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Rainwater Harvesting with Earth Acting as a Slow Sand Filter in Cold Regions

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ABSTRACT- In India, crop land has become increasingly reliant on groundwater, causing groundwater decline. Rainwater harvesting (RWH) for the aquifer is one potential alternative to addressing the groundwater issue. This is mirrored in a rise in water supply expansion plans. Which includes RWH as a key building component. Assessing the overall impact of these construction projects is crucial to achieving a beneficial net effect on groundwater both economically and within the watershed. As a result, the focus of this analysis is on the meteorological effects of RWH on recharge in rural regions, at both the local (individual structure) and watershed levels. There is relatively limited field data on the claimed positive outcomes at the small scale, and a variety of proposed adverse effects have been identified at the watershed scale. The watershed level is now largely overlooked in field studies and is typically only addressed through modelling. Modelling is seen as a potential method for augmenting constrained data sets, and situation studies will be used to examine possible dangers. Unfortunately, many previous RWH model simulations had a specific scope or were based on insufficient information.

To be coupled with increased data gathering, different modelling tools must be established. New opportunities can include growing use of spatial data and improved analytical techniques. In contrast, several test items are suggested to evaluate the meteorological and other impacts of RWH as part of water harvesting at the local and district levels. Additionally, with the Earth acting as a natural filtering material, it will enrich the rainwater with minerals, resulting in water that exhibits freshwater qualities.

KEYWORDS- Rainwater Harvesting, Slow Sand Filtration, Earth Filtration, Cold Regions, Groundwater Recharge, Rooftop Catchment, Runoff Coefficient.

I. INTRODUCTION

Water represents one of the most crucial resources for environmental stability, human survival, and socioeconomic development. Despite the fact that water covers about 70% of the Earth's surface, only 2.5% of it is freshwater, and less than 1% is readily exploitable by humans [1]. Global freshwater supplies are increasingly stressed by rapid population growth, urbanization, industry, and climate change [2]. These challenges are particularly pronounced in cold regions, where reliable water supply options are limited by long freezing temperatures, a general lack of surface water, and poor infrastructure access.

Under these conditions, the usage of earth as a natural slow sand filter enhances the quality of collected water, and rainwater gathering becomes a feasible and cost-effective method for extending water supplies [3]. Rainwater harvesting is the collection and storage of rainwater from roofs, land surfaces, or other catchment areas for beneficial use as presented in Figure 1. Some of the ancient civilizations that used this method include India, China, Rome, and the Middle East [4]. Interest in rainwater collection has been revived during the last decades due to groundwater depletion, frequent droughts, as well as an increase in demand for potable water [5].

Collected rainwater can be used for household purposes, irrigation, recharging groundwater, and, if adequately treated, consumption. In cold regions, where the chances of failure of a centralised water delivery system are very high during winter owing to frozen pipelines and impassable terrain, rainwater collection provides a more reliable and decentralized alternative source of water [6].

Cold regions have different hydrological challenges: either polar or sub-polar climate zones and high-altitude mountainous areas. For extensive periods, surface water bodies are frozen, precipitation more often takes the form of snowfall rather than rainfall, and the replenishment of groundwater is limited by reduced infiltration in frozen soils [7]. Due to this, it is both technically challenging and expensive to establish and operate classic water delivery systems. Communities also often rely upon seasonal streams, springs, or glacial meltwater-all of which are very vulnerable to seasonal variations and climate change [8]. Harvesting rainwater, therefore, during warmer months and its storage for use at a later time becomes an essential aspect of water management.

Although rainwater collection provides a different source of water, its quality depends on the conditions of storage, contaminants of the catchment surface, the materials used for roofing, and atmospheric deposition. The quality of collected rainwater can be degraded by substances like dust, organic matter, heavy metals, bird droppings, and microbes [9]. Hence, to assure safe water for household use, appropriate filtration and disinfection technologies are needed. Classic treatment technologies, including rapid sand filtration and chemical treatment, are not adaptable for cold and remote areas due to high expenses, as well as operational and maintenance difficulties, which include sensitivity to freezing [10]. A simple, low-cost, and feasible approach in this condition is to consider the ground as a natural slow sand filter.

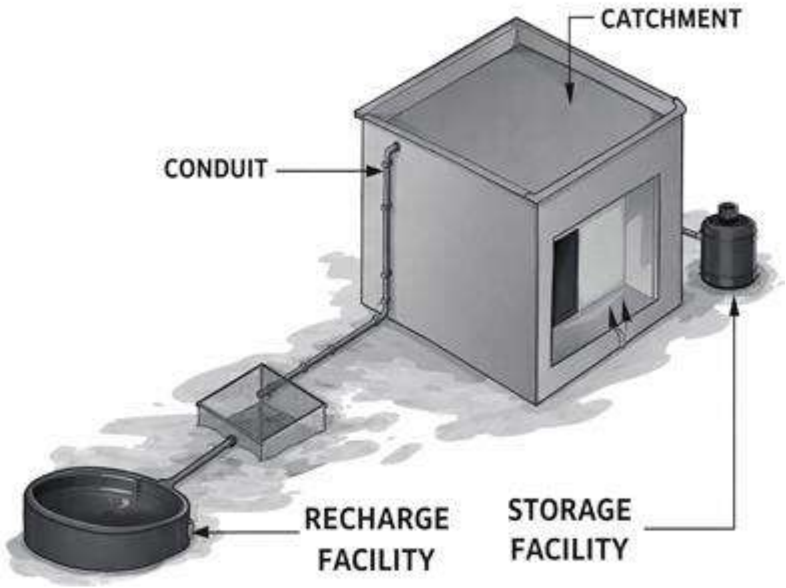

Figure 1: Elements of a Typical Water Harvesting System

For over 200 years, slow sand filtration has constituted one of the most conventional and reliable methods of water treatment [11]. Within a layer of fine sand, the process relies on chemical adsorption, biological degradation, and physical straining. The schmutzdecke, a biologically active layer developed on the surface of the sand is critical to remove organic materials and infections [12]. In cases where natural earth or soil is used as a filtering medium, there are similar processes which allow microbial activity, adsorption, and sedimentation to remove bacteria, suspended particles, and parts of dissolved contaminants [14]. It follows the principle of natural aquifer recharge and bank filtration systems, known to be effective, in allowing the collected rainfall to percolate through the soil, sand and gravel layers before being stored or recharged [13].

The advantages of the earth-based filtration include inexpensive building and maintenance costs, low energy use, and the compatibility with decentralised systems, which makes them especially suitable for remote and cold areas.

Low temperatures in cold climes reduce chemical processes, suppress microbial activity, and increase the risk of mechanical failure from freezing-all of which severely degrade the performance of conventional water treatment [3]. Earth-based filtration, in contrast, is favored by soil's insulating properties, which maintain underground temperatures relatively stable under even the most adverse wintery conditions [6]. By accelerating glacier retreat, altering snowfall patterns, reducing snowpack storage, and increasing the prevalence of extreme weather events, climate change has rendered water security challenges in chilly locations decidedly more critical [7]. Even areas with adequate annual precipitation may experience periodic shortfalls in supply. A valuable approach to addressing this challenge has been to integrate rainwater harvesting into earth-based filtering and underground storage-allowing for the safe collection of water during wet seasons for use during dry or frozen months. These approaches also limit soil erosion, reduce surface runoff, and promote sustainable groundwater recharge [9].

Rainwater collection coupled with earth serving as a slow sand filter presents a feasible and scalable option for hilly and developing areas where financial and technical resources are limited. Schools, hospitals, and small towns represent typical communal, institutional, and family environments in which these systems may be implemented [15]. Treated water, once disinfected, may be used for drinking, cooking, laundry, irrigation, and animal needs. However, the performance of such systems is influenced by soil texture, permeability, organic content, frost action, and seasonal biological activity. Frost-induced changes in soil permeability and reduced microbial activity during winter may influence filtration efficiency [5]. Scientific research and field-based performance evaluation are therefore essential to optimize system design and ensure dependability throughout the year.

This study focuses on the use of earth as a slow sand filter in cold climates, as shown in Figure 2, to assess the technological viability, filtering effectiveness, and appropriateness of rainwater harvesting as a sustainable water supply system. The role of natural soil filtration in improving the physical, chemical, and microbiological quality of the collected rainwater in cold climates is emphasized. The current research work was undertaken with the objective of providing comprehensive knowledge regarding the applicability of earth-based slow sand filtration for water security in cold and remote areas by discussing system components, filtration mechanisms, environmental impacts, and performance characteristics.

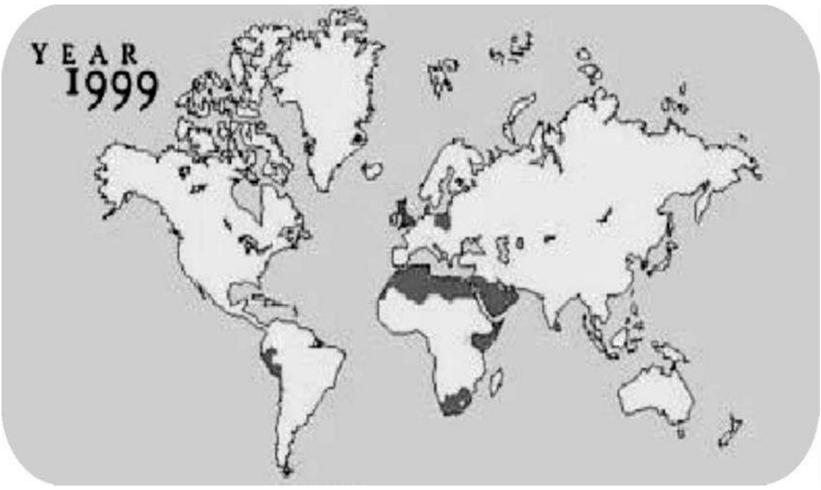

Figure 2: Shaded 31 countries facing serious water Shortage

Rainwater harvesting allied to earth-based slow sand filtration is an appropriate, low-cost, sustainable system for solving the water supply problem in cold regions. These appropriate technologies constitute an effective long-term strategy in water management by integrating scientific knowledge with traditional practices. Nature-based water harvesting and purification processes will continue to play a fundamental role in ensuring adequate, reliable supplies of water into the foreseeable future in response to accelerating water scarcity linked to climate change and human impact..

II. LITERATURE REVIEW

P. Sai Rukesh Reddy and A. K. Rastogi [1] performed important research. This study focused on the collection and conservation of rainwater falling on two campus residence halls. The possible ways of allocating the collected rain water, such as the quick depletion approach and the rationing method, were analyzed. The construction cost of the required storage tank was also estimated by the authors.
Beniston et al. [2] provide an assessment of current cryosphere research in Europe and point to the different domains requiring further research. Emphasis is given to our understanding of climate–cryosphere interactions, cryosphere controls on physical and biological mountain systems, and related impacts. By the end of the century, Europe's mountain cryosphere will have changed to an extent that will impact the landscape, the hydrological regimes, the water resources, and the infrastructure.
Bouwer [3] design a system for artificial recharge of groundwater, infiltration rates of the soil must be determined and the unsaturated zone between land surface and the aquifer must be checked for adequate permeability and absence of polluted areas. The aquifer should be sufficiently transmissive to avoid excessive buildup of groundwater mounds.
Bradshaw [4] aims to investigate the extracellular polymeric substances composition (carbohydrates and proteins), biomass, dissolved oxygen, and microbial community in two types of HSSFs and identify a correlation between them and their efficiency.
Campisano et al. [5] practices of rainwater harvesting (RWH) can be traced back millennia, the degree of its modern implementation varies greatly across the world, often with systems that do not maximize potential benefits.
P. Dillon [6] developed sustainable water treatment capacity of aquifers is often under-estimated and new knowledge is needed to define the extent to which aquifer treatment can be relied upon within a risk management framework
Ellis [7]. It is from these references that we obtained detailed structural analysis and costing methods for underground sump systems. We therefore resorted to these documents to carry out the structural design and estimate the overall cost of constructing the proposed storage tank.

III. OBJECTIVES

- To address water scarcity at Kashmir University campus
- To evaluate rainwater harvesting as a sustainable water management technique
- To assess rooftop catchment potential
- To determine storage tank capacity and design
- • To encourage groundwater recharge and lower the need for drinkable water

IV.STUDY AREA AND DATA COLLECTION

A. Study Area

Located on an enormous land of just under 247 acres lies the main campus of the University of Kashmir at Hazratbal, within the boundaries of the famous Dal Lake of Srinagar. Numerous courses are offered at the university by 47 departments, covering all undergraduate and post-grad levels of education. Living facilities are provided on the university campus. However, these facilities are strictly restricted by the number of available seats. As of current data, the number of hostel seats is allocated to 1,076 students.
As the population in the campus continues to grow, together with the proposed plans for its development, the need for infrastructure and its maintenance will be on the rise. The need for water may be considered a priority, as its availability or scarcity will impact the way of living. It may be considered a challenge in India, and the residential towers in the university are not excepted either.
Water harvesting from rainfall is also a high priority for

Kashmir University, which provides various benefits when established on the university campus. The most important aspect of such harvesting is optimizing the rooftop area for harvesting, which increases the runoff for more water harvesting.
The major campus spans approximately 247 acres of land where there are various teaching departments, residence halls, administrative departments, as well as major facilities. These facilities offer adequate roof space where rainwater harvests would be most effective. The facilities to be found within the campus infrastructure are administration buildings, test wings, student welfare facilities, a health service, and the Allama Iqbal Library, which contains a vast number of books and resources as well as resources for teachers and students. Additionally, there are residence halls, guest houses, and recreational facilities offering ample roof space.
In the research, all major buildings with considerable roofing are taken into account in order to maximize the concept of rainwater harvesting. In this context, the proposed catchment areas include the seven major hostels, all the various departmental buildings, the University Guest Houses, the Audio-Video hall, and the Allama Iqbal Library of the University. All the above-mentioned areas are pivotal to ensure the creation of a wide rooftop area where the concept of rainwater harvesting can be efficiently initiated..

B. Rainfall Data Collection

A good 1,585 meters above mean sea level, Kashmir University rests in Jammu and Kashmir at 34.13° N, 74.84° E. The Kashmir Valley that surrounds the university possesses a unique geography that brings in four definite seasons and a temperate climate unlike many other places. The topography surrounding it-ringded by the ranges of Pir Panjal, Zanskar, and Himalayan-shapes the rainfall pattern and helps moderate temperatures.
The winters here are cold and snowy, the summers mild to warm, and the seasonal variations are well marked. Rainfall and snowfall are major forms of precipitation, with snow dominating in winters. The average annual rainfall of the area is about 120–160 cm. These weather conditions heavily influence the surface runoff, infiltration, and groundwater recharge in general over the campus.
The average monthly rain data comes from the Meteorological Department in Srinagar, Jammu & Kashmir, and the campus is expected to mirror the city's monthly rainfall. Using this rainfall data, we estimated how much rainwater the campus could collect and how much runoff would come from rooftop catchments throughout the year.
The following monthly rainfall figures are thus taken from Table 1, and thereby the runoff volume, storage requirement, and the optimum size of the tank for a rainwater harvesting system in the University campus of Kashmir will be calculated.

Table 1: Monthly rainfall records at Kashmir University

Month	**Rainfall (mm)**
January	14.9
February	25.1
March	15.9
April	15.9
May	41.1
June	236.9
July	385.9
August	394.1
September	212.1
October	68.1
November	9.4
December	3.9
Total	**1422.60**

V. METHODOLOGY

A. Hydrological Analysis

In 1865, Henry Darcy, a French scientist, proposed a law based on experimental work describing the movement of water through porous soils. Darcy's law states that discharge (the rate of flow) is inversely proportional to the length of sample and directly proportional to hydraulic head difference and the cross sectional area of the soil. In simple terms, discharge can be given as a product function of the permeability coefficient and hydraulic gradient.
With this methodology, the rainwater collection potential in a catchment was evaluated. The term "rainwater legacy" describes the overall amount of water that rainfall over an area could potentially provide. The water-harvesting potential is that portion of the rainfall that can actually be collected and put to use. In other words, the computation depends on the amount of rainfall, runoff resulting from it, and the capacity of the system to harvest.
It gives the proportion of the rainfall that leaves the catchment as surface runoff. It generally lies in the range of approximately 0.5 to 1.0 and considers the losses due to infiltration, evaporation, soil moisture, leakage, and spilling. The eco-climatic factors-rainfall distribution and intensity-along with catchment surface characteristics, become vital in determining the rainwater collection potential.
In this study, rooftop catchments were considered to be perfectly impervious; therefore, the value of a runoff coefficient was taken as 1.0. This can be justified by considering that impervious surfaces reduce infiltration losses to a minimum and allow the highest possible proportion of rainfall to become surface runoff. In the below table 2 of typical runoff coefficients for different surface types was consulted to guide the hydrological analysis.

Table 2: Runoff coefficient values for different surfaces

S. No.	Types of Area	Flat Terrain (0–5% slope)	Rolling Terrain (5–10% slope)	Hilly Terrain (10–30% slope)
I	City Areas	0.54	0.64	–
II	Single-Unit Housing	0.31	0.31	0.31
III	Cultivated Land	0.51	0.62	0.71
IV	Grazing Land	0.31	0.35	0.41
V	Forest or Woodland Areas	0.31	0.34	0.51

B. Storage and Distribution Methods

It is vital to store the harvested rainwater from the rooftops of different buildings. The quantity harvested directly determines the size of the tank required. There are two approaches to distributing the harvested rainwater. These approaches are referred to as the Rapid Depletion Method (RDM) and the Rationing Method (RM).
Generally, it begins with a hall or an example building, and then every procedure is broken down with mathematical calculations. For every technique, we determine how many days the water will cover the demand, then use these crucial steps for the remaining buildings.

- Rationing Method - To extend this supply from the rainwater tank, the RM distributes the water stored in the tank among the residents by restricting the consumption rate. The RM may achieve this consumption restriction by allocating a maximum useage limit of 100 liters per day per resident.

The number of students in M.S.S. Hall is 300. This means the total number of demand per day is 300 × 0.1 = 30 M³. By using the formula of total stored divided by the total demand per day, it is possible to determine the number of days the supply will last. For example, the tank can store 3,600 M³ of water as given for the Allama Iqbal Library. This means 3,600 ÷ 30 = 120 days of supply. When it comes to long-term storage, it is essential that appropriate water-preserving or disinfecting agents be used.

- Rapid Depletion Method (RDM)- The rainwater you can harvest is any amount you like. In this method, users can access the supply as much as they need on any given day, and as such, the total supply runs low with increased demand. In this method, it can be assumed that the total rainwater supply is your only source, and when it is exhausted, you source water from somewhere else until the next rainfall refills it.

Since it is estimated that every individual requires approximately 150 liters, their total daily requirement will be 300 × 0.15 = 45 m³/day. When distributed on the basis of their requirement, their total water storage of 3,600 m³ will last for 3600 ÷ 45 = 80 days, which is about 2.7 months. Therefore, since the community harvests 3,600 m³ of water, the harvest water will last for approximately 80 days when the "Rapid Depletion Method" is used, compared to the 120 days the same volume of water in store could provide for when the “Rationing”.

C. Gis Analysis

Geographic information systems give students, researchers, and investigators a flexible means to store, organize, analyze, and visualize data linked to specific places. It is much more than a mapping tool, as it combines georeferenced images into layered datasets or themes which can be combined with other data to develop meaningful geographic representations.
These outputs are more than just outlining the borders, as valuable contexts across disciplines such as health, economics, agriculture, and transportation are provided. In this study, the ILWIS 3.0 software will be used for GIS analysis, mainly to develop a DEM from the Kashmir University campus map.
The DEM provides an effective representation of the surface topography by delineating the rise in elevation across the surface. The DEM represents higher elevations, such as hills, as contours that are closer together, while the lower-lying areas, including valleys, are represented by contour lines set further apart, as depicted by Figure 3.

Figure 3: Generated Contour Map

VI. OPTIMISTIC DETERMINATION OF SIZE AND TYPE OF TANK

The building chosen as the representative structure for the initial analysis is the M.S.S. Hall, and the calculations are performed for this hall. This process continues as the project moves ahead for the other buildings as well. The area of focus for the study under consideration is the Allama Iqbal Library & Boys Hostel, capable of accommodating approximately 300 students and staff.

The facility provided by the Allama Iqbal Library includes a roof area of approximately 2,609m2, which can be harnessed for harvesting the rainwater. Based on the rainfall data provided by the Meteorological Department of J&K, the estimated runoff for the actual roof area of the library, considered as the pavement area, will be calculated, and subsequently, the estimated runoff will be determined to be approximately 3,600m3 per annum, considering the use of the water by the library throughout the rainy season. The capacity of the storage tank will be marginally less than the actual runoff.

The volume of the annual runoff is calculated using the discharge equation from Section 5.1. The average annual rainfall recorded by Kashmir University is 1,400 mm. To obtain the potential surface runoff water, 2,609 m^2 is multiplied by 1.4 m. The total potential surface water runoff is 3,600 m^3 per year.

For the Allama Iqbal Library, to find out the appropriate storage capacity of the tank, we consider that the whole amount of storage capacity marked as 3,600 m^3 in Figure 5 represents the total annual requirement. Taking the height of the tank to be 4 m, we can derive its base area by dividing its capacity by its height. This gives us a base area of 900 m^2. This reproduces a square tank of approximately 30 meters on each side, which is not economical, as marked in Figure 4.

In actuality, the tank requires a storage of only the extra water not utilized during the highest demand months of June, July, and August since the storage of water is done every month. Given the approximated monthly use of 300 $\times$ 0.1 $\times$ 30, this amounts to 900 cubic meters every month. The actual amount of harvested water during July and August is 1,008.12 cubic meters and 1,027.69 cubic meters, respectively. In aggregate, this amounts to 2,035.81 cubic meters. The amount of water consumed during this period is approximated at 1,800 cubic meters.

The volume for the required tank is obtained by subtracting 1800 from 2035.81, which equals 235.81 m^3. If the height for the tank is 4 m, then the base area is about 60 m^2. The optimal measurement for the base is 7.8 m and 7.8 m for 60 m^2. Hence, the most appropriate tank is 4 × 7.8 × 7.8 m..

Figure 4: Satellite View of Study Area

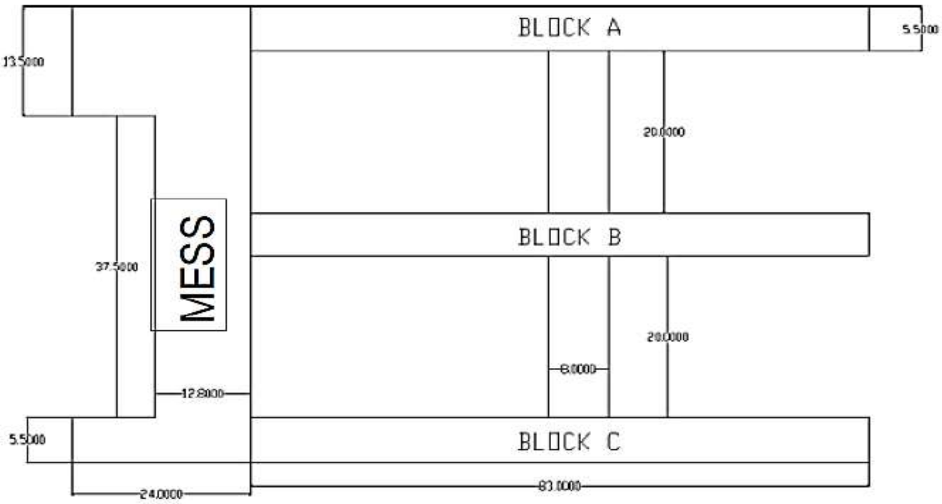

Figure 5: AutoCAD layout of Allama Iqbal Library

In the above figure 5 shows a layout plan of hostel buildings with a common mess, used to illustrate building arrangement and dimensions (likely for rainwater harvesting or infrastructure analysis).

Table 3: Monthly rainfall and discharge runoff data

S. No.	Month	Rainfall (mm)	Discharge (m³)
1	January	14.9	40.103
2	February	25.1	63.007
3	March	15.9	41.12
4	April	15.9	41.12
5	May	41.1	104.1
6	June	236.9	617.13
7	July	385.9	1007.92
8	August	394.1	1028.12
9	September	212.1	549.11
10	October	68.1	168.16
11	November	9.4	23.1
12	December	3.9	11.01
Total		**1422.60**	**3694**

Table 3 presents the monthly rainfall and the corresponding water discharge (runoff volume) for a full year, typically used in rainwater harvesting or hydrological analysis**.**

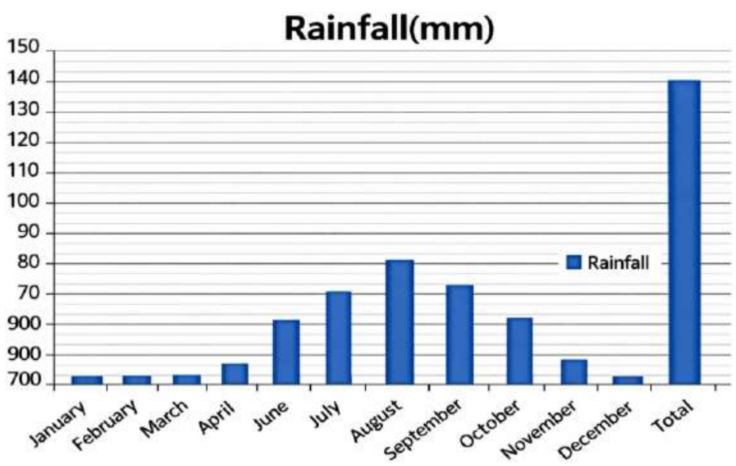

Figure 6: Yearly rainfall graph

Figure 6 shows yearly Rainfall graph through the months.

Figure 7 showing a bar chart the monthly volume of harvested/available rainwater (in m³) over one year.

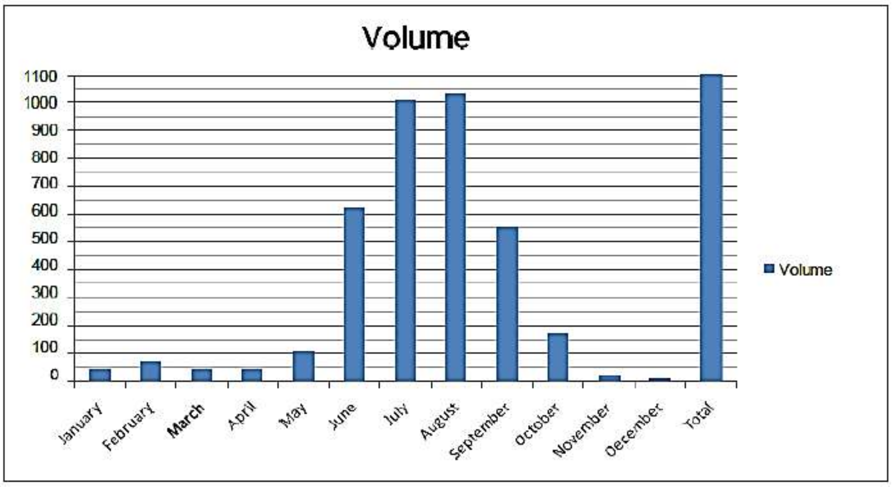

Figure 7: Yearly Runoff Volume Graph

A. *Types of Storage Tanks*

Rainwater run-off from the roof can be stored in two basic forms of tanks: lined and unlined storage reservoirs.

In a lined storage tank, after the completion of earthworks, an RCC water tank is constructed underground and fully covered. The remaining space is utilized as a parking area, playground, or anything else.

In an unlined storage tank, excavation by earth results in a pit where rainwater can freely drain into it. The technique has two advantages: first, it increases the water table by refilling the ground with water, thereby making the soil suitable for planting and agriculture. The second advantage is that it allows water to be obtained from the ground to meet daily water requirements.

VII. CONCLUSION

A workable, affordable, and environmentally responsible method that has recently been proposed and implemented for addressing the issues of water shortage in cold areas is rainwater harvesting and using the soil as a slow sand filter. In areas where the winters are freezing, in situations where centralized supply networks become inadequate as the water freezes in the pipes or where access is difficult in mountainous areas, rainwater harvesting is a viable alternate source. The earth works as a natural filter, and it improves the quality of the harvesting water by physically settling suspended materials and most bacterial contaminants along with soluble materials.

The insulation properties of soil ensure that the temperatures are more stable below the ground, particularly in the colder seasons of the year. This is pivotal for earth filtration to operate on a consistent basis. Slower sand-type soil filtration is most suitable for colder regions where it may not always be easy to operate on a 24/7 basis. Collecting rainwater using soil filtration increases the sustainability of groundwater recharge.

For areas that are hilly and developing, with minimal financial and technological resources, this combination presents a practical and scalable alternative. It can be employed for various uses, such as drinking following disinfection, cooking, washing, irrigation, and supply for animals. It can be employed at a household, institutional, or a communal level.

CONFLICTS OF INTEREST

The authors declare that they have no conflicts of interest.

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