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Design of an Efficient Rainwater Harvesting System with Effective Filtration Unit for Urban Building

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ABSTRACT -

The increasing global population has led to a surge in the demand for clean and reliable water sources. Conventional water supplies, such as surface and groundwater, are being depleted faster than their natural replenishment rates, posing a serious threat to water security. This study explores rainwater harvesting (RWH) as a sustainable and decentralized solution to address water scarcity. RWH, a traditional water conservation practice, is gaining renewed attention worldwide due to its potential to supplement existing water systems, reduce pressure on urban infrastructure, and mitigate groundwater depletion. The research focuses on the design and performance analysis of RWH systems, considering technical, environmental, and practical aspects. Additionally, the study evaluates the impact of RWH implementation in different regions, highlighting its role in soil conservation, urban water management, and climate resilience. The findings support the broader adoption of RWH systems as a viable strategy for achieving water self-sufficiency and ensuring long-term sustainability.

Keywords:- Rainwater Harvesting, Water Filtration, Groundwater Recharge, Sustainability, Cost-effective Water Systems Rainwater Harvesting (RWH) system with effective filtration unit

1. Introduction

It gathers, stores, and exploits rainwater for different activities. The activity has gained extensive attention globally owing to issues associated with water shortage, global warming, and urbanization. This could be interpreted as a means to achieving water availability and environmental sustainability as populations expand and use traditional sources over time[1]. As land availability continues to shrink, urban areas are expanding vertically, while rural regions are increasingly clearing forests to make space for farming. In India, many small-scale farmers still rely heavily on the monsoon season, which lasts from June to October. However, a significant portion of the rainfall during this period quickly runs off the surface and is lost. While irrigation is often seen as the go-to solution during dry spells, it remains expensive and is accessible only to a limited number of farmers.

This has led to growing interest in a more affordable and sustainable alternative: Rainwater Harvesting (RWH). This approach involves collecting rainwater directly, either for immediate use or for recharging underground water sources. Essentially, it's about capturing and storing runoff so it can be used productively, rather than letting it go to waste. With rising demand for water and increasing urbanization, utilizing rainwater as a resource is becoming essential—especially as major cities face the looming threat of water shortages.

2. Literature review

Rainwater collection is not a new concept it has been practiced for thousands of years. In ancient times, civilizations such as those in the Indus Valley and Mesoamerica developed advanced systems to collect and store rainwater, especially in dry and semi-arid regions where other water sources were limited. These systems were used for both household needs and irrigation.

Today, with the help of modern technology and engineering, these age-old practices are being revived to tackle current water management challenges. Rainwater harvesting can be a valuable supplement to existing water sources, especially as the demand for freshwater continues to grow and supplies become scarcer. This method is particularly useful in drought-prone areas, where communities can collect and store rainwater during the rainy season for use during dry periods.

2.1 Groundwater Recharge

Rainwater harvesting helps replenish groundwater aquifers. If this collected rainwater is channeled to the ground, groundwaterlevels are preserved, hence sustaining ecosystems while preventing land subsidence [5].

2.2 Cost Effectiveness

Installation of rainwater harvesting systems can lead to significant cuts in water bills where and when the cost of water is high or where water is scarce. The initial investment in a storage and filtration systemoften pays itself off through dollars saved in water after some time. Environmental Benefits: RWH encourages sustainable practices because it reduces the dependency on municipal water supplies and lowers the energy consumption used in transporting and treating water. It also reduces pollution since rainwater is filtered naturally through soil and vegetation[5].

Implementation Strategies: Rainwater harvesting needs proper planning anddesign to correctly implement .Design of the System: In this, collection surfaces should be chosen as roofs andstorage systems may be through tanks or cisterns, with proper means of filtration for water to become safe for the purpose in which it will be put to use [2].

2.3 **Public Awareness and Education**

The benefits and techniques of rainwater harvesting must be made known to the public. Through education, communities will be able to understand how they can establish and maintaineffective RWH systemsRainwater can be collected and stored in overhead tanks, sumps, or underground storage systems and then used directly for everyday purposes like flushing toilets, watering gardens, and washing. This is known as rainwater harvesting. Alternatively, rainwater can be allowed to soak into the ground using methods like recharge pits, soak pits, bore wells, dug wells, or recharge trenches. This helps in recharging the groundwater table, ensuring long-term water availability.

3. Methodology

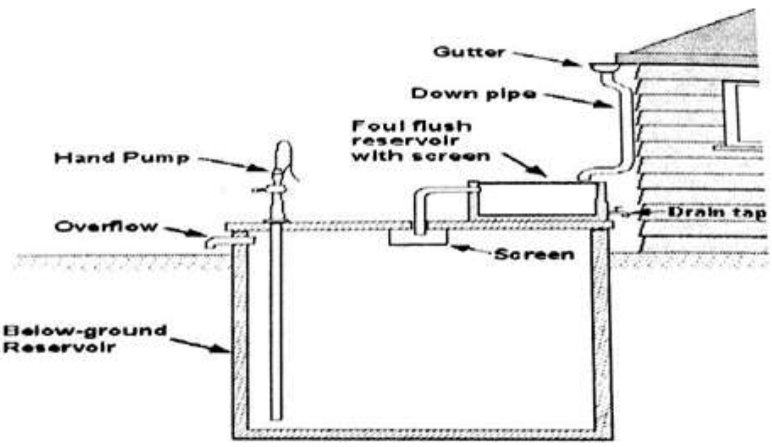

Figure 1.1 Catchment Area

A surface which collects rainfall. It is usually a building roof. Common materials include metal, tiles, concrete, and asphalt. Material selection depends on the water quality, thus affecting collection efficiency[2].

3.1 Gutters and downspouts are pipes or channels that help carry rainwater from the roof (catchment area) to the storage system. They guide the water properly, prevent it from splashing around, and help it drain smoothly.

3.2 Storage Tank is container for storing harvested rainwater. There are above ground tanks and underground tanks and they can be made of plastic, concrete, or fiberglass [2].

3.3 Filtration System This system ensures that sediments, debris, and contaminants from collected rainwater are removed [6]. Options range between sediment filters, mesh screens, and activated carbon depending on the use for the water, be it for irrigation or drinking.

3.4 Distribution System: It is the plumbing and other infrastructure used in transferring the stored rainwater to points of need. It can cover pumps, pipes, and faucets, and can be designed forgravity flow or pressure systems.

3.5 Treatment System (if necessary): It is supplementary systems that treat the collected rainwater tomake it fit for drinking.Treatment methods: UV purification, chlorination, or reverse osmosis.

3.6 Overflow System meant for controlling overflow when the tank is saturated. It ensures that overflow water flows away from the foundation safely and does not flood.

4. Filter used in model

4.1 The filter is made by our group in which we have used the following things :-

1. Coconut shell
2. Coal
3. Crashed sand
4. Cotton
5. Scrub

Image 1.1 : Filtration unit

4.2 Reason for using this material in the filter

1 Coconut Shell is used for obstructing the large particles presents in water

2 Coal is used to reduce the hardness of water

3 Crashed sand is used for obstructing the small particles presents in water

4 Cotton is used for obstructing the fine particles presents in water

5 Scrub is used to increase the flow of the water On an average these filters more then 70 lit

4.3 Sample water of the filter

A water sample was taken from the borewell, and soil was intentionally added to it to simulate dirty water. This sample was then passed through the filter to test its performance and effectiveness.

Image 2.1 : Sample water

Borewell water is used in this case because it contains a high level of hardness. A laboratory test was conducted to check the water quality. Based on the results of this test, the filtration system is performing well and is providing good quality water within acceptable parameters.

5. Result and discussion

5.1 Muddy water

LABORATORIES

AQUA LABORATORIES INDIA (OPC) PVT. LTD.

ISO 9001:2015 305024031528Q

ANALYTICAL REPORT

Report No.	ALPL-24-25-1307	Lab Identification No.	AQ-10716
Report Date	19-03-2025		
Client Name	Pimpri Chinchwad Polytechnic		
Address	Nigadi,Pune-411044.		
Sampling Date	15-03-2025	Sample Name	Muddy Water Sample
Time	3:00 PM	Sample Collected By	Party
Nature/Source of Sample	Muddy Water Sample	Date of Sample Received in Lab	17-03-2025

RESULT DETAILS

Sr.No.	Parameter	Unit	Result	Limit	Test Method Name
1	pH	~~~	7.53	6.5 to 8.5	IS 3025 Part 11
2	Turbidity	NTU	18.00	1 (Max)	IS 3025 Part 10
3	Total Hardness (as CaCO3)	Mg/lit	245.00	200 (Max)	IS 3025 Part 21
4	Total Dissolved Solids (TDS)	Mg/lit	430.00	500 (Max)	IS 3025 Part 16
5	Conductivity at 25 degree celcius	µmhos/cm	767.85	~~~~	~~~~
6	Total Coliform	CFU/100ml	TNTC	Nil	IS 1622
7	E. Coli	CFU/100ml	Absent	Absent	IS 1622
8	Colour	~~~	Yellowish-Brown	Colourless	IS 3025 Part 4
9	Odour	~~~	Agreeable	Agreeable	IS 3025 Part 5

Remarks: IS:10500:2012 Standard. As Per Sample Received & Test Performed Chemical & Bacteriological Analysis All Above mentioned results are non-complies.

Lab Incharge   Lab Chemist   Authorized Signatory

Note: 1) Results related to tested sample Only. 2)Test report should not be reproduced partially 3)'mg per l' is equivalent to 'ppm' 4)Based upon request, Sample was tested for above mentioned parameters only. 5)Report is Intended to be used for informational purpose only & should not be used for regulatory and,or legal purposes. 6) If water source as borewell water it's recommended to have RO treatment for drinking. 7) Samples will be disposed of 7 days after testing from the date of issue of the report,unless otherwise requested by the sender. 8) TNTC-Too Numerous to Count 9) BDL-Below Detection Limit

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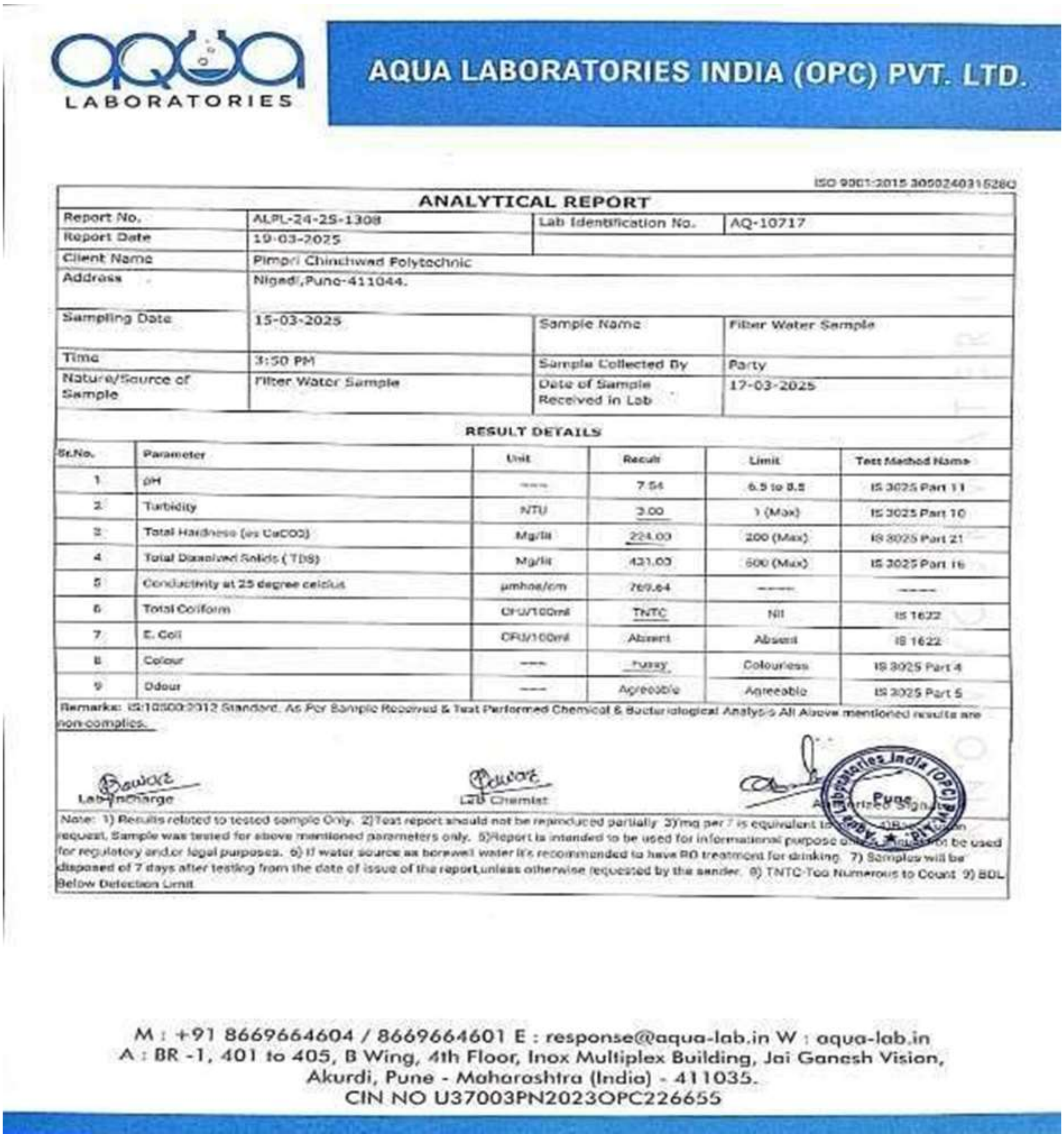
CIN NO U37003PN2023OPC226655

Report 1.1 : Muddy water

5.2 Filtered water



AQUA LABORATORIES INDIA (OPC) PVT. LTD.

ISO 9001:2015 305024031528O

ANALYTICAL REPORT

Report No.	ALPL-24-25-1308	Lab Identification No.	AQ-10717
Report Date	19-03-2025		
Client Name	Pimpri Chinchwad Polytechnic		
Address	Nigadi,Pune-411044.		
Sampling Date	15-03-2025	Sample Name	Filter Water Sample
Time	3:50 PM	Sample Collected By	Party
Nature/Source of Sample	Filter Water Sample	Date of Sample Received in Lab	17-03-2025

RESULT DETAILS

Sr.No.	Parameter	Unit	Result	Limit	Test Method Name
1	pH	----	7.54	6.5 to 8.5	IS 3025 Part 11
2	Turbidity	NTU	3.00	1 (Max)	IS 3025 Part 10
3	Total Hardness (as $CaCO_3$)	Mg/lit	224.00	200 (Max)	IS 3025 Part 21
4	Total Dissolved Solids (TDS)	Mg/lit	431.00	600 (Max)	IS 3025 Part 16
5	Conductivity at 25 degree celcius	µmhos/cm	769.64	-----	-----
6	Total Coliform	CFU/100ml	TNTC	Nil	IS 1622
7	E. Coli	CFU/100ml	Absent	Absent	IS 1622
8	Colour	----	Fussy	Colourless	IS 3025 Part 4
9	Odour	----	Agreeable	Agreeable	IS 3025 Part 5

Remarks: IS:10500:2012 Standard. As Per Sample Received & Test Performed Chemical & Bacteriological Analysis All Above mentioned results are non-complies.

Lab Incharge   Lab Chemist   Authorized Signatory

Note: 1) Results related to tested sample Only. 2) Test report should not be reproduced partially 3) mg per l is equivalent to ... request. Sample was tested for above mentioned parameters only. 5) Report is intended to be used for informational purpose only ... not be used for regulatory and/or legal purposes. 6) If water source as borewell water it's recommended to have RO treatment for drinking. 7) Samples will be disposed of 7 days after testing from the date of issue of the report,unless otherwise requested by the sender. 8) TNTC-Too Numerous to Count 9) BDL Below Detection Limit

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CIN NO U37003PN2023OPC226655

Report 2.1 : Filtered water

5.3 Our test report

Parameters	Muddy water	Filter water
PH	7.53	7.54
Turbidity	18.00 NTU	3.00 NTU
Total Hardness	245.00 Mg/l	224.00 Mg/l
Total Dissolved Solids (TDS)	430.00 Mg/l	431.00 Mg/l
Color	Yellowish- Brown	Fussy
Odour	Agreeable	Agreeable

5.4 Tap water test

Parameters	water
PH	7.2
Turbidity	1 NTU
Total Hardness	145 Mg/l
Total Dissolved Solids (TDS)	365 Mg/l
Color	Colorless
Odour	Aggreeable

We have used the bore well water so there is higher than limit and the conclusion is that the rainwater is near by the limits so with the help of the filter the rainwater can be drinkable.

6. Case Study of Pimpri Chinchwad Polytechnic

6.1 Area of the Building A

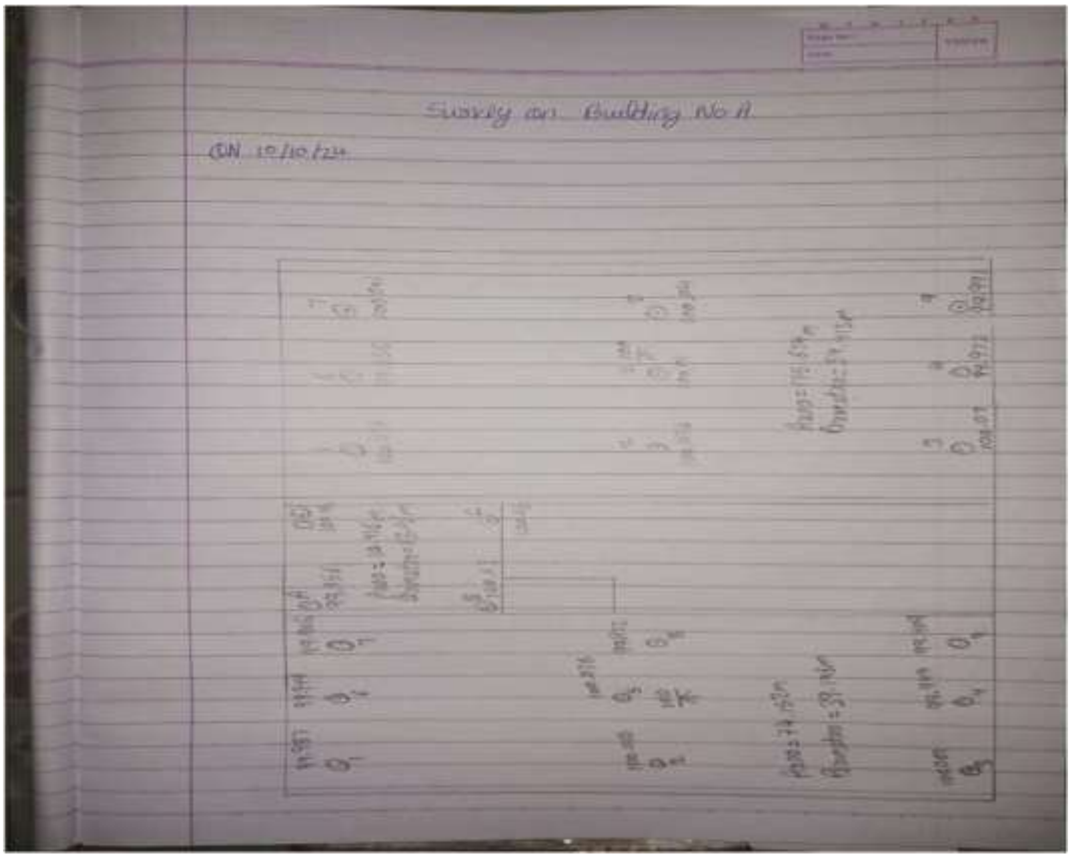

Image 3.1 : Area of A building

Total Area of the Roof :- 260.192m

Height of Building :- 27.8m

Distance from building to the tank :-10.5m

6.2 Area of the Building B

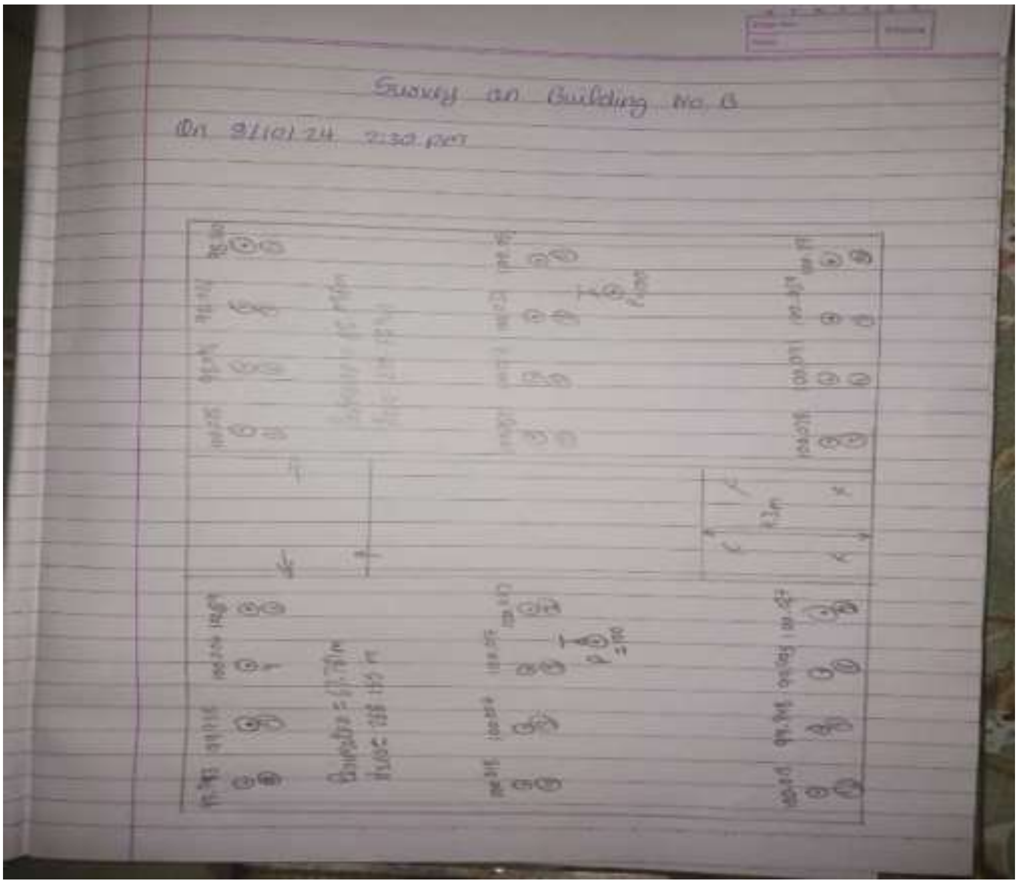

Image 4.1 : Area of B building

Total Area of the Roof :- 135.879m Height of Building :- 48.05m

Distance from building to the tank :- 10.5m

Image 5.1 : Area on Cad

Total length :- 27.8+40.05+10.5=85.90m M to feet = 1*3.28084

In feet =85.90*3.28084 = 281 feet

6.2.1 Material for Project

1. 4 inch pipe of 10 feet
2. T joint
3. Elbow

6.2.2 Pipe Required

1. 281/10 = 28 piece
2. inch pipe of 10 feet :- 28
3. T joint :- 3
4. Elbow :- 2

6.2.3 Estimate

1. Elbow=2*390=780/-
2. T joint=3*430=1290/-
3. Pipes=28*700=19600/-
4. Sand filter=13500/-
5. Installation Charges= 1000/- Total cost of the project =36170/-

7. Conclusion

Harvesting rainwater is essential to respond to fresh water scarcity, sustainability, and growing demands for fresh water. With affordable efficient methods of collecting rainwater on roofs, filtering, and recharging to the groundwater, communities can reduce dependence on freshwater supplies. [3] This study evaluates the viability of implementing a rainwater harvesting system with minimal equipment including a pipe, T-joint, elbows, and a user-built filtration system of coconut shells, coal, washed sand, cotton and scrub. The system improves water quality in turbidity and hardness as shown by the laboratory tests. With an approximate total cost of the project at Rs 36,170 and Rs 3,000 for the filtration system (replace every year), the system is a reasonable and cost- effective alternative to address water shortages. New techniques of purification technologies such as UV light and chemical treatments may assist to elevate rainwater to potable condition. [3] Governments and community members can raise recognition and help assist with rainwater harvesting as a method of water conservation. By using modern filtration methods and involving the public to participate, rainwater harvesting can become a part of the solution to water shortages and environmental sustainability.[6]

Future scope for using water as potable

As water failure and challenges due to climate change escalate encyclopedically, the unborn compass of using rainwater as drinkable water is more promising. Rainwater can be treated efficiently to meet norms of drinkable water with the advancement of filtration and sanctification technologies.[2] Urbanization, especially in regions that formerly suffer from water failure, can be possible through harvesting rainwater, and therefore reduce the need for a centralized water source. pastoral and off- grid areas can have a dependable and cost-effective water source with harvesting rainwater without complex distribution systems involved for achieving clean drinking water. [5] Governments are also encouraging rainwater harvesting by programs and regulations, which are farther pushing its growth. When people come more apprehensive of sustainable water operation, rainwater for drinkable use is anticipated to grow further for conserving water, dwindling environmental impacts, and getting more flexible to climate variability.

Ultraviolet (UV) Light Treatment

Ultraviolet (UV) light treatment is one of the most effective and recommended methods for purifying rainwater in harvesting systems. It helps make collected rainwater safe to drink. This method is popular because it works well, is easy to use, requires little maintenance, and doesn’t need any chemicals. That means you don’t have to deal with measuring, storing, or handling chemicals.

How Does UV Light Treatment Work?

A UV water treatment system uses a special light bulb that gives off ultraviolet rays—part of the light spectrum that we can’t see. When water passes through this light, any harmful microorganisms (like bacteria and viruses) are exposed to strong UV rays.

This process is called UV irradiation. The UV rays don’t kill the germs directly but stop them from reproducing. If they can’t reproduce, they can’t cause illness. So, while the pathogens are still there, they are no longer harmful.

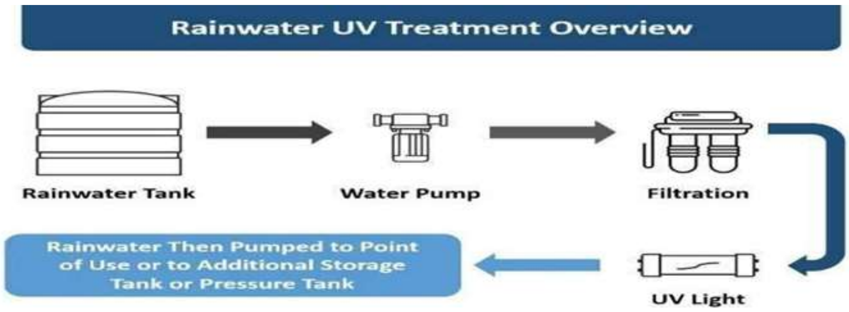

Figure 2.1 : UV treatment

Figure 3.1 : Chlorine

Chemical Treatment of Rainwater

1. Chemical treatment is a reliable and effective method to purify rainwater collected through harvesting systems. When done properly, it can make the water safe enough for drinking and other household uses. This method offers several unique benefits and is often considered a dependable way to ensure the water reaches a safe, potable (drinkable) quality.

Common Chemical Used in Rainwater Treatment

Chlorine is the most commonly used chemical to disinfect rainwater and make it safe to use. The process is called chlorination. In this method, chlorine acts as the main disinfectant that kills harmful germs and bacteria present in the water. It helps ensure the water is clean and safe for drinking or other household uses.

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