Heritage Institute of Technology, Kolkata, West Bengal

Summer Training Report on

Ground Water Recharge through Rainwater Harvesting

Submitted by

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CERTIFICATE

This is to certify that **Rohit Kumar Prince** of Heritage Institute of Technology has carried out this training report on "Groundwater Recharge through Rainwater Harvesting". This training was carried out at Groundwater Hydrology Division of National Institute of Hydrology (NIH), Roorkee.

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Rohit kr. Prince

Rohit Kumar Prince

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Abbreviations Used

mbgl	meter below ground level
GW	Ground water
MAR	Managed Aquifer Recharge
CAD	Computer Aided Design
USGS	United States Geological Survey
GIS	Geographical Information System
DEM	Digital Elevation Model
SRTM	Shuttle Radar Topography Mission
NIH	National Institute of Hydrology
HITK	Heritage Institute of Technology, Kolkata
KMC	Kolkata Municipal Cooperation
IMD	Indian Meteorology Department
CWGB	Central ground water board
MWS	Ministry of Water Resources
GoI	Government of India

ABSTRACT

India is blessed with good rainfall but however large of it lost through runoff and it can be impounded on the surface at suitable sites for surface storage. In recent decades groundwater is also threatened by over exploitation, contamination etc. The exploitation of groundwater resources more than its annual replenishment has caused continuous decline of water level, declined well yields, dry of shallow wells and deterioration of groundwater quality. Kolkata has no exception to it. According to KMC reports, declining trend of ground water level at the rate of 0.33m/year has been observed. In order to overcome the situation and increase the groundwater levels, the present study has been carried out to identify Rainwater Harvesting potential in campus area of Heritage Institute of Technology, Kolkata. The analysis of 15 years daily rainfall data (2001-2015) shows that the annual rainfall in Kolkata varies from 1049mm-2265mm with an average rainfall of 1581.85mm. 80% of the rainfall occurs during the monsoon season, and it gets wasted due to poor management. Therefore, there is a need to adopt rainwater harvesting structures. The maximum quantity of rainwater that can be recharged through the soil in the study area comes out to be 258.69 cum.

1. Introduction

Groundwater is found in the saturated zones below the surface of the earth. Groundwater is an integral part of the hydrologic system and a vital natural resource. The movement of water in the pore spaces of rocks beneath Earth's surface is a geologic process. Groundwater is not rare or unusual. It is distributed everywhere beneath the surface of Earth. It occurs not only in humid areas, but also beneath desert regions, under the frozen polar regions, and in high mountain ranges.

In many ways, groundwater systems are like river systems. There is a collecting system, transporting system, and a dispersal or discharge system. For groundwater, the collection area is the zone of recharge where surface water enters the subsurface. The path followed by the slowly moving groundwater is controlled by permeability and porosity of the rocks in an aquifer. Along the flow path, groundwater, like river water, picks up materials and transports them. In groundwater systems, most of the transported materials are carried away as ions dissolved in water. Finally, like a river, a groundwater system has a discharge zone where the water comes back to the surface or enters a lake, river, or ocean.

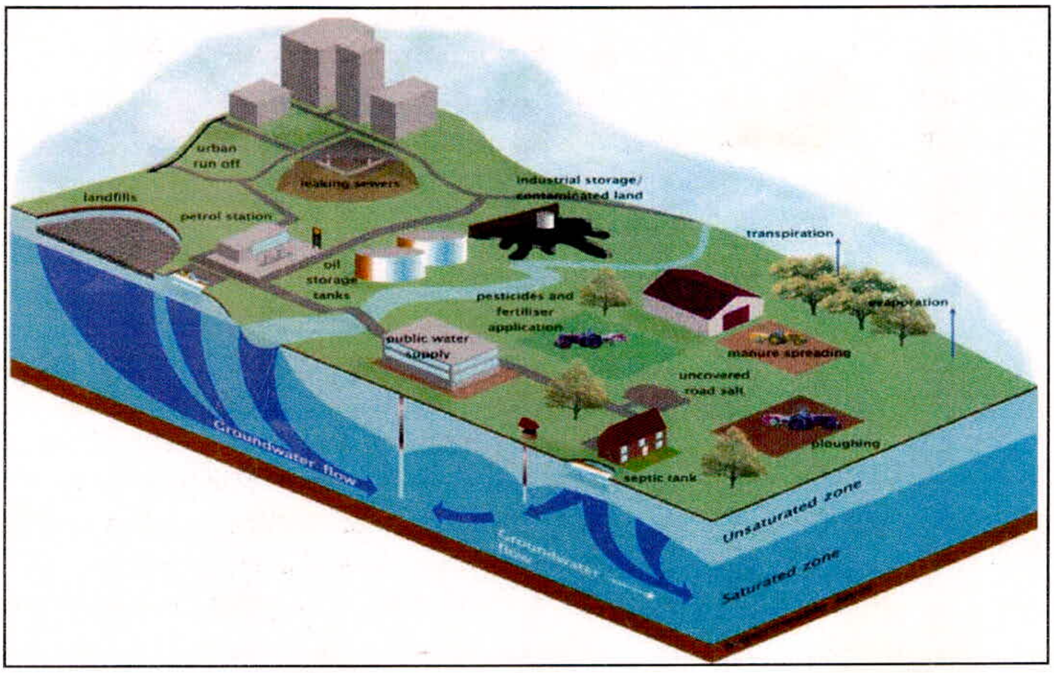


Figure 1.1: A Schematic Diagram of a Groundwater System (Source: The Investigation and Assessment on Groundwater Organic Pollution, Hongqi Wang, Shuyuan Liu and Shasha Du.)

1.1 Importance of Ground Water

Groundwater has emerged as the primary democratic water source and poverty reduction tool in India's rural areas. On account of its near universal availability, dependability and low capital cost, it is the most preferred source of water to meet the requirements of various user sectors in India. Ground water has made significant contributions to the growth of India's Economy and has been an important catalyst for its socio economic development. Its importance as a precious natural resource in the Indian context can be gauged from the fact that more than 85 percent of India's rural domestic water requirements, 50 percent of its urban water requirements and more than 50 percent of its irrigation requirements are being met from ground water resources. This resource has become an important source of drinking water and food security for teeming millions of the state. The significant contribution made for Green Revolution and also as primary reliable source of irrigation during drought years has further strengthened the people's faith in utilization of ground water as dependable source.(2008, Jha & Sinha)

1.2 Ground Water Issues

Unplanned growth of cities is one of the major issues related to ground water. It has created high water demands which further created pressure on groundwater resources due to excessive pumping. Also in village areas, excessive pumping of groundwater can be observed for irrigation purposes. The quality of groundwater is also getting polluted due to use of various chemicals, poor waste management techniques and lack of waste water treatment plants in the industries. There is a lack of groundwater recharge techniques in most parts of the country, rainwater which is one of the major source of water get wasted.

Experts believe that India is fast moving towards a crisis of ground water overuse and contamination (2016, Suhag). Ground water overuse or overexploitation is defined as a situation in which, over a period of time, average extraction rate from aquifers is greater than the average recharge rate. In India, the availability of surface water is greater than ground water. However, owing to the decentralized availability of groundwater, it is easily accessible and forms the largest share of India's agriculture and drinking water supply.

These issues can be understood by two sides:
1. Supply Side Issues:

- Transformation of open lands into paved areas, sedimentation and siltation of water bodies, closure of water bodies, etc.
- Impact of climate change on hydrological variables - modification in rainfall pattern, intensity & duration, reduction in natural GW recharge, etc.
- Leaching of contaminants from surface sources
- Excessive withdrawal leading to groundwater level depletion in many areas - 2009 report: Out of 5842 assessment units, 802 units over-exploited, 189 unit 'critical', 523 unit 'semi-critical, 70 blocks underlain by saline groundwater.
- Quality deterioration due to geogenic source of contamination - Arsenic , Fluoride, Fe2+, and Inland salinity contaminated aquifers

- Seawater ingress threat in many coastal aquifers.

2. Demand Side Issues:

- Dependability on GW in rural sector is more, - easily accessible, less risk free, self ownership and no obligation of withdrawal
- Demand increasing in all sectoral uses.
- Conflicts of interest increasing, - Equity in access in different sectoral usages, conflicts in sharing of GW in local level, etc. (2014, Ghosh)

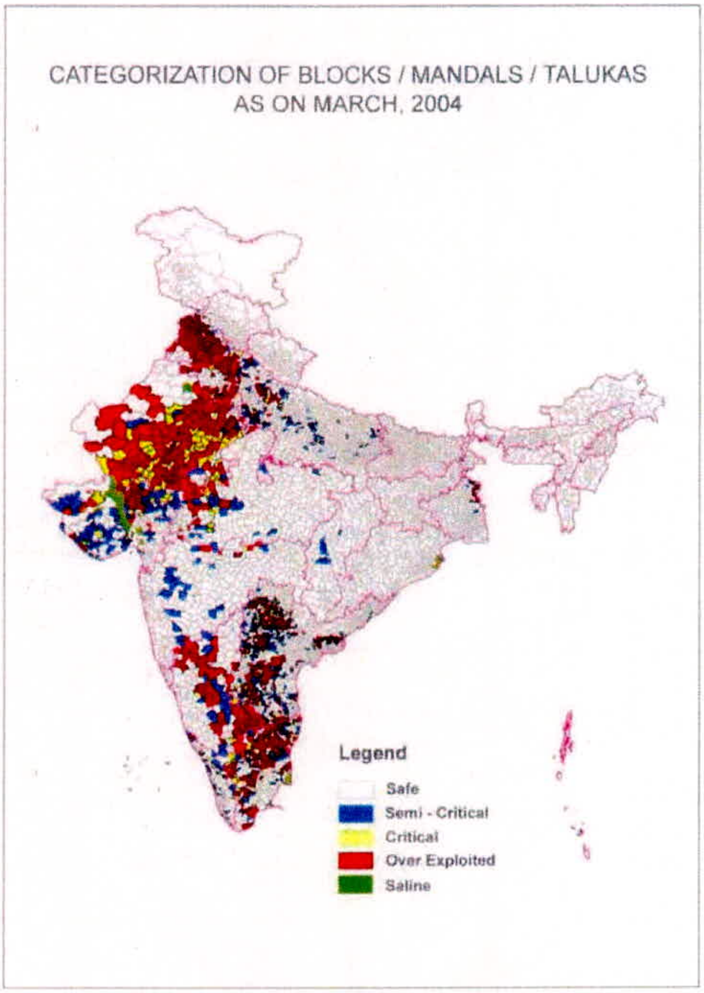
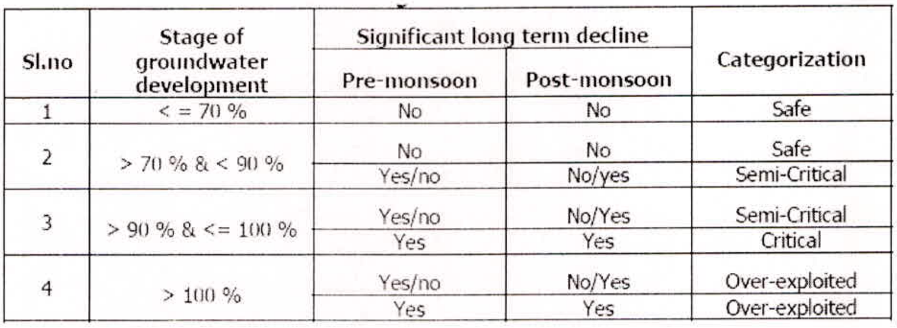


Fig: 1.2. Categorization of Assessment Units Based on the Stage of Ground Water Development in India (As on March 2004) (Source: CGWB)



Sl.no	Stage of groundwater development	Significant long term decline		Categorization
		Pre-monsoon	Post-monsoon	
1	< = 70 %	No	No	Safe
2	> 70 % & < 90 %	No	No	Safe
		Yes/no	No/yes	Semi-Critical
3	> 90 % & <= 100 %	Yes/no	No/Yes	Semi-Critical
		Yes	Yes	Critical
4	> 100 %	Yes/no	No/Yes	Over-exploited
		Yes	Yes	Over-exploited

Table.1.1 Criteria for categorization of assessment units.

1.3 Solution to Ground Water Problems

There is a need to preserve groundwater both in terms of quantity and quality. Natural replenishment of ground water reservoir is slow and is unable to keep pace with the excessive continued exploitation of ground water resources in various parts of the country. This has resulted in declining ground water levels and depleted ground water resources in large areas of the country. In order to augment the natural supply of ground water, artificial recharge to ground water has become important. The techniques of artificial aquifer recharge means to relate the source water to ground water reservoir and are dependent on the hydro geological situation of the area. Rainwater can be used as source water for recharge purposes. The rainfall occurrence in the country is monsoon dependent and in large part of the country rain fall is limited to about three-four months period. The natural recharge to ground water reservoir is restricted to this period only. The artificial recharge techniques aim at increasing the recharge period in the post-monsoon season and hence give additional recharge.

Groundwater problems should also be addressed at the community level. Some of the possibilities are to use the principle of reduce and reuse on a larger scale, proper management of solid waste and wastewater to prevent the soil from any contamination, judicial use of water etc.

1.4 Importance of the Study

This study has been done to know the importance of groundwater and various methods of groundwater recharge. This has become important in the present time because the pressure on groundwater resources in India is maximum in the world. The rapid growth of cities is creating high water demands and therefore pressure on groundwater is increasing as well. Kolkata, which is one of the biggest cities in the country, is facing groundwater issues both in terms of quantity and quality. Therefore, in this dissertation work, the campus of Heritage Institute of Technology, Kolkata has been taken as study area by using rooftop harvesting as a source of groundwater recharge to understand the various procedures of recharge through rooftop rainwater harvesting. If some part of monsoon water can be trapped and put in aquifer, groundwater augmentation can be done and using suitable measures, it can be prevented from contamination also.

2 Hydrological Cycle

2.1 Surface & Groundwater intersection

The Hydrologic cycle is a continuous process by which water is transported from the oceans (earth's surface) to the atmosphere to the land and back to the sea. Sun is the driving force of the hydrological cycle. Water is taken up by the atmosphere from the earth's surface in vapour form through evaporation. It may then be moved from place to place by the wind until it is condensed back to its liquid phase to form clouds. Water then returns to the surface of the earth in the form of either liquid (rain) or solid (snow, sleet, etc.) precipitation. Water transport can also take place on or beneath the Earth's surface by the flow. The hydrologic cycle is used to model the storage and movement of water between the biosphere, atmosphere, lithosphere and hydrosphere. Many processes work together to keep Earth's water moving in a cycle. There are five processes at work in the hydrologic cycle: condensation, precipitation, infiltration, runoff, and evapotranspiration. These occur simultaneously and, except for precipitation, continuously. The water quality also changes during passage through the cycle; for example, sea water is converted to fresh water through evaporation.

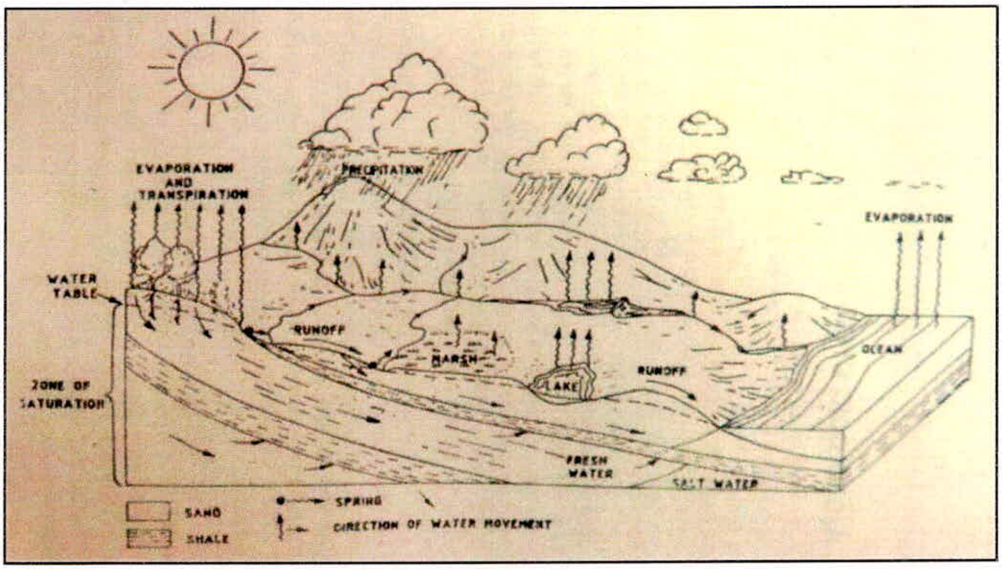


Fig. 2.1 A Schematic Diagram of Hydrologic Cycle (Source: Water Nature's Wonder Hydrologic Cycle, NIH, Roorkee)

2.1.1 Components of the Hydrologic Cycle

2.1.1.1 Evaporation

The conversion of water in the liquid form to vapour and transportation in this form to atmosphere is known as evaporation. In the hydrologic cycle evaporation takes place from water surface, land surface as well as from intercepted water. Although lower air pressure helps promote evaporation, temperature is the primary factor

2.1.1.2 Transpiration

It is the process by which water in the soil is transferred to the atmosphere by plants as water vapour.

2.1.1.3 Precipitation

It refers to all forms of water derived from atmospheric vapour and deposited on the Earth's surface. Precipitation occurs due to condensation of atmospheric water vapour. Depending on the temperature and location, precipitation may occur in a variety of forms like rain, snow, mist, hail, sleet.

2.1.1.4 Interception

The rain that falls on the vegetative cover is partly retained by vegetation and the balance goes to the ground. The portion of the rainfall that is retained by vegetation is referred to as interception.

2.1.1.5 Infiltration

A part of the precipitation reaching the land surface enters the soil. The process by which water enters surface strata of the soil and moves downward is known as infiltration.

2.1.1.6 Runoff

The portion of precipitation that makes its way towards streams, lakes and oceans as surface or subsurface flow is known as runoff.

2.1.2 Groundwater occurrence

Groundwater in nature occurs in two different zones: unsaturated zone and saturated zone.

2.1.2.1 Unsaturated zone

The unsaturated zone occurs immediately below the land surface in most areas and contains both water and air. In the unsaturated zone flow occurs beneath the land surface and above the groundwater table. The groundwater table forms the boundary between unsaturated subsurface flow (above it) and saturated subsurface flow (below it). In the unsaturated zone the preferred path of movement of moisture is vertical, by percolation, toward the saturated zone.

2.1.2..2 Saturated zone

Water in the saturated zone is the only water under the surface that is available to supply wells and springs and is the only water to which the name groundwater is correctly applied. Recharge of the saturated zone occurs by percolation of water from the land surface through the unsaturated zone. The water table is the level in the saturated zone at which the hydraulic pressure is equal to the atmospheric pressure and is represented by the water table. Below the water table, the hydraulic pressure increases with increasing depth. In the saturated zone the preferred path of movement of moisture is horizontal, toward aquifer discharge areas. A generalized vertical section, showing the different zones, is presented in Figure 4.2.

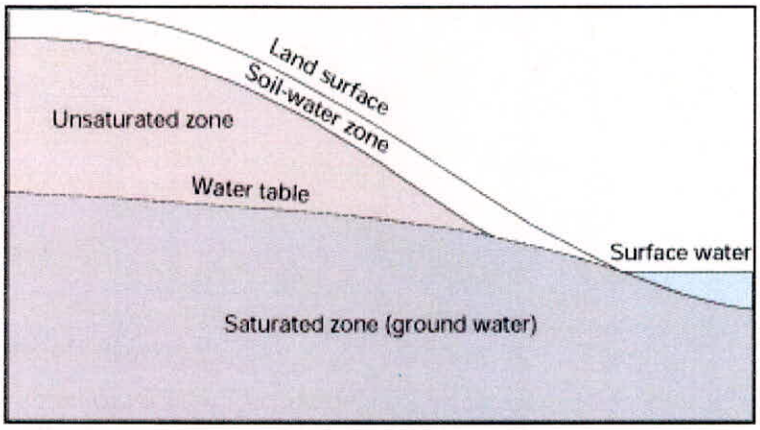


Fig. 2.2: Saturated and Unsaturated zone of a subsurface system, (Source: http://pubs.usgs.gov/circ/circ1139/htdocs/boxa.htm)

2.2 Groundwater Resources of India

India has vast ground water resources. The average annual rainfall over the country is about 110 cm as a whole and this rainfall over India's geographical area of 328 million hectares gives a total precipitation of 4000 billion cubic metres. Only about 22 percent of this total rainfall percolates under the ground. Of this total amount, about 430 billion cubic metre reaches upto the upper surface of the soil, remaining 384 billion cubic metre reaches the pervious strata which could be obtained by dugging the well. But only 70 percent of this amount can be exploited economically.

Table 2.1: Groundwater Resources of India

Sr.No.		
1.	Annual Replenishable Ground Water Resources	431 bcm
2.	Net Annual Ground Water Availability	396 bcm
3.	Annual Ground Water Draft for Irrigation, Domestic & Industrial uses	243 bcm
4.	Stage of Ground Water Development	61%

The dynamic ground water resources, also known as Annual Replenishable Ground Water Resources, of the States and Union Territories, have been assessed jointly by the CGWB and State Ground Water Departments. The Annual Replenishable Ground Water Resource for the entire country has been assessed as 431 billion cubic meter (bcm). The major source of ground water recharge is the monsoon rainfall. About 57% of the annual replenishable resources i.e. 246 bcm are contributed by monsoon rainfall recharge. The overall contribution of rainfall to country's Annual Replenishable Ground Water Resource is 68% and the share of other sources viz. canal seepage, return flow from irrigation, recharge from tanks, ponds, and water conservations structures taken together is 32%. The contribution from other sources such as canal seepage , return flow from irrigation, seepage from water bodies etc in Annual Replenishable Ground Water Resource is more than of 33% in the states of Andhra Pradesh, Delhi, Haryana, Gujarat, Goa, Jammu & Kashmir, Karnataka, Punjab, Tamil Nadu, Uttar Pradesh, and UT of Puducherry. Keeping 35 bcm for natural discharge, the Net Annual Ground Water Availability for the entire country is 396 bcm.

Table 2.2: Groundwater Aquifer System in India

System	**Coverage**	**Ground water potential**
Unconsolidated formations - Alluvial	Indo-Gangetic, Brahmaputra plains	Enormous reserves down to 600 m depth. High rain fall and hence recharge is ensured. Can support large-scale development through deep tube wells
	Coastal Areas	Reasonably extensive aquifers but risk of saline water intrusion
	Part of Desert area Rajasthan and Gujarat	Scanty rainfall. Negligible recharge. Salinity hazards. Availability at great depths.
Consolidated/semi-consolidated formations - sedimentaries, basalts and crystalline rocks	Peninsular Areas	Availability depends on secondary porosity developed due to weathering, fracturing etc. Scope for GW availability at shallow depths (20-40 m) in some areas and deeper depths (100-200 m) in other areas. Varying yields.
Hilly	Hilly states	Hilly states

2.3 India's Hydrological Formation & Map.

The groundwater behaviour in the Indian sub-continent is highly complicated due to the occurrence of diversified geological formations with considerable lithological and chronological variations, complex tectonic framework, climatological dissimilarities and various hydrochemical conditions. Based on characteristically different hydraulic parameters, rock formations, the hydrogeological formations of the country have been classified broadly into two groups: Porous formations and Fissured formations. These formations are further classified into sub-groups, which are shown in the flowchart Fig. 2.4

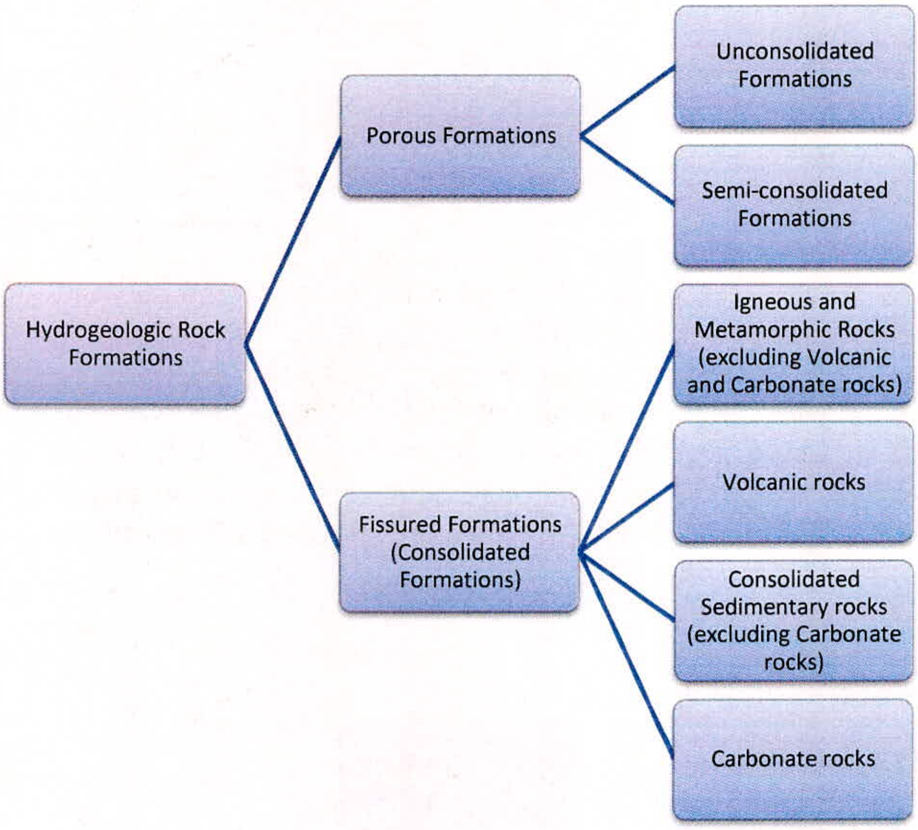


Fig. 2.3: Showing the classification of various Hydrogeological Rock Formations

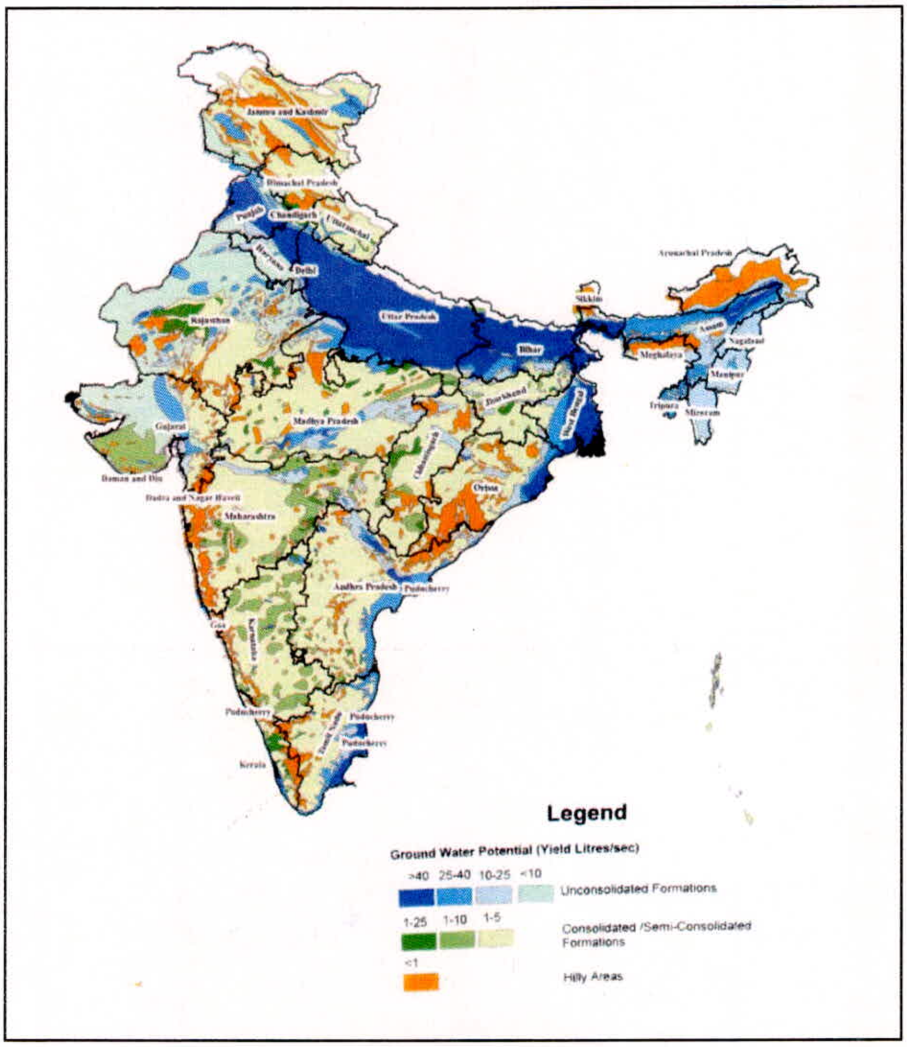


Fig.2.4: Hydrogeologic map of India (Source: NIH, Roorkee)

The hydrogeological map of India developed by the CGWB (Central Ground Water Board) superimposing the different states political boundaries as developed by NIH are given at Fig. 2.4.

2.4 Major Problems of India's Groundwater Resources

Ground water management is the foremost challenge being faced today in India. Central Ground Water Board, being the apex organization at the central level with vast experience in the ground water sector, has taken a proactive role in identifying various key issues, which need immediate attention. These issues are discussed below in brief

2.4.1 Ground Water Depletion

Indiscriminate ground water development has led to substantial ground water level declines both in hard rocks and alluvial areas threatening sustainability of this resource. Long-term decline of ground water levels is being observed in many areas, mostly in the states of Rajasthan, Gujarat, Tamil Nadu, Punjab, Delhi and Haryana. Apart from this, in most of the cities depending on ground water for drinking water supplies, water level declines up to 30 m and more have been observed. Traditional water harvesting methods have either been abandoned or have become defunct in most cases. There is an urgent need to revive these methods.

In some parts of the country like Rajasthan, Gujarat, Haryana and Delhi, static ground water resources are also limited and depletion in ground water level is resulting in ground water drought scenario. Excessive ground water development has resulted in deterioration of ground water quality in coastal areas due to saline water ingress. Dependence on use of ground water for agriculture due to monsoon failures is accelerating ground water depletion. Excessive withdrawal of ground water is further creating the stress on ground water system due to free/subsidized power in some States.

2.4.2 Ground Water Pollution

Ground water resources in several areas of the country are getting polluted due to over application of fertilizers and pesticides, indiscriminate disposal of effluents from industries and urban sewerage. Presence of naturally occurring Arsenic, Fluoride and Iron in ground water in excess of permissible limits recommended for human consumption prohibits its use for drinking purposes in several states of India. Research and Development studies need to be taken up for finding cost-effective solutions to this problem. Dilution of pollutant concentration through ground water recharge can be one of the effective ways to mitigate the hazards of high concentration of these constituents. It is also desirable that rural water supply schemes be formulated and arrangements made to utilize fluoride / arsenic rich water for purposes other than drinking.

2.4.3 Drinking Water Shortage in Urban Areas

There are several urban areas in the country where water supply systems are based mainly on ground water resource. Sustainability of urban water supply is one of the core issues the planners across the country are facing at present. The problem may get aggravated in near future with the rapid pace of urbanization being witnessed in India. Potable drinking water is an important input for providing municipal supply to the urban complexes. Due to steep increase in population, the stress on ground water system has increased tremendously resulting in steep water level declines in and around these cities.

2.4.4 Seawater Ingress in Coastal Aquifers

The unconsolidated deltaic and coastal sediments form thick and regionally extensive aquifers having prolific yield potential that can sustain deep, moderate to high capacity tube wells. The ground water in these aquifers exists in a fragile dynamic equilibrium with seawater. Indiscriminate exploitation of ground water from such aquifers can disturb this equilibrium and result in the development of landward hydraulic gradient, ultimately leading to seawater intrusion into the fresh water aquifers. Coastal aquifers in parts of Gujarat, Tamil Nadu and Andhra Pradesh are already suffering from the problem of salinity ingress. (2007, CGWB)

3. Objective

The prime objective of the study is to learn about

(i) The importance of groundwater

(ii) Problems related to groundwater in India

(iii) Methods of groundwater recharge

(iv) Rainwater Harvesting for groundwater recharge

4. Methodology:

1. Study the importance and methods for groundwater recharge.
2. Lithological study of the selected area.
3. Estimation of runoff and potential quantity of source water for groundwater recharge.
4. Suitable recharge structure.

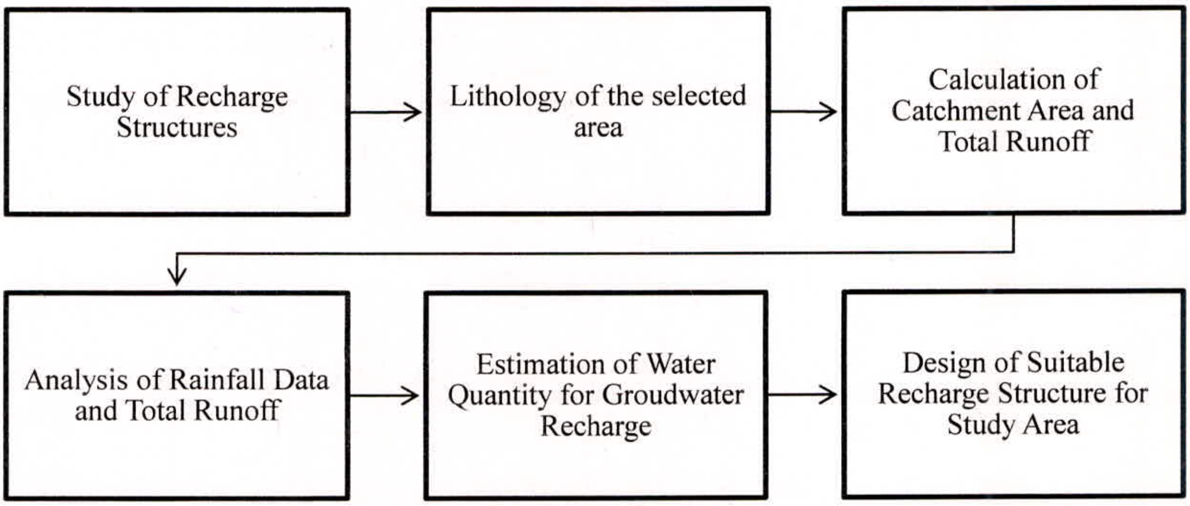


Fig.4.1: Flowchart of methodology

Tools/ Software Used

1. Google Earth

Google Earth is a tool which displays satellite images of the Earth's surface. It allows users to see cities and houses at various angles. Imagery resolution ranges from 15 meters of resolution to 15 centimeters. One can easily identify the locations, measure the distance between the locations, elevation, land uses, road network, drainage (Rivers, Canals, Nalla etc). It is also useful in marking user's location.

2. ArcGIS

ArcGIS is a geographic information system (GIS) for working with maps and geographic information. It is used for creating and using maps, compiling geographic data, analyzing mapped information, sharing and discovering geographic information, using maps and geographic information in a range of applications, and managing geographic information in a database. Data captured and used in GIS commonly are represented on paper or other hard copy maps. In GIS, data are georeferenced to the coordinates of a particular projection system. This allows precise placement of features on earth's surface and maintains the spatial relationships between mapped features.

3. AutoCAD

AutoCAD is a computer-aided design (CAD) and drafting software application. It is used for creating 2D and 3D designs. Apart from simple drawings, one can easily draw plan, different elevations and various views and projections of buildings, bridges, or any kind of structures using AutoCAD.

5. Basics of Grounwater

5.1 Basic Definitions

5.1.1 Aquifer: A permeable stratum or a geological formation of permeable material, which is capable of yielding appreciable quantities of groundwater under gravity, is known as aquifer. The term 'appreciable quantity' is relative, depending upon the availability of ground water.

5.1.2 Aquitard: A geological formation or a group of formation through which virtually no water moves. It is a semi confining stratum that permits some groundwater flow at a very low transmission rate. eg. a leaky confining bed.

5.1.3 Aquiclude: A body of earth material of low permeability, which can absorb water, but cannot transmit it at a rate sufficient for economic extraction by wells.

5.1.4 Aquifuge: An aquifuge is a geological formation with low permeability and porosity. This does not transmit any groundwater and does not contain groundwater in appreciable quantities.

5.2 Types of aquifers

5.2.1 Unconfined Aquifer

A groundwater aquifer is said to be unconfined when its upper surface (water table) is open to the atmosphere through permeable material. As opposed to a confined aquifer, the water table in an unconfined aquifer system has no overlying impervious rock layer to separate it from the atmosphere.

5.2.2 Confined Aquifer

A confined aquifer is a water-bearing stratum that is confined or overlain by a rock layer that does not transmit water in any appreciable amount or that is impermeable. Confined aquifers are bounded above and below by aquicludes or aquitards. Water is under pressure from overlying rock and hydraulic pressure from recharge.

In confined aquifers we get artesian wells and springs.

Artesian well: A situation in which groundwater under pressure rises above the level of the aquifer.

Spring: A place where groundwater naturally comes to the surface resulting from water table meeting the land surface.

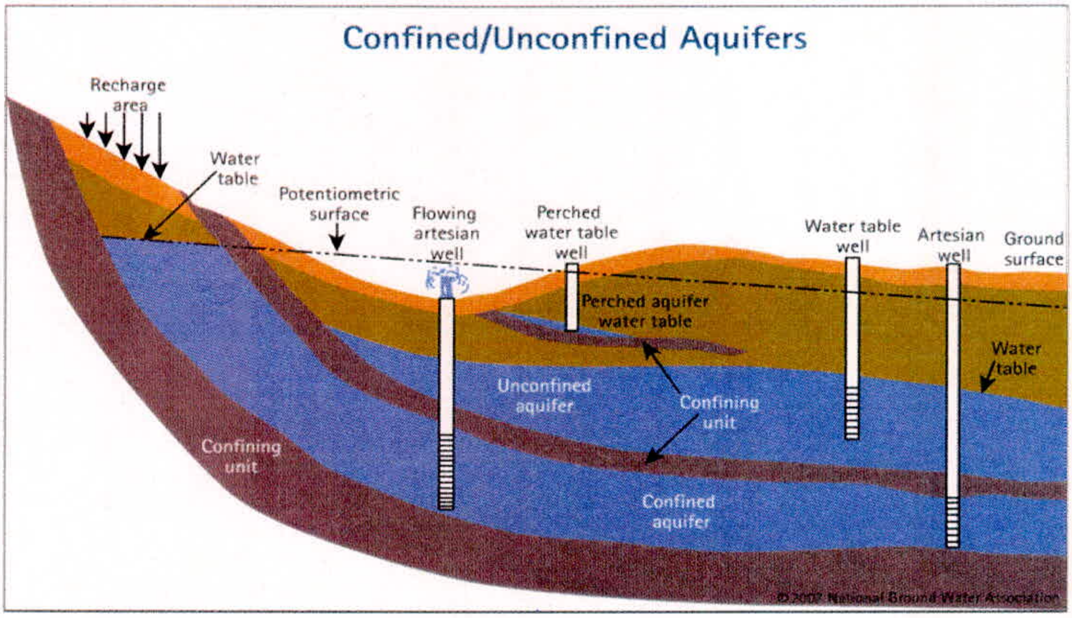


Fig. 5.1: Shows different types of aquifers in a groundwater surface. (Source: http://www.artinaid.com/2013/04/types-of-aquifers/)

5.3 Darcy's Law

5.3.1 Groundwater movement

When in fluid form, the motion of water is governed by various laws as mentioned below. Because "motion" involves measurements of time and distance so the main law may be stated outright as 'The velocity, or distance travelled over some time interval, is proportional to some driving force.Groundwater moves from areas of higher elevation or higher pressure/hydraulic head (recharge areas) to areas of lower elevation or pressure/hydraulic head.' This is where the groundwater is released into streams, lakes, wetlands, or springs (discharge areas).

In 1856 in Dijon, France, Henry Darcy conducted his now famous experiment of pouring water through sediment-packed pipes to see how much would flow through them in a given amount of time [volume of flow per unit time]. A schematic of Darcy's experiment is shown in Figure 5.1.

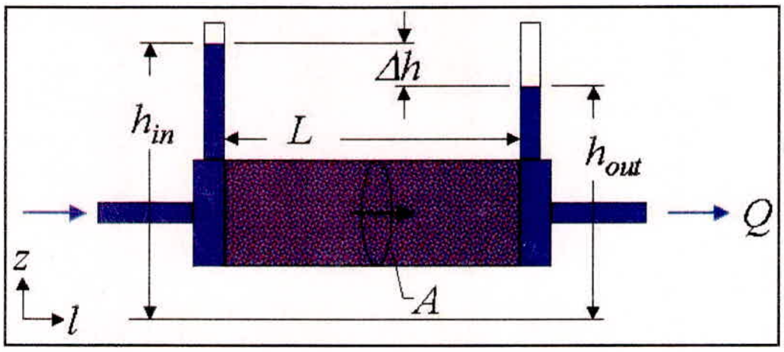


Fig 5.2: Experimental setup for verifying the Darcy's law (Source: http://biosystems.okstate.edu)

Darcy's law is the basic empirical relationship governing the movement of groundwater through a porous medium. The equation describing the Darcy's law is:

$$Q = -KA\frac{h_{in} - h_{out}}{dl}$$

Where, Q is the hydraulic discharge, $[L^3T^{-1}]$; A is the cross-sectional area, $[L^2]$; k is the hydraulic conductivity, $[LT^{-1}]$; h_{in} is the height of water in the upper piezometer, [L]; h_{out} is the height of water in the lower piezometer, [L]; dl is the distance between piezometers, [L].

The negative sign was introduced to obtain a positive value for the discharge; indeed, the groundwater flows in the direction of the head loss, which is negative.

$$h = z + \frac{p}{\gamma} + C$$

where, h=the piezometer head[L]; z= the elevation above a datum[L]; p= the hydrostatic pressure$[ML^{-2}]$; C= an arbitrary constant; γ = the specific weight of water$[ML^{-3}]$.

The direction of groundwater flow follows a curved path through an aquifer from areas of high water levels to areas where water levels are low; that is from below high ground, which are recharge areas, to groundwater discharge points in valleys or the sea. The direction of flow is indicated by the slope of the water table which is called the *hydraulic gradient*.

$$q - = K\frac{\Delta h}{\Delta l} = -K\frac{dh}{dl} \quad \longleftarrow \quad \text{Hydraulic gradient}$$

5.3.2 Hydraulic Head

In a groundwater system in saturated zone, hydraulic head at a point can be expressed as

$$h= z + \frac{p}{\rho g}$$

where, z is the elevation head above datum plane [L]; P is the fluid pressure at a point applied by the column of water above the point (Pa); ρ is the water density$[ML^{-3}]$; g is the gravity constant$[LT^{-2}]$; ρg expresses the specific weight of water (γ).

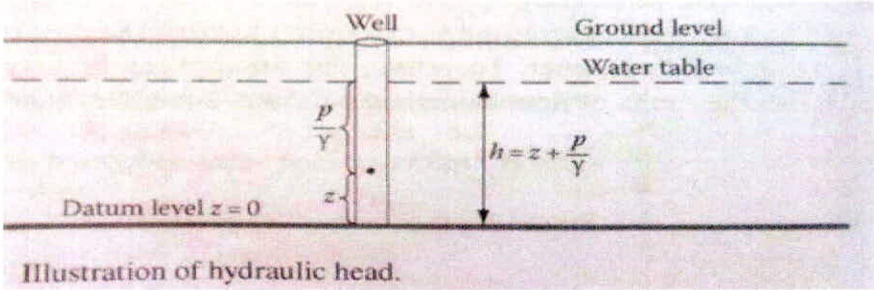


Fig. 5.3: A schematic of hydraulic head (Source: Groundwater Hydrology Engineering, Planning and Management, Mohammad Karamouz, Azadeh Ahmadi, Masih Akhbari.)

5.4 Hydraulic properties

5.4.1 Porosity and Void Ratio

The porosity of a rock is the major geological criteria for occurrence of ground water. It is generally defined as 'the percentage of the voids present in a given volume of aggregate.

$$n = \frac{V_v}{V_T}$$

Where V_v is the void volume $[L^3]$ and V_T is the total volume $[L^3]$. A related parameter is termed the void ratio, designated as e, and stated as:

$$e = \frac{V_v}{V_s}$$

where V_s is the solid volume$[L^3]$. As the total volume is the sum of the void and solid volume, the following relationship can be derived to relate void ratio and porosity.

$$e = \frac{n}{1-n} \qquad \text{or} \qquad n = \frac{e}{1+e}$$

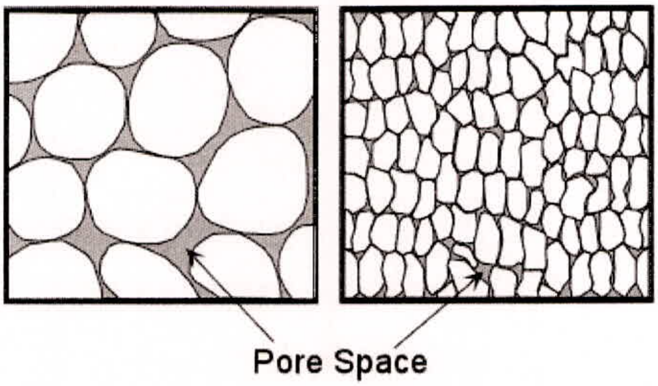


Fig. 6.4: A schematic showing pore space in the soil masses. (Source: internet)

5.4.2 Permeability

The permeability is defined as the ability of a rock or unconsolidated sediment, to transmit or pass water through itself. Degree of permeability depends upon the size and shape of the pores, the size and shape of their interconnections. The darcy is the standard unit of permeability.

1 darcy= $0.987\times10^{-8}cm^3$ or $1.062\times10^{-11}ft^2$.

5.4.3 Transmissivity (T)

It is the property to transmit water. It is defined as the rate at which water is transmitted through unit width and full saturated thickness of the aquifer under a unit hydraulic gradient. It has the dimension of $[L^2T^{-1}]$.

5.4.4 Hydraulic Conductivity or Coefficient of Permeability (K)

From Darcy's Law, hydraulic conductivity can be defined as the rate of flow of water through a unit cross sectional area of water bearing stratum under a unit hydraulic gradient. It has the dimension of $[LT^{-1}]$.

$$K = \frac{T}{h}$$

Where h is the thickness of the aquifer [L]; and T is the Transmissivity $[L^2T^{-1}]$.

5.4.5 Specific Yield (S_y)

The volume of groundwater extracted by gravity-drainage from a saturated water bearing material is known as the yield, and when it is expressed as the ratio of the volume of the total material drained, then it is known as specific yield. It is a dimensionless quantity.

$$S_y = \frac{Vol.of\ water\ obtained\ by\ gravity\ drainage}{Total\ vol.of\ the\ material\ drained} * 100$$

5.4.6 Specific Retention (S_r)

The quantity of water retained by the material against the pull of the gravity is known as specific retention. It is also a dimensionless quantity and expressed as the percentage of the total volume of the material drained.

$$S_r = \frac{Volume\ of\ water\ held\ against\ gravity\ drainage}{Total\ volume\ of\ material\ drained} * 100$$

The summation of Specific yield and Specific retention of an aquifer gives the porosity of an aquifer: $n = S_y + S_r$

5.4.7 Coefficient of Specific Storage (S) or Storativity

It is the property of aquifer to store water in the soil/rock pores. The storage coefficient/storativity is defined as the volume of water released or stored per unit surface area of the aquifer per unit decline in hydraulic head. It is a dimensionless parameter.

6. Managed Aquifer Recharge (MAR)

Managed Aquifer Recharge (MAR) describes intentional storage and treatment of water in aquifers for subsequent recovery or environmental benefits (Dillon et al, 2009). The term "artificial recharge (AR)" commonly used in India also describes the similar activity as in MAR without consideration of quality of water resources.

MAR is the process of adding a water source including recycled water to aquifers under controlled conditions for withdrawal at a later stage, or used as a barrier to prevent saltwater or other contaminants from entering the aquifer. Water can be recharged by a number of methods including infiltration via basins or galleries or by the use of injection wells. AR can be defined in many ways. Stating in simple words, AR is a process by which excess surface water is directed into the ground – either by spreading on the surface, by using recharge wells to replenish an aquifer. Except the contemplation on quality of water, MAR and AR have same physical significance and purpose. MAR as part of the groundwater manager's tools may be useful for replenishing and re-pressurising depleted aquifers, controlling saline intrusion or land subsidence and improving water quality through filtration and chemical and biological processes. On its own it is not a cure for over-exploited aquifers, but can merely enhance volumes of groundwater. (2012, Ghosh)

6.1 MAR as Groundwater Augmentation

MAR can used to address a wide range of water management issues as depicted in Fig 6.1

Considering the excessive use of groundwater resources in the country, there is no reason to believe that the growth of groundwater structures and uses of groundwater are going to slow down in future, unless otherwise controlled by enforcing legislation, rather will continue to rise because of growing concern with quality of public water supply, increasing living standards and socio-cultural dimensions of the rural sector. Therefore, there is need to conserve monsoon runoffs and store them appropriately for subsequent uses during non-monsoon months to meet the growing demands of water for various uses. MAR is one of the ways to conserve excess surface runoffs as groundwater storage and can address the lack of groundwater availability. The main advantages with MAR are; aquifer storages are naturally available and there is no need for additional large scale investment, groundwater moves slowly in the aquifer, therefore, storages are largely available in local scale, etc. It has been estimated by CGWB (2007) that an area of 4,48,760 km^2 about 14% of total land area of India is suitable for MAR and a volume of 36 BCM of water can be recharged annually. This volume is equal to about 16% of 221 BCM of groundwater that is currently utilized annually for irrigation. (2012, Ghosh)

Fig.6.1 Some important groundwater conservation and management issues, which can be addressed by MAR (Source: NIH)

6.2 Methods of Groundwater Recharge (*Source: 2007, CGWB)*

I) Direct Methods

A) Surface Spreading Techniques : a) Flooding, b) Ditch and Furrows, c) Recharge Basins, d) Runoff Conservation Structures: i) Bench Terracing, ii) Contour Bunds and Contour Trenches, iii) Gully Plugs, *Nalah* Bunds, Check Dams, iv) Percolation Ponds e) Stream Modification / Augmentation

B) Sub-surface Techniques: a) Injection Wells (Recharge Wells), b) Gravity Head Recharge Wells, c) Recharge Pits and Shafts

II) Indirect Methods

A) Induced Recharge from Surface Water Sources;
B) Aquifer Modification: i) Bore Blasting, ii) Hydro-fracturing

III) Combination Methods
In addition to the above, ground water conservation structures like Subsurface dykes (*Bandharas*) and Fracture Sealing Cementation techniques are also used to arrest subsurface flows.

DIRECT METHODS

A) Surface Spreading Techniques

These are aimed at increasing the contact area and residence time of surface water over the soil to enhance the infiltration and to augment the ground water storage in phreatic aquifers. The downward movement of water is governed by a host of factors including vertical permeability of the soil, presence of grass or entrapped air in the soil zone and the presence or absence of limiting layers of low vertical permeability at depth. Important considerations in the selection of sites for artificial recharge through surface spreading techniques include:

i) The area should have gently sloping land without gullies or ridges.

ii) The aquifer being recharged should be unconfined, permeable and sufficiently thick to provide storage space.

iii) The surface soil should be permeable and have high infiltration rate.

iv) Vadose zone should be permeable and free from clay lenses.

v) Ground water levels in the phreatic zone should be deep enough to accommodate the recharged water so that there is no water logging.

vi) The aquifer material should have moderate hydraulic conductivity so that the recharged water is retained for sufficiently long periods in the aquifer and can be used when needed.

The most common surface spreading techniques used for artificial recharge to ground water are flooding, ditch and furrows and recharge basins.

(a) Percolation tank

In this method, series of earthen dams are constructed on suitable sites for storing of adequate quantity of surface water. The tank area should be selected in such a way that significant amount of water infiltrates through the bed of the tank and reaches the groundwater table. This method is very effective in alluvial area as well as in areas with hard rock. This method is very useful in providing continuous recharge after the monsoon.

(b) Flooding

This method is suitable for relatively flat region where water can be spread as a thin layer. Water is distributed over the region using a distribution system. This method can achieve higher rate of infiltration in a region having thin vegetation cover or sand soil cover.

(c) Stream augmentation

In this method, seepage from natural stream or river is artificially increased by putting some series of check dams across the river or stream. The placing of check dams spread the water in a larger area which eventually increases groundwater recharge. The sites for the check dams should be selected in such a way that sufficient thickness of permeable bed or weathered bed is available for quick recharging the stored water.

(d) Ditch and furrow system

This method is used for uneven terrain. In this technique, a system of closely spaced flat bottom ditch or furrow is used to carry the water from the source. This system provides more opportunity to percolate the water into the ground. The spacing of the ditch depends on the permeability of the soil. For less permeable soil, more densely spaced ditch or furrow should be provided.

(e) Contour bund

Contour bund is a small embankment constructed along the contour in hilly region to retain the surface runoff for longer time. This scheme is adopted for low rainfall area where internal subsurface drainage is good.

Subsurface Techniques

Subsurface techniques aim at recharging deeper aquifers that are overlain by_impermeable layers, preventing the infiltration from surface sources to recharge them_under natural conditions. The most common methods used for recharging such deeper_aquifers are a) Injection wells or recharge wells, b) Recharge pits and shafts, c) Dug_well recharge, d) Borehole flooding and e) Recharge through natural openings and_cavities.

(a) Recharge well

Recharge wells are used to recharge water directly to the aquifer. Recharge wells are similar to pumping wells. This method is suitable to recharge single wells or multiple wells. This method is costlier than the other method as wells are required to be bored. However, sometimes abandoned tube wells can be used for recharging water into the aquifer.

(b) Recharge Pits and Shafts

Recharge pit of variable dimensions are used to recharge water to unconfined aquifer. Most of the time, especially in case of agricultural field, a layer of less permeable soil exists. Due to the existence of the less permeable strata, the surface flooding methods of recharge do not show satisfactory performance. For such type of cases, recharge pit can be excavated which are sufficiently deep to penetrate the less permeable strata. On the other hand recharge shaft is similar to the recharge pits, but the cross sectional size of the recharge shaft is much lesser than the recharge pits. Like the recharge pits, recharge shafts are also used to recharge water to unconfined aquifer whose water table is deep below the land surface and a poorly impermeable strata exist at the surface level.

(c) Dug well

Dug wells can also be used to artificially recharge the groundwater. Generally, water level of dug wells depletes during the non monsoon period. Sometime the dug wells even dried up in the non-monsoon period. These dug wells can be used for recharging groundwater. The water from various sources can be collected through a distribution system and can be discharged at the dug wells.

INDIRECT METHODS

Indirect methods for artificial recharge to ground water does not involve direct supply of water for recharging aquifers, but aim at recharging aquifers through indirect means. The most common methods in this category are induced recharge from surface water sources and aquifer modification techniques.

(a) Induced Recharge

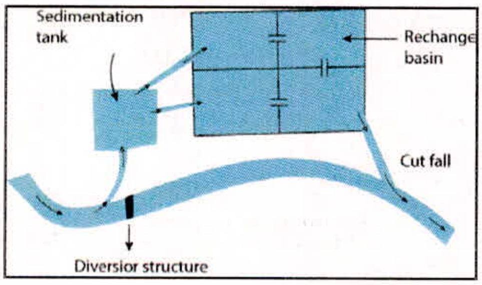
It is an indirect method of artificial recharge. In this method water is pumped from the aquifer hydraulically connected to the surface water sources like stream, river or lake. Due to pumping, a reverse gradient is formed and water from the surface water source enters into the aquifer and thus the aquifer is recharged. This method is good, especially when quality of the surface water is poor. The filtration of surface water through soil strata removes the impurities of the water. Thus the quality of the water receives in the wells is much better than the surface water.

(b) Aquifer modification method

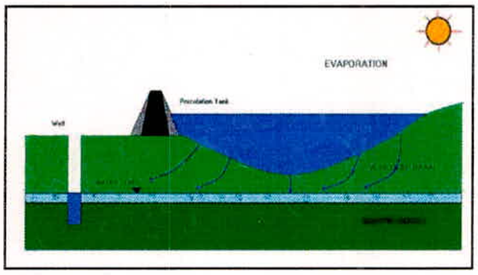
This is also an indirect method of artificial recharge. In this method, some techniques are used to change the aquifer characteristic so that aquifer can store more water and also can transmit more water. After application of these techniques, more recharge takes place under natural condition as well as under artificial condition. The most commonly used techniques are, bore blasting method, hydro-fracturing method, jacket well techniques, fracture seal cementation and pressure injection grouting, etc.

COMBINATION METHODS

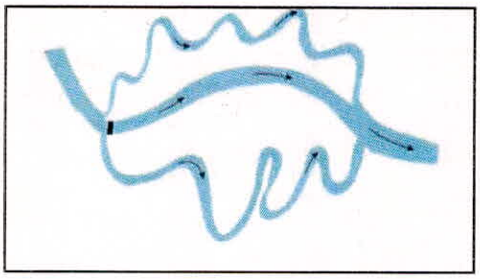
Various combinations of surface and sub-surface recharge methods may be used in_conjunction under favorable hydro geological conditions for optimum recharge of_ground water reservoirs. The selection of methods to be combined in such cases is_site-specific. Commonly adopted combination methods include a) recharge basins_with shafts, percolation ponds with recharge pits or shafts and induced recharge with_wells tapping multiple aquifers permitting water to flow from upper to lower aquifer_zones through the annular space between the walls and casing (connector wells) etc.



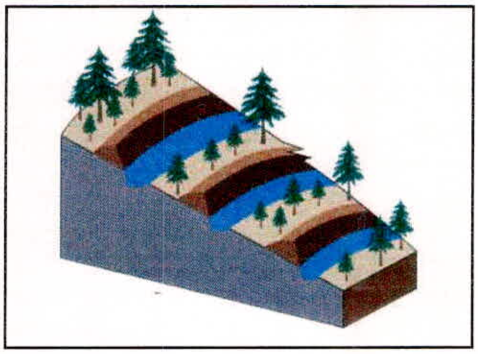
Flooding Method



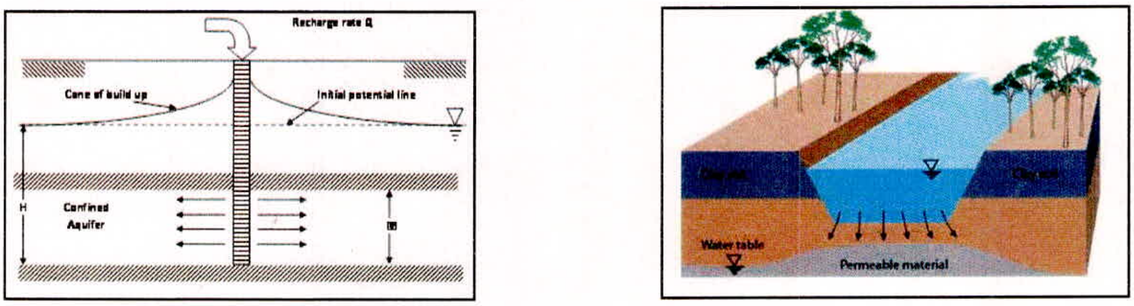
Percolation Tank



Contour Ditch

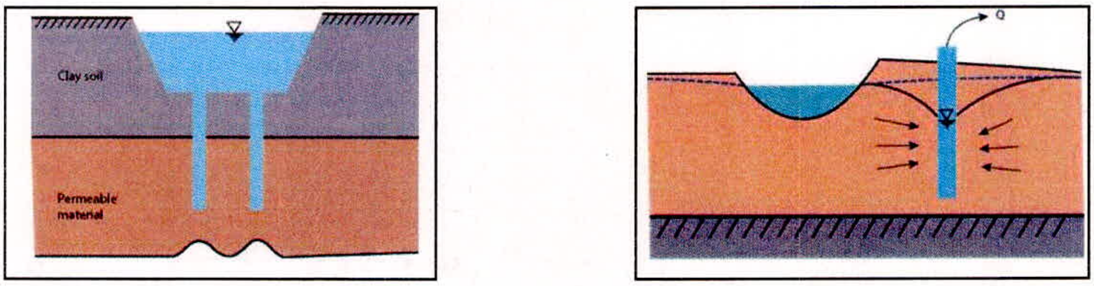


Contour Bund



Recharge Well

Recharge Pit



Recharge Shaft

Induced Recharge

Fig. 5.2 Various Recharge Structures (Source: Internet)

7. Rainwater Harvesting: A Case Study

The study for rainwater harvesting has been carried out in the campus of Heritage Institute of Technology, Kolkata. It is situated near the East Kolkata Wetlands in West Bengal. The geographical location of the campus is 22°31'4"N 88°25'6"E.

Fig.7.1: Campus Area (Satellite View)

7.1 Lithology Anaysis

The study area is situated near the East Kolkata Wetlands, Kolkata. The area is a part of the lower deltaic plain of the Bhagirathi-Ganga river system and is entirely covered by fluviatile sediments of Quaternary age. Based on the bore log data, the nature of the soil in the campus is of silty clay, sand and sand mixed with occasional gravel. The variation of soil layer is shown below:

Depth(m)		**Thickness(m)**	**I.S. Classification**	**Description**
From	To			
0	1.3	1.3		Soft mottled brown/grey silt clay
1.3	12	10.7	CH-OH	Very soft grey silty clay
12	17	5	CH	Mottled brown silty clay
17	20.5	3.2	SM	Dense brownish yellow silty fine sand
20.5	31	10.5	SM	Very dense yellowish brown silty clay
31	40	9	CH	Very stiff mottled grey high plastic silty clay

40	48.7	8.7	MI	Hard/ very hard brown clayey silt
48.7	50.6	1.9	SM	Very dense brown silty fine sand

Table 7.1: Bore Log Data (*Source: Geotest Engineers Pvt. Ltd, Kolkata)*

As per the data available through Central Ground Water Board Year Book, the hydraulic conductivity of the aquifer material of different depths varies from 6 m/day to about 55 m/day). Storage coefficient of the aquifer ranges from 3.78×10−5 to 3.3×10−3 and indicates confined to semi confined nature of the aquifer.

The depth of occurrence of the basal clay varies from place to place but in general it occurs from 300 to 450 m bgl and the top clay bed (10 m to more than 60m thick) overlies the entire alluvium sequences in KMC area. The sub-surface disposition of the aquifers indicates that the clay (10 to 60 m thick) at the top of the sedimentary sequence imparts confined to semi-confined condition to groundwater occurring in the aquifers below this clay blanket. The aquifers below this clay bed consist of fine to coarse sand, which are occasionally mixed with gravel. The sediments show facies variation at a few places, which is characteristic of typical deltaic deposition and the top clay bed shows a transition from aquiclude to aquitard. The thickness of the aquifer varies from place to place with the frequent occurrence of clay lens within them. The principal productive fresh water aquifer (yield = 90 to 120 m3/hr) occurs within the depth span of 60-180 meter below ground level (mbgl) in the major part of the area except in the western part.

7.2 Calculation of catchment area

A catchment area is defined as the land area where the surface water from precipitation sources is collected and gets drained towards a common exit and finally leads to formation of other water body such as rivers, streams and lakes. In this study, we carry out the assessment of rainwater harvesting potential of all buildings in HITK campus, and hence, the catchment area is taken to be the rooftop area. The catchment area measurement is done with the help of Google earth images and ArcGIS software. First the KML file is extracted from the Google Earth images which is further converted to shapefile. These are first converted into projection coordinated system from geographic coordinate system using ArcGIS and then area is calculated.

S. No.	Building Name	Area(sqm)
1	MCA	200.8322
2	CME	1130.926
3	CB	1560.098
4	ICT	882.344
5	SAC	787.6298
6	Degree College	449.9763
7	Ankuran	592.5859
8	Vivekananda Hostel	106.8318
9	Nivedita Hostel	85.95571
10	Ramchandra Hostel	93.35198
11	Aashram 1	108.356

12	Aashram 2	86.23214
13	Aashram 3	114.0389
14	Residential 1	117.7871
15	Residential 2	92.63949
16	Residential 3	401.5942
17	Residential 4	113.0679
18	Residential 5	236.0821
19	Residential 6	112.5527
20	C.V.Raman Hostel	37.74489
21	Aurvindo Hostel	81.40309
22	J.C.Bose Hostel	44.2789
23	Vidyasagar Hostel	52.27842
Total		7488.588

Table 7.2: Rooftop area of different buildings

7.3 Analysis of Rainfall Data

The rainfall pattern for last 15 years was observed on a daily basis for this study. Annual rainfall data are shown in the chart and graph below:

Year/ Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	**Sum**
2001	0	3.0252	41.9454	30.9496	227.5307	395.8319	227.9221	283.9398	196.8871	246.283	14.9769	0	1669.292
2002	25.6779	0	16.9853	64.9967	143.0068	376.7556	336.701	447.4512	260.2331	96.5719	85.0225	0	1853.402
2003	0	5.2666	118.8624	27.083	135.0949	311.2446	342.7879	208.7488	157.6922	363.8035	15.735	19.1095	1705.428
2004	0	0	20.3138	84.7074	47.0336	290.5559	215.6889	365.5057	311.016	313.9095	0	0.2093	1648.94
2005	19.9998	6.0091	99.9576	12.9945	62.0042	167.9733	225.6346	141.5855	58.3973	403.3116	0	7.2011	1205.069
2006	0	0	0	6.0011	151.447	138.1793	288.1533	191.174	475.0921	65.9763	0.9994	0	1317.023
2007	0	75.8	53	54.1	93.5	196.8	503.9	258.7	539.4	52.8	8	0	1836
2008	18.9	17.8	15.1	32.3	116.9	329.3	472.7	291	209.8	62.7	3.7904	0	1570.29
2009	0	25.2	13	0.1	343.3	65.4	224.1971	171.02	204.9173	99.7157	6.4305	0.3514	1153.632
2010	3.8	16.1	2	52.3	110.4	172.8	267.2	111.6354	177.8	57.3	11.9	66.5447	1049.78
2011	0	8.0681	25.0105	56.9631	136.3124	389.9876	307.9108	489.412	298.8554	34.9805	0	0	1747.5
2012	76.2	16.6	0	125.4	102.7	114.8	260.0	251.8	326.7	105.9	32.8	25.4	1438.

	91	055		056	33	189	506	726	198	274	296	369	691
2013	8.1845	10.2768	2.2059	54.3116	140.2186	376.6106	338.4413	586.1984	267.5237	480.6537	0	0	2264.625
2014	0.4729	40.3341	16.496	0.1636	99.8001	263.7119	331.9596	264.601	264.1417	72.2888	0	4.0038	1357.974
2015	26.4468	4.8279	53.0219	109.6414	54.6956	244.9765	759.6597	357.0614	222.6792	58.3498	0	8.2479	1899.608

Table 7.3: Annual Rainfall for 15 years (*Source:* Indian Meteorology Department)

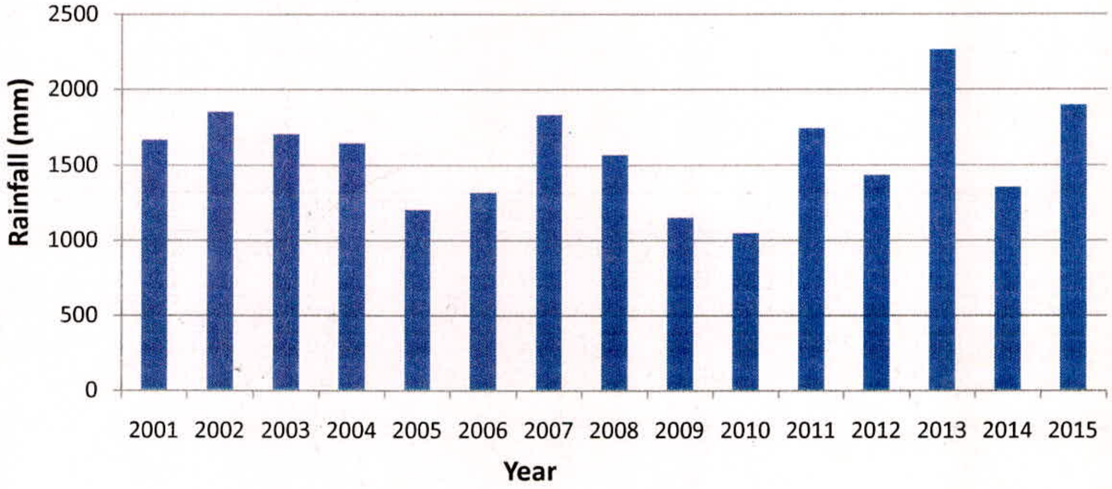


Fig. 7.2: Annual Rainfall (for 15 years)

Probability of Exceedance

The total rainfall received in a given period at a location is highly variable from one year to another. Because of the strong variability of rainfall in time, the design and management of rainwater harvesting systems are not based on the long-term average of rainfall records but on particular rainfall depths that can be expected for a specific probability or return period.
The probability of occurrence of a rainfall depth greater than some given value is known as probability of exceedance.

The first step in the probability analysis is the ranking of the rainfall data. After the rainfall data are ranked, a serial rank number (r) ranging from 1 to n (number of observations) is assigned. Subsequently the probability have to be determined that should be assigned to each of the rainfall depths. If the data are ranked in descending order, the highest value first and the lowest value last, the probability is an estimate of the probability that the corresponding rainfall depth will be exceeded. For the calculation, method by Sevruk and Geiger (1981) has been used:

$$P = \frac{r - 0.375}{n + 0.25} * 100$$

Where, r = rank of the observation, n = no. of observations, P = Probability

For the rainfall data for the study area, P has been calculated as follows:

Year	**Rainfall (mm)**	**Rank**	**P (%)**
2013	2264.6251	1	4.10
2015	1899.6081	2	10.66
2002	1853.402	3	17.21
2007	1836	4	23.77
2011	1747.5004	5	30.33
2003	1705.4284	6	36.89
2001	1669.2917	7	43.44
2004	1648.9401	8	50
2008	1570.2904	9	56.56
2012	1438.6909	10	63.11
2014	1357.9735	11	69.67
2006	1317.0225	12	76.23
2005	1205.0686	13	82.79
2009	1153.632	14	89.34
2010	1049.7801	15	95.90

Table 7.4: Probabilities of exceedance of the ranked annual rainfall

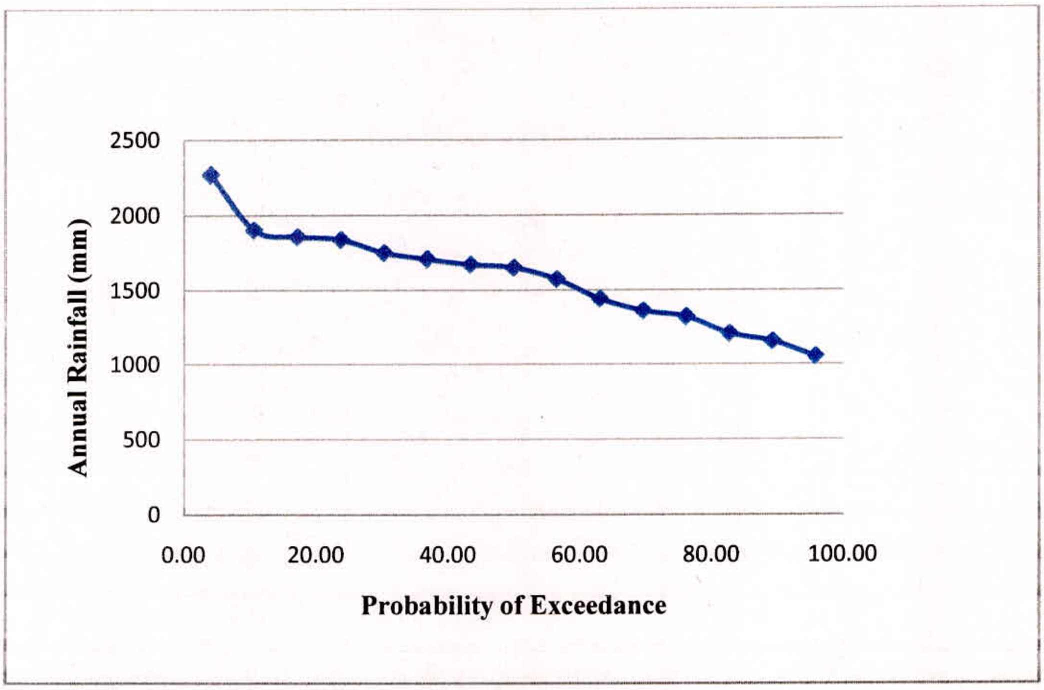


Fig. 7.4: Probability plot of the total annual rainfall

The rainfall at probability of exceedance 75% is calculated using the interpolation

$$Rainfall = 1317.0225 - \frac{76.23 - 75}{76.23 - 69.67} * (1317.0025 - 1357.9735)$$

The value of rainfall to be used for design is 1324.685mm. The year having rainfall nearest to the estimated rainfall is 2006 with 1317.0225mm rainfall. So, this is considered for the design purpose. The design rainfall can be found by shifting the daily rainfall value by (1324.685/1317.0025), and the curve is also shown below.

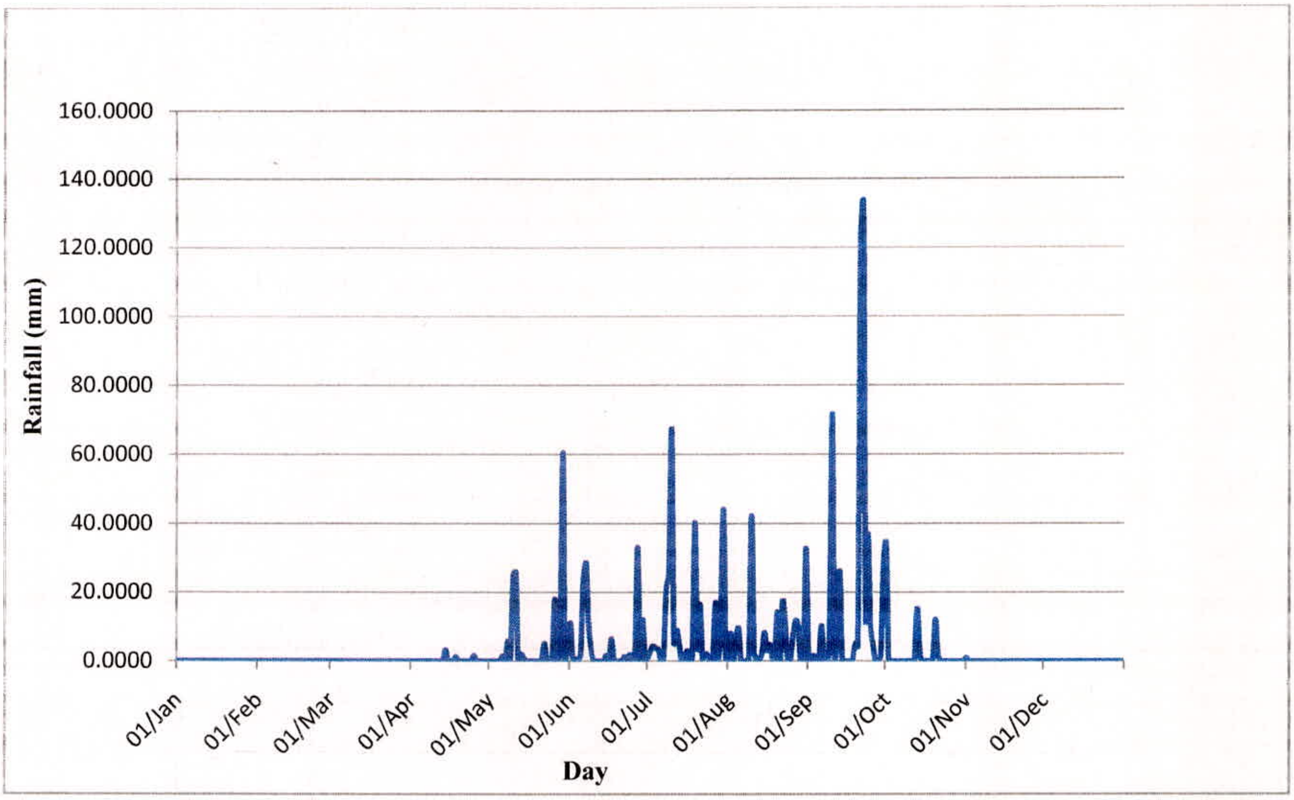


Fig.7.5: Daily Rainfall variation for P=75%

7.3.1 Run-off Calculation

Run-off is basically the water flowing away from a catchment area after precipitation. Runoff is dependent on the type of catchment area (surface features) and the size of the area. There are many parts of the hydrologic cycle that affect the runoff coefficient. These include interception, evaporation, infiltration, slope, soil types (not applicable to roof top systems), etc. Therefore to estimate run-off coefficient, following parameters need to be assessed – Roof type; slope; soil type; land use; degree of imperviousness; surface roughness and duration and intensity of rainfall. Considering all factors for the rooftop area, there would be 40% loss of rainwater. So the value of run-off coefficient is taken as 0.6. Formula used for runoff calculation:

$$Runoff = C * I_d * A$$

where, C = runoff coefficient, Id = rainfall intensity (mm/day) and A = Total catchment area.

Month	Rainfall(P=75%)(mm)	Area(sq m)	Volume(cum)
Jan	0	7488.5880	0
Feb	0.00000	7488.5880	0
Mar	0.00000	7488.5880	0
Apr	6.0361	7488.5880	27.12114815

May	152.3304	7488.5880	684.4439392
Jun	138.9853	7488.5880	624.4823893
Jul	289.8342	7488.5880	1302.269307
Aug	192.2892	7488.5880	863.9846655
Sep	477.8635	7488.5880	2147.113567
Oct	66.3612	7488.5880	298.1708364
Nov	1.0052	7488.5880	4.516517195
Dec	0	7488.5880	0
Total	1324.7051		5952.1024

Table 7.5: Month wise Run-off for design

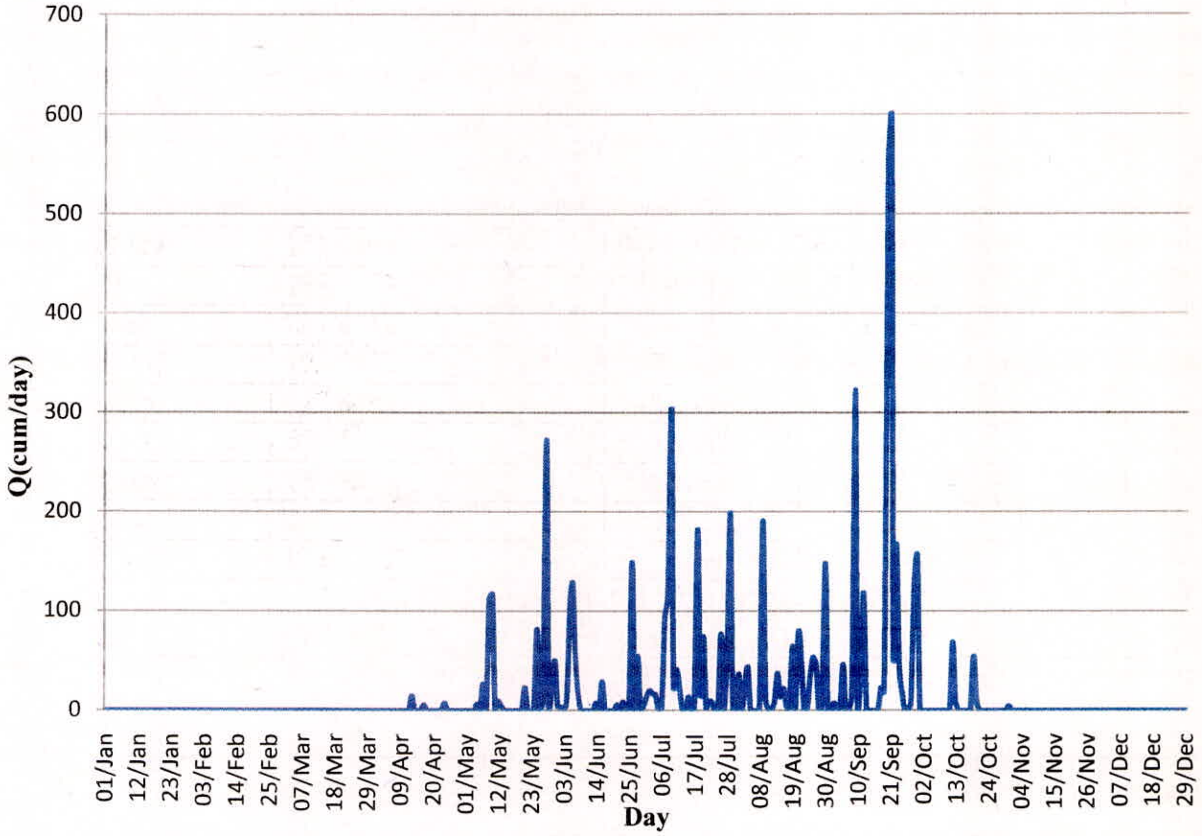


Fig. 7.6: Run-off Curve for design

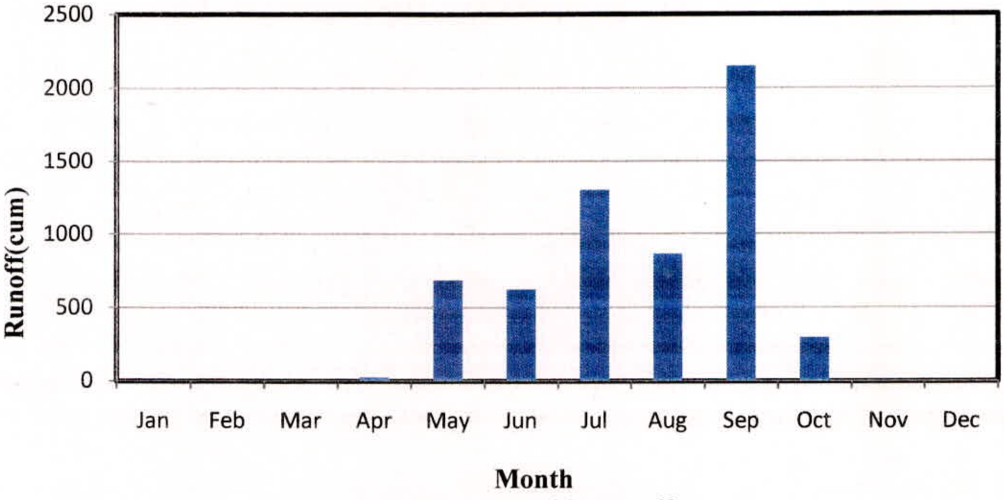


Fig.7.7: Monthly Runoff

7.5 Recharge Structure for the Study Area

In Kolkata Municipal Corporation area the presence of a thick clay layer at the top of the sedimentary sequence and the metalled and concrete pavement in the surface restrict the rainfall recharge to ground water in the area. Considering hydro geological set up of KMC area gravity head recharge tube well using the roof top rainwater is the only recharge structure feasible. The roof top rainwater after being filtered through beds of coarse sand (1-2 mm size), gravel (2-5 mm size) and boulder (6-9 mm size) placed successively from the top in the recharge trench will enter recharge well through the slot put against the bottom filtered beds. This water will then disperse into the aquifer to be recharged through the slots put against the aquifer. The exact depth, dimension of the tube well and position of slots will be decided on the basis of the depth of aquifer to be recharged and the quantum of roof top rainwater available. (2011,CGWB)

To find out the best location for the recharge structure, the slope in the campus should be known. Digital Elevation Model (DEM) has been used for this purpose. This has been done by selecting the particular area in Earth Explorer by USGS(United States Geological Survey) and converting it into SRTM file which is further used in ArcGIS. The DEM for the campus looks like as shown in the fig.8.

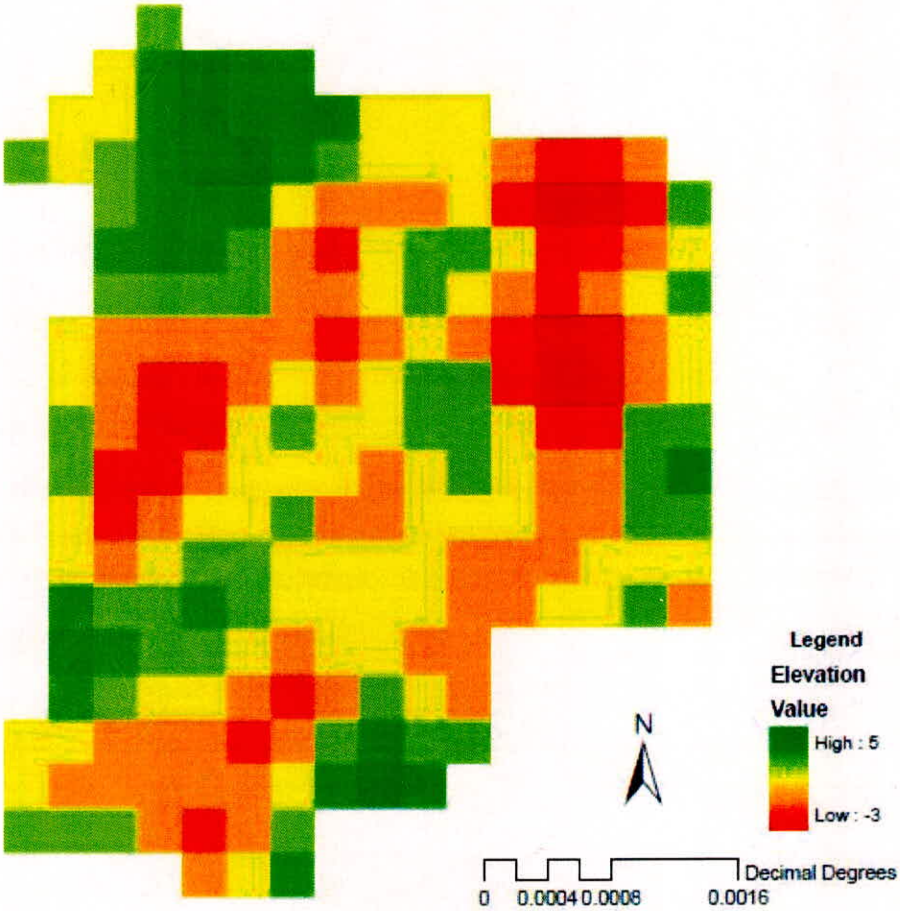


Fig. 7.8: DEM of the study area

Based on the Digital Elevation Modelling of the study area, the area behind the MCA building can be used for the design of the recharge pit. The size of the pit is dependent on the amount of rainfall discharge.

Total Rainfall in the year = 1324.685mm

Rainfall during Monsoon Season (June to Sept.) = 1098.972mm

Catchment area (HITK) = 4581.836sqm

Runoff Coefficient = 0.6

Since, the first rain is used to clean the catchment area and not considered for recharge, and 80% of rainfall occurs in the monsoon season, so only that amount of rainfall is considered for recharge.

Volume of water for recharge for 120 days = 0.6*1098.9772*4581.836/1000 = 3021.19 cum

Design Capacity of the tank = 3021.19/120 = 25.176 cum

Tank area = 5.595sqm

Therefore, volume of the tank = 364.945cum

Let length = 2*breadth

Depth of the tank = 4.5m

Therefore, Area = 25.176/4.5 = 5.595sqm

Breadth = 1.68m, Length = 3.36m

Therefore, dimensions of the tank will be **3.36m*1.68m*4.5m**

From Darcy's Law,

$$Q = A * K * \frac{dh}{dl}$$

Where, Q= runoff, K = coefficient of permeability, dh = head loss and dl = length of the soil sample. Since, equivalent vertical hydraulic conductivity is given by

$$K_{eq} = \frac{\sum h}{\sum h/K}$$

Values of K for coarse sand = 45m/day, for fine gravel = 450m/day and coarse gravel = 150m/day (Source: Groundwater Hydrology by D.K. Todd)

Value of K for soil in Kolkata = 30.5m/day

Water level during pre-monsoon = 14.84mbgl

Water level during post-monsoon= 13.25mbgl (Source: Ground water information booklet by KMC)

Average ground water table level = 14.045mbgl

(Here, average values have been taken, since the exact value at the study area was not available)

L = 9.545m

H1 = 4.5+9.545 = 14.045m

H2 = 17-14.045 = 2.955m

Putting all values in the equation for equivalent K, we get,

$$K_{eq} = 35.64\, m/day$$

And from Darcy's Law,

$$Q = 5.595 * 35.64 * \frac{[15 - 2.955]}{9.545}$$

Which gives Q = 258.69 cum/day

Therefore, maximum amount of water that can percolate through the soil in a day = 258.69cum

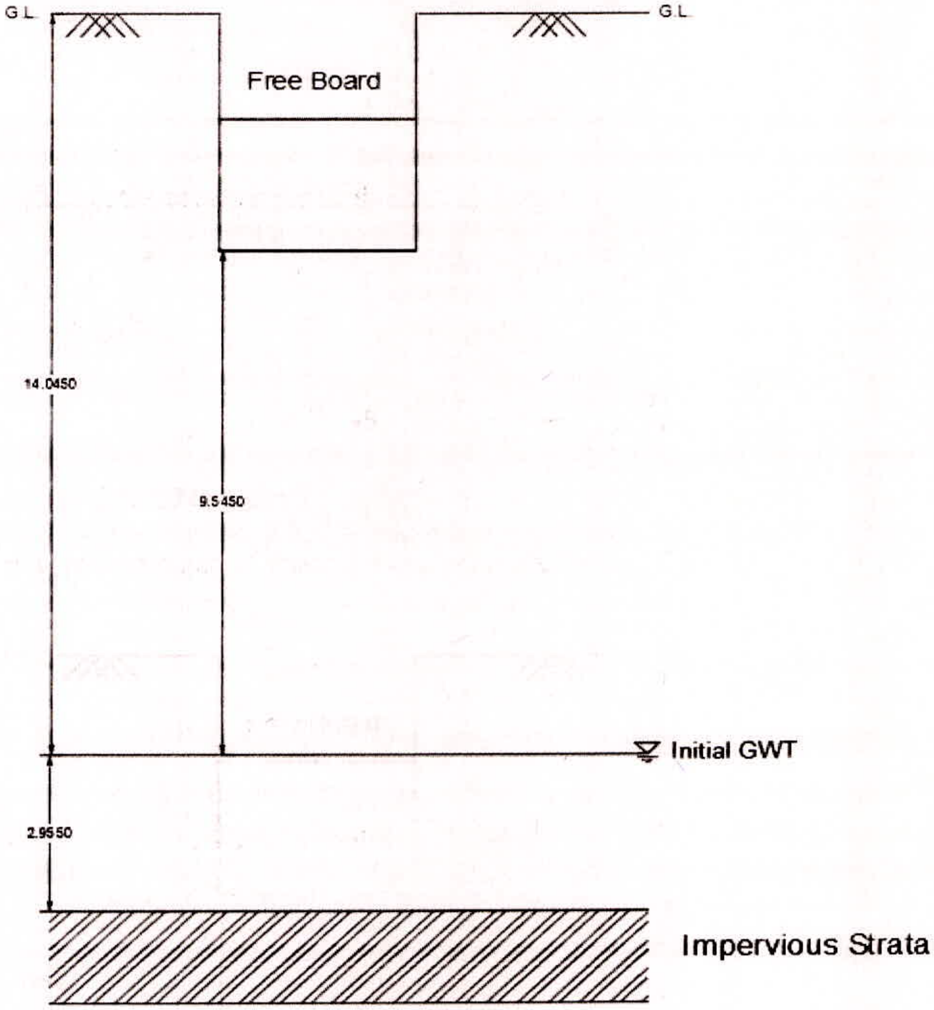


Fig. 7.9: Schematic Diagram of Recharge Basin and its Parametric Description

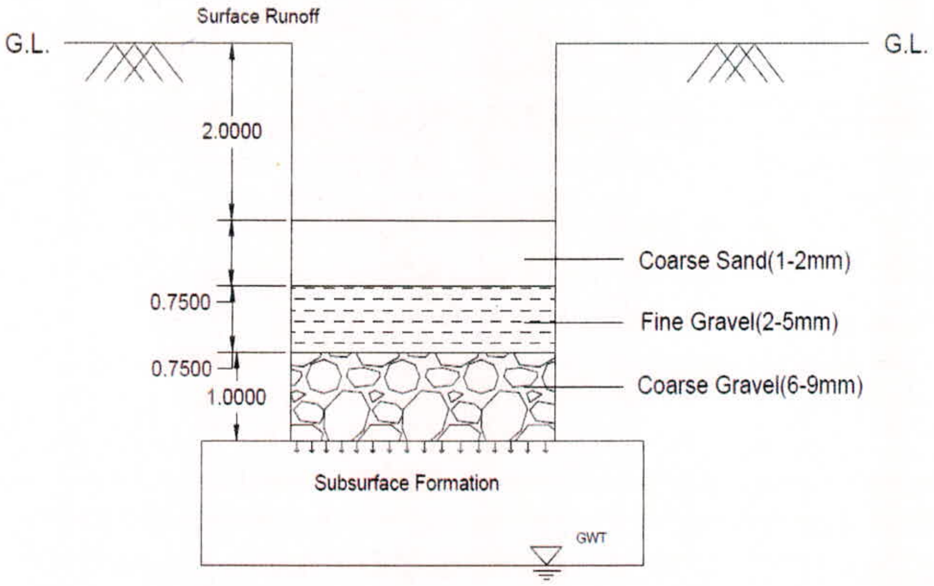


Fig.7.10: Conceptualised Diagram of the Recharge Pit

9. Conclusion

The main objective of this study was to learn about groundwater hydrology and importance and methods of groundwater recharge. The report is focused on the rainwater harvesting as groundwater recharge method. Since freshwater resources are limited and rainwater harvesting helps in utilizing precipitation water that can be reused, especially in urban areas like Kolkata. In this training work, rainwater harvesting as a tool of groundwater recharge has been studied taking the campus of Heritage Institute of Technology, Kolkata as the study area. The water available during the monsoon season is enough for recharge to some extent in that area. However, the cost estimation of the recharge structures has not been done.

The analysis of 15 years daily rainfall data (2001-2015) shows that the annual rainfall in Kolkata varies from 1049mm-2265mm with an average rainfall of 1581.85mm. The groundwater level varies from 10.68-19mbgl during pre-monsoon and 8.25-18.25mbgl during post-monsoon. The groundwater level of the city is declining at a rate of 0.33m/year, as per KMC reports. Since the exact values of groundwater levels were not available, average values have been taken. The maximum quantity of water that can be used to recharge in a day come out to be 258.69cum.

Water is essential for the environment, for ensuring agriculture growth and for ensuring food security. Since most of the population of the country is dependent on ground water for almost all kind of water requirements, it becomes important to save groundwater for the future. Hence, rainwater harvesting technique to utilize and store precious water that otherwise would go waste, should be adopted on a larger scale for sustainable utilization of groundwater.

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