Design and Construction of Rainwater Harvesting System for ACET

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ABSTRACT - Rainwater harvesting (RWH) is a cost-effective strategy that involves collecting and storing precipitation for various uses, including groundwater recharge. This practice necessitates a carefully designed system with key components such as roof catchments, gutters, storage tanks, and filtration units. RWH systems can help alleviate water scarcity, enhance groundwater quality through dilution, and provide an economical solution, particularly in areas with limited access to conventional water sources. The efficacy of rainwater harvesting hinges on the system design, project scale, and local conditions. This research paper aims to explore the potential for designing and constructing a rainwater harvesting system for Anjuman College of Engineering & Technology. The study will evaluate the feasibility of implementing such a system, considering factors like rainfall patterns, roof area, storage capacity, and potential end-uses.

INTRODUCTION:

Sustainable water management has become increasingly vital due to escalating global water scarcity [1]. Rainwater harvesting is a viable and environmentally-friendly approach for water conservation and resilience, particularly advantageous for educational institutions [2]. This research outlines the design and construction of a rainwater harvesting system for Anjuman College of Engineering & Technology, aiming to enhance the college's sustainability profile and reduce reliance on municipal water supplies. The system is designed considering applications such as toilet flushing and landscape irrigation, aligning with non-potable water demands. The design process thoroughly evaluates rainfall data, catchment area, and water demand to optimize system performance and ensure long-term viability [1]. This includes appropriately sizing storage tanks based on local rainfall patterns.

While rainwater harvesting has been practiced in Ethiopia and India for centuries [3] [4], its development has been impeded by inefficient techniques and poor design [4]. This project aims to implement a well-designed system to avoid those pitfalls.

Rainwater harvesting offers significant environmental and social benefits, aligning with the Sustainable Development Goals and promoting responsible water management [5]. These benefits include enhanced water security, reduced energy consumption, and mitigation of stormwater runoff, ultimately improving local water quality [6] [7]. Furthermore, such systems contribute to decentralized water management, which is increasingly recognized as an important strategy for improving water security and resilience, particularly in urban areas. The economic viability of rainwater harvesting depends on factors like initial cost, maintenance, and the value of water saved [8] [9]. This paper presents a cost-effective design achieved through careful planning and consideration of site-specific constraints.

LITERATURE REVIEW:

Rainwater harvesting is an ancient technique that has been practiced since biblical times [10]. This process involves collecting runoff from various surfaces, such as roofs and parking areas [11], and storing it for future use [12]. This simple method provides a practical solution to supplement water supplies, particularly in regions facing water scarcity or unreliable access to potable water [13]. Rainwater harvesting has emerged as a sustainable water management strategy, offering numerous benefits for individuals and communities [14] [15].

These systems are highly adaptable, ranging from small-scale residential setups to larger commercial and industrial installations, tailored to specific water demands and site conditions. As urbanization continues, rainwater harvesting is becoming increasingly important for mitigating the impacts of development on the natural water cycle [16]. It can also contribute to groundwater conservation [2].

Typical rainwater harvesting systems consist of a collection surface, a conveyance system, a storage tank, and a distribution system [5] [17]. The collection surface captures rainwater and directs it to the storage tank via the conveyance system. The storage tank serves as a reservoir, holding the harvested rainwater until it is needed, while the distribution system delivers the water to its point of use [5]. The collected rainwater can be utilized as a non-potable water supply for various purposes, such as car washing, laundry, and toilet flushing [18]. Rainwater harvesting also plays a role in managing urban discharges during rainy weather through ecological engineering techniques that enhance natural purification and water filtration [19]. Additionally, it can help manage stormwater runoff by promoting optimal collection, infiltration, and storage techniques [20].

In-situ rainwater harvesting is employed to maximize water storage during wet seasons for use during dry seasons [21]. Urbanization disrupts the natural water cycle, leading to increased stormwater runoff, decreased infiltration, and reduced groundwater recharge [22]. This disruption can result in increased flooding and diminished water availability. Sustainable urban drainage systems, including rainwater harvesting, offer an alternative approach to mitigate these impacts. The effectiveness of rainwater harvesting also ties into the concept of "Sponge Cities" [23], which aim to capture and utilize urban resources to minimize pollution and environmental issues.

METHODOLOGY:

Developing an effective rainwater harvesting system requires a comprehensive understanding of local climate, water demand, and site-specific factors [24]. The first step is a thorough assessment of available rainfall data, including averages, patterns, frequency, and duration. The rainfall data can also predict expected runoff and theoretical permeability [25].

Rainfall data: Accurate and reliable rainfall data is crucial for informed decision-making across sectors influenced by weather conditions. This data serves as the foundation for effective planning, resource management, and mitigation strategies, enabling stakeholders to make well-informed choices that account for local climate and hydrology. Collecting and analysing rainfall data is essential for understanding patterns, trends, and variability, which in turn informs the design and implementation of sustainable water management solutions, such as rainwater harvesting systems. Rainwater harvesting not only provides a supplementary water source but also supports broader ecological goals by reducing stormwater runoff, recharging groundwater reserves, and conserving potable water supplies.

Evaluating Water Quality Parameters:

Assessing water quality is vital for ensuring the safety of water used for drinking, recreation, and industrial purposes. Water quality testing examines various parameters, such as pH, turbidity, conductivity, and total dissolved solids. While pH offers an initial assessment, a more comprehensive analysis of factors like hardness, turbidity, and potential contaminants is necessary to confirm the water's suitability for its intended application.

Designing an Efficient Water Collection System:

Developing an effective water collection layout requires thorough planning of the infrastructure and processes needed to gather, store, and distribute water in a streamlined manner. Key elements to consider include the catchment area, conveyance system, storage tank, filtration unit, and distribution network. Properly sizing the system components, selecting suitable materials, and incorporating essential features are crucial for system optimization.

Design of Filter

Developing an effective water filter is an important component of a rainwater harvesting system. The filter goes through several design stages, from initial conception to final implementation. Water comes into contact with various surfaces, such as roofs or gutters, potentially picking up contaminants like minerals, chemicals, leaves, or dust.

The filter design is a key, as it employs treatment processes like slow sand filtration, chlorination, and solar disinfection to purify the collected rainwater for potable use. Using appropriate filtration and disinfection methods is essential to ensure the harvested rainwater meets the required water quality standards for its intended application. Implementing a rainwater harvesting system with an effective filter contributes to a more sustainable and resilient water management strategy. It reduces the burden on traditional water sources and provides a localized, decentralized water supply - an increasingly recognized approach for improving water security and resilience, particularly in urban areas.

An example multi-layered filter design (Fig) includes:

- Layer 1: Coarse Aggregate Layer - Traps larger debris like leaves, stones, and other large particles. Uses crushed stone or gravel (20-40 mm) with a 15 cm thickness.
- Layer 2: Fine Sand Layer - Uses clean, washed river sand (0.5-1 mm) with a 20 cm thickness.
- Layer 3: Activated Carbon Layer - Uses granular activated carbon with a 10 cm thickness.

Conducting quality checks on the filtered water is essential to ensure its safety and effectiveness for the intended use. Additionally, the disposal of water, especially after filtration or treatment, must be handled carefully to protect the environment and comply with regulations.

A key benefit of rainwater harvesting is its potential to be economical and portable, as it can utilize readily available materials [25].

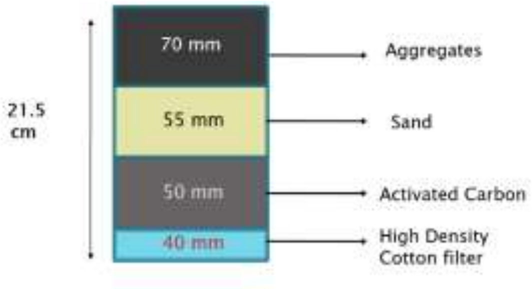


Fig.

Filter water testing:= Conducting quality checks for filtered water is essential to ensure its safety and effectiveness for intended use.

Disposal of rain water: Disposal of water, particularly after filtration processes or during water treatment, must be handled carefully to protect the environment and comply with regulations.

EXPERIMENTAL WORK

Rainfall Data Collection from IMD (June 2024 - December 2024) Our team collected and analysed rainfall data for Nagpur from the official IMD website. The following is a month-wise breakdown of recorded rainfall. Average Rainfall.

Total Rainfall

Total Rainfall =172+360+305+170+50+10

=**1,067mm**

Average Rainfall (6 months)

Average Rainfall= $\frac{1,0676}{6}$ =**177.83 mm**

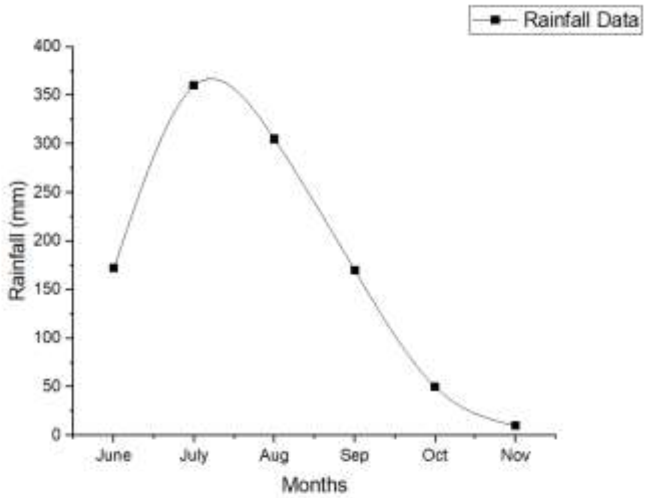


Fig.

Analysis of Water Quality: Water quality analysis is essential to assess the usability of rainwater for drinking, irrigation, and other purposes. Several parameters are considered in water quality assessment, including pH, turbidity, dissolved solids, and microbial contamination.

Comparative Water Quality Testing water quality tests were conducted on various water sources to compare their suitability for different uses. The results are summarized in the table below:

Parameter	**Normal Range**	**Hand Pump Water**	**Distilled Water**	**Well Water**
pH	6.5 – 8.5	7	6	8
Turbidity	< 1 NTU	2 NTU	0 NTU	3 NTU
Conductivity	50 – 500 µS/cm	350 µS/cm	5 µS/cm	450 µS/cm
TDS	< 500 mg/L (ideal < 300 mg/L)	300 mg/L	10 mg/L	400 mg/L

Table no. 1: Water Samples testing

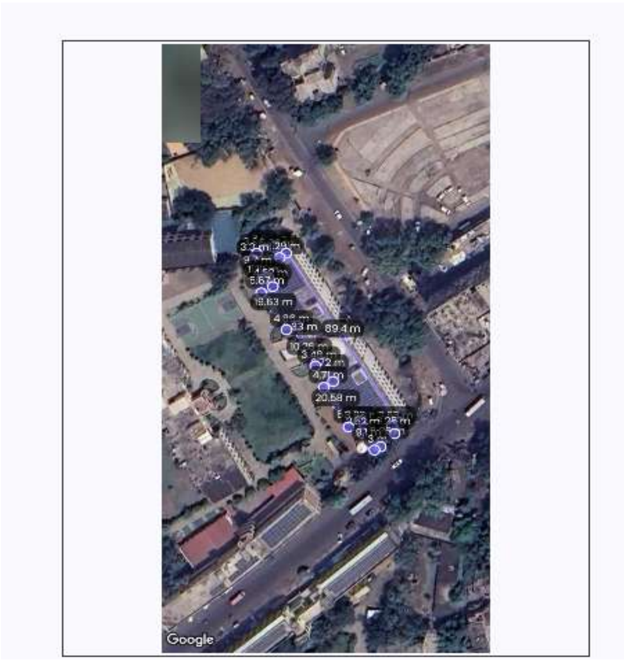
Layout design

Layout Design of Anjuman College of Engineering and technology Main Building (Academic Block)

Total Area: 15,843 sq.m

Floors: Ground + 3 upper floors

Rain water harvesting Installed across rooftop and terrace area (15,843 sq.m)



Anjumn college of engineering and technology

Outlet and collection pattern:

Known Parameters

Catchment Area (Rooftop Area of Main Building):- 15,843 sq.m

Average Rainfall (Jun–Nov 2024):- 177.83 mm = 0.17783 m

Runoff Coefficient (for concrete rooftop): 0.9

Equation:

Rainwater Volume (liters) = Area (m²) × Rainfall (m) × Runoff Coefficient × 1000

Volume = 15,843×0.17783×0.9×1000

=15,843×160.047 ≈ 2,536,648liters

Assume a Rain Event Duration

Let's assume this **entire rainfall volume occurs over 2 hours** in a heavy storm, which helps us size the pipe for worst-case discharge:

Time=2 hours=7200 seconds

Flow Rate (Q) = $\frac{2,536,650}{7200}$ ≈ 352.6liters/second

Divide Flow into 3 Pipes

$\frac{352.6}{3}$ ≈ 117.5 L/s.

Choose Pipe Size

Using empirical flow capacity:

250 mm diameter pipe: ~90–120 L/s at 1% slope

300 mm diameter pipe: ~120–160 L/s at 1% slope

Recommended: Use 3 pipes of 300 mm diameter (12-inch)

Each pipe will easily handle the flow of ~117.5 L/s.

DEVELOPMENT OF FILTER:

Water purification is a critical need across various sectors, ranging from residential and municipal water treatment to recreational facilities such as swimming pools. Sand filtration, a time-tested and efficient water treatment method, plays a vital role in providing clean and safe water. The sand filter we have designed is a versatile and effective solution for removing suspended particles and impurities from water, based on a simple yet highly functional filtration process

Our sand filter is designed to leverage the natural properties of sand to effectively remove contaminants, relying on the principle of physical filtration Show in the fig. The filter uses multiple layers of sand with varying particle sizes, which allows it to capture a broad range of particulate matter. As water passes through the sand bed, larger particles are trapped on the surface, and smaller particles are filtered as they move deeper into the bed. The clean water then emerges from the bottom, free from most suspended solids.

Fig 1.1 Fillter

Filter water testing Result

The purpose of this testing was to evaluate the effectiveness of the multi-layer sand filter designed for rainwater harvesting. The filter consists of aggregate (20–40 mm), fine sand (0.5–1 mm), granular activated carbon (10 cm thickness), cotton, and pebbles (20 mm). The primary goal was to assess improvements in water clarity, chemical purity, and microbial reduction before and after filtration.

Water Quality Parameters Tested

We conducted a series of tests to analyze the effectiveness of the filter. The following parameters were evaluated:

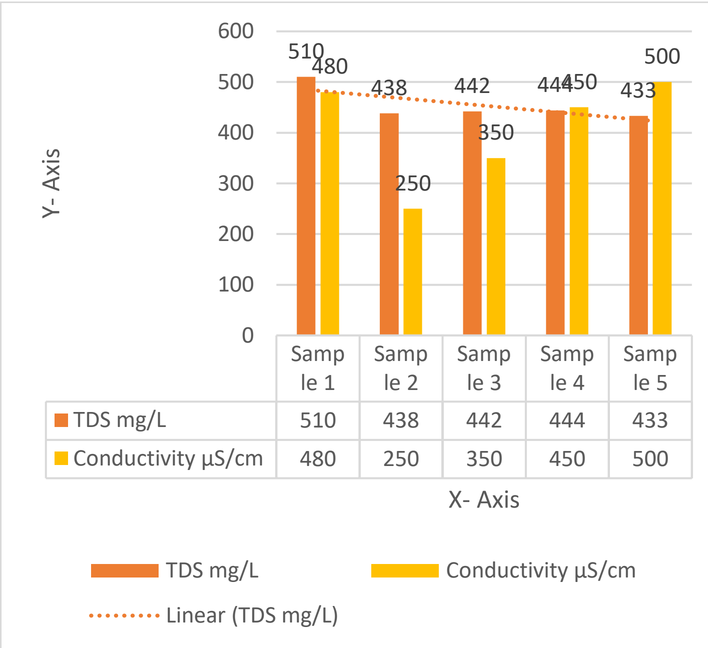
1. Turbidity (Water Clarity Test) – Measures the presence of suspended particles.
2. Chemical Contaminants – Includes organic impurities, chlorine, and other dissolved chemicals.
3. Microbial Load – Determines the presence of bacteria and other microorganisms.
4. Odor and Taste – Evaluates the improvement in water freshness.
5. pH Level – Checks whether the water remains within a safe range for drinking and irrigation.

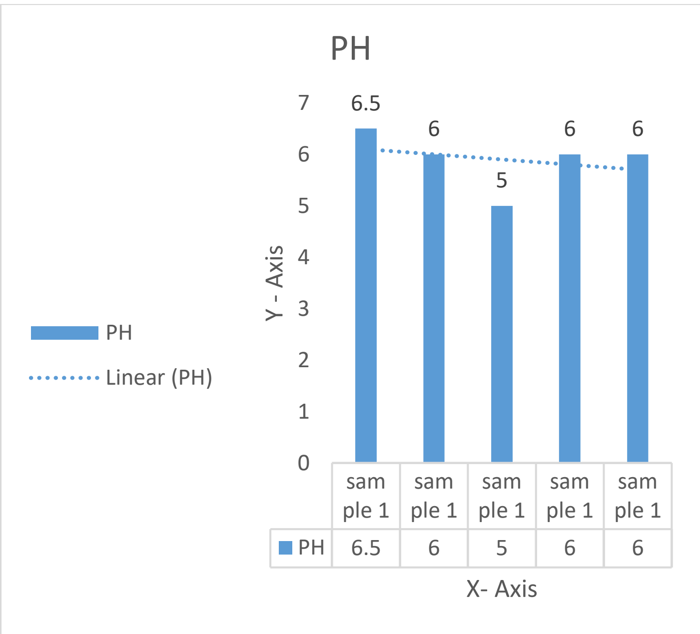
Parameter	**Rain water (Sample 1)**	**Tank Water (Sample 2)**	**Hand Pump Water (Sample 3)**	**Well Water (Sample 4)**	**Distilled Water (Sample 5)**
pH	6.5	6	5	6	6
Turbidity	3 NTU	1 NTU	2 NTU	3 NTU	0 NTU

Conductivity	480 µS/cm	250 µS/cm	350 µS/cm	450 µS/cm	500 µS/cm
TDS	510 mg/L	438 mg/L	442 mg/L	444 mg/L	439 mg/L

Represented in the graph

TDS and Conductivity test





TEST RESULTS

Parameter	Before Filtration	After Filtration
Turbidity (Clarity)	Cloudy, visible particles	Clear, no visible particles
Chemical Contaminants	Presence of organic matter & chlorine	Significantly reduced
Microbial Load	Possible bacterial contamination	Reduced significantly
Odor and Taste	Mild organic/musty smell	Odor-free and fresh taste
pH Level	Slightly acidic (due to rainwater absorption)	Balanced, within safe range

CONCLUSION

The rainwater harvesting system designed for Anjuman College of Engineering is a sustainable and efficient approach to conserving and utilizing natural water resources. Based on the **average rainfall of 177.83 mm** (from June to November 2024) and the **terrace area of 15,843 m²**, the estimated volume of rainwater that can be harvested is approximately **2.53 million liters**. This volume represents a significant potential to supplement water demands and reduce dependency on groundwater or municipal supply.

To effectively collect and manage this runoff, **three major collection pipes**, each with a **diameter of 300 mm**, have been strategically placed:

- **Pipe A** – Western block
- **Pipe B** – Central block
- **Pipe C** – Eastern block

Each pipe is designed to manage approximately one-third of the terrace area with a flow capacity of ~117 liters per second. The collected water is directed into a **central filtration tank** that incorporates multiple layers:

- High-Density Cotton (for initial filtration of fine particles)
- Fine Sand (0.5–1 mm)
- Granular Activated Carbon (10 cm layer for odor and chemical purification)
- Gravel Layer (20 mm pebbles for support and drainage)

The turbidity was significantly reduced, as the fine sand and cotton layers effectively trapped suspended particles, making the water clearer. The activated carbon layer played a key role in removing chemical impurities and odors, resulting in fresher and better-quality water. The pH remained stable, indicating that the filter does not alter the natural water balance significantly.

Water quality testing confirmed that **rainwater is among the purest sources**, with low turbidity and total dissolved solids (TDS). However, treatment and proper storage are necessary to maintain potability and usability, especially when compared to hand pump or well water. This rainwater harvesting system not only contributes to water sustainability but also serves as a **model solution** for institutions aiming to conserve water, recharge groundwater, and reduce urban runoff. With proper maintenance and community involvement, this system will have long-term environmental, educational, and economic benefits.

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