic and agricultural demands has resulted in a significant decline in groundwater levels. Natural recharge through rainfall alone is insufficient to offset this depletion, necessitating artificial recharge as a key conservation strategy. Artificial recharge, through methods such as the Auger Hole Technique, enhances groundwater replenishment at rates much higher than natural percolation.

This study, conducted at the Water and Land Management Institute (WALMI), Bhopal, evaluates the effectiveness of the Auger Hole Technique for artificial groundwater recharge. The geomorphological characteristics of the study area, including its clayey soil type and structural plateau, alongside highly variable rainfall patterns, and declining groundwater level underscore the critical need for systematic water resource management. Annual rainfall in Bhopal exhibits high variability, with frequent droughts occurring every four years on average, highlighting the urgency of effective recharge mechanisms.

Experimental results from infiltration tests at four sites revealed a significant improvement in infiltration rates after the stabilization of auger holes. The infiltration was found to be increased by 25 to 40 times from the same land surface area compared to pre-auger hole construction. Thus, it is recommended that these structures are very useful wherever there is stagnation of water on the surface. These findings demonstrate the potential of the Auger Hole Technique to significantly enhance groundwater recharge, particularly in areas with similar climatic and geological conditions. Thus, techniques like the Auger Hole improve infiltration rates, further optimizing groundwater recharge. The optimized design parameters ensure simplicity, and efficiency, making an Auger hole method a promising to address groundwater scarcity.

The Auger hole method, evaluated for its design, construction, infiltration, and cost-effectiveness, is a simple, efficient, and scalable solution for groundwater recharge through rainwater harvesting. Its use of locally available materials enhances its adaptability and promotes broader acceptance. This method proved to be a simple, cost-effective technique for rainwater harvesting and groundwater recharge, particularly suited for urban sprawls, rural areas and agricultural fields. It involves drilling small, vertical holes in the ground using an auger, typically to a depth that reaches permeable soil layers or the water table. These holes act as infiltration points, directing rainwater or surface runoff into the ground. Auger holes can be strategically placed in parks, gardens, and residential areas to combat waterlogging, reduce urban flooding, and replenish aquifers. Enhanced with gravel or perforated pipes, they improve efficiency and longevity. As these structures do not directly connect to any groundwater body, therefore chances of groundwater quality deterioration are minimal. This eco-friendly approach helps mitigate water scarcity while promoting sustainable urban water management. Anticipated impacts of implementation of Auger holes on a large scale in urban or rural areas are an increase in groundwater levels, involvement of masses in recharge activities, increased base flow, increased groundwater recharge possible through impervious urban landscapes, and reduction in intensity of flash floods. Thus, the auger hole method enhances groundwater recharge by harvesting rainwater, offering an effective solution to combat water scarcity and mitigate urban flooding.

6.0 RECOMMENDATIONS FOR IMPLEMENTATION

- **Adoption and Implementation:** The Auger hole technique can be effectively adopted and implemented in the urban sprawls, rural areas, and agricultural fields and integrated into government initiatives such as Nagar Nigam, Nagar Palika, Zilla Panchayat programs, IWMP, Jal Jeevan Mission, and watershed management programs.
- **Site Assessment:** Conduct soil testing to identify areas with high permeability and suitable depth for effective infiltration.
- **Strategic Placement:** Focus on locations like parks, greenbelts, gardens, and underutilized open spaces to maximize recharge potential.
- **Gravel Layer:** Line auger holes with coarse gravel or sand to prevent clogging and improve water infiltration efficiency.
- **Runoff Diversion:** Install structures to channel roof and surface runoff into the auger holes.
- **Maintenance:** Periodically clean and inspect the holes to remove debris, silt, or blockages.
- **Community Engagement:** Educate local communities about the importance of rainwater harvesting and involve them in implementation and upkeep.
- **Integration with Urban Planning:** Incorporate auger holes into urban landscaping and infrastructure development projects.
- **Monitoring and Evaluation:** Use groundwater level sensors to track the impact and ensure long-term sustainability.
- **Generating Livelihood:** Engage local artisans for the construction of Auger hole and use locally available material for filter media.

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