A Case Study of Rainwater Harvesting as a Solution to Drinking Water in Vadodara City

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Abstract Roof Top Rainwater collection is one of the solutions for solving or reducing the problem of water scarcity, where there is an inadequate groundwater supply and surface source water is either lacking or insignificant. Rainwater and snowmelt are thought to be the primary sources of all drinking water in the world. In Vadodara city, the average rainfall is around 900 mm, but due to impervious surfaces almost all water runs away in the river. If we promote Rainwater Harvesting Technique, it will not only mitigate the flood problem partially but also give drinkable water to the rainwater harvesting (RWH) - using family. This will increase the groundwater Water Table in the area as it decreases due to chaotic extraction of groundwater for drinking purposes. Drinking water is generally obtained from two sources: groundwater (wells, bore holes, etc.) and surface water (rivers, lakes, etc.). Thus, it is evident that there are considerable scope for the collection of rainwater when it falls. The potential of RWH and the urgency of mitigating water-scarcity-related problems are also confirmed by the fact that many researchers are working on these issues. RWH is a simple technique of collecting rainwater instantly making sure that it does not run off in to river or stream or does not become contaminated. Here in this paper, we have attempted to show case few cases executed in the Vadodara city where people are facing problem of low water table, nonavailability of water in few months of year, deteriorated quality of water (coloured and odour), and high cost of potable water. These case studies show that the rainwater harvesting technique is a sustainable long- term solution for solving the drinking water problem with comparison to other sources of water.

Keywords: rainwater harvesting (RWH), Water- scarcity, Ground water level, water quality, Flood control.

I Introduction

Water scarcity is a rapidly intensifying global challenge driven by population growth, urban expansion, agricultural intensification, and climate change. Traditional centralized water supply systems are increasingly unable to meet rising demand, while aquifer depletion and seasonal droughts exacerbate stress on existing freshwater resources. In response, decentralized and sustainable water supply alternatives such as rainwater harvesting (RWH) have garnered significant scientific and policy attention as resilient solutions to both water scarcity and stormwater management challenges [1, 2].

Roof- and pond- based systems remain the most widely studied and deployed configurations: reviews summarize decades of work on design components, storage sizing, yield estimation, and water- quality implications, while also documenting innovations such as integration with Sustainable Urban Drainage Systems (SUDS) and combined groundwater recharge strategies. These analyses report consistent evidence that, when properly sized and managed, rooftop harvesting can meet significant fractions of domestic and irrigation demand and can contribute meaningfully to urban water neutrality under supportive institutional settings [3, 4].

At the same time, systematic reviews and field studies point to persistent barriers: variability in rainfall and storage needs, contaminant management for potable reuse, inconsistent performance data, and gaps in policy/institutional support and community engagement that limit adoption and long-term operation. Several comprehensive literature syntheses call for integrated assessment frameworks that jointly evaluate water savings, public- health risks, economic viability, and co- benefits such as reduced stormwater loads and groundwater recharge [5].

Growing population, rapid urbanization [6], and climate change are intensifying freshwater scarcity in many regions worldwide, forcing researchers and planners to revisit decentralized alternatives for resilient water supply. Rainwater harvesting (RWH) — the capture, storage and use of rainfall at- site- has emerged as a promising multi- benefit solution: it supplements potable and non- potable demand, reduces stormwater runoff and urban flooding, and can recharge depleted aquifers when properly implemented. Recent literature highlights both the technical potential and the social- institutional barriers to wide adoption, indicating that RWH is no longer only a rural or emergency measure but a viable component of integrated urban water management [7].

Extensive reviews and bibliometric studies have synthesized decades of RWH research across engineering, environmental science and policy. Campisano et al. provide a broad synthesis of practical, theoretical and social aspects of urban RWH systems, stressing the need to evaluate multi- purpose performance (water savings, storm- water mitigation and energy impacts) rather than single metrics in isolation. At the same time, work on the life- cycle energy and environmental implications — for example analyses of the energy intensity of RWH systems — shows that design choices (treatment, pumping, storage sizing) affect net sustainability and must be considered in techno- economic assessments [8].

Rainwater harvesting—defined as the process of collecting, conveying, storing, and utilizing rainfall from rooftops or other catchment areas—constitutes one of the earliest known techniques for water supply in human history, with evidence found in hydrological records that date back thousands of years. The modern adaptation of this practice aims not only to increase water availability but also to lessen the burden on overexploited surface and groundwater sources, mitigate urban flooding, and aid in climate adaptation strategies in areas experiencing water stress. The core principles and technological aspects of RWH systems have been extensively documented in foundational literature and technical analyses, establishing the engineering and hydrological principles that underpin contemporary research [9].

Comprehensive critical reviews have also emphasized the multifunctionality of RWH systems, noting that their performance depends on spatial variability in rainfall, demand patterns, system sizing, and institutional support mechanisms. Such work highlights barriers to implementation—which include modeling limitations, regulatory weaknesses, and community acceptance issues—as well as emerging opportunities to contribute to global sustainable development agendas (e.g., water security, sustainable cities, and climate resilience) [10].

Technical evaluations of RWH performance at building and urban scales have also appeared in the literature. These studies commonly assess water saving, reliability under variable rainfall regimes, and stormwater capture efficiencies, while accounting for climate variability and future long- term performance under changing precipitation patterns [11]. Numerous research avenues have investigated the dynamics of water quality and the factors influencing public acceptance, highlighting that harvested rainwater can be appropriate for non- potable applications and, with suitable treatment, for potable uses. Furthermore, user perceptions play a crucial role in shaping adoption trajectories [12].

Monsoon rainfall is mostly wasted through drains, while groundwater levels fall due to cemented surfaces and overuse of wells. Rainwater harvesting is a simple and cost- effective method to store rainwater and recharge groundwater for future domestic and agricultural needs [13].

Water scarcity is a pressing challenge in India, driven by seasonal rainfall variability, rapid urbanization [14], and intensive groundwater abstraction. During the monsoon large volumes of runoff are lost to drains instead of being captured and used or allowed to percolate to recharge aquifers; simultaneously, expanding impervious surfaces and rising demand have accelerated the decline of shallow wells and increased reliance on deep borewells. Indian studies have repeatedly highlighted that localized rainwater harvesting (RWH) and artificial recharge remain among the most practicable, low- cost measures to improve water security and reduce vulnerability to drought [15].

Recent Indian modelling and case studies have begun to close some of these gaps by combining field measurements with hydrological models to quantify how RWH changes flow, recharge and storage dynamics under current and future climates. Technical evaluations by practitioners (including regional ICAR and state watershed programs) demonstrate that carefully designed RWH and recharge systems can raise local groundwater levels and increase resilience of rain- fed agriculture, though the magnitude and spatial extent of benefits vary widely [16, 17].

Frequent flooding in Vadodara city is a consequence of evolving rainfall patterns and the encroachment of natural waterways resulting from urbanization. The Vishwamitri River, in conjunction with the upstream Ajwa dam, serves a crucial function, especially during periods of heavy rainfall when surplus water is released and the reservoir reaches its capacity. The encroachments along the riverbanks have markedly diminished the river's discharge capability, leading to flooding in lower- lying regions. Furthermore, waterlogging is widespread as a result of the blockage of stormwater drainage systems, which encompass ponds and lakes. This study utilizes GIS mapping to analyze the encroachments and their repercussions on significant flood events [18].

The improper open dumping of municipal solid waste [19] and chemical waste from industries [20] leads to the generation of leachate, which can contaminate both groundwater and surface water. This study investigated leachate from the Vadodara landfill and groundwater samples obtained from locations both near and far from the landfill. The results indicated that groundwater in and around the landfill was polluted, showing elevated levels of TDS, hardness, chloride, fluoride, sodium, and ammonia that exceeded safe drinking thresholds. Additionally, heavy metals such as cadmium (Cd), chromium (Cr), and lead (Pb) were found to be above the BIS drinking water standards. This research emphasizes the urgent requirement for improved waste management practices to ensure the protection of public health and the environment.

Bibliometric mapping of this field indicates a rapid increase in publications and highlights key areas such as urban stormwater harvesting, green- roof integrated systems, and water- energy analyses — indicating where future research efforts are likely to be focused. Case studies, such as multi- city reliability and economic evaluations, illustrate that well- structured RWH systems can greatly diminish mains demand and offer substantial supply augmentation in variable climatic conditions, while also emphasizing the necessity for localized sizing and cost- benefit analysis frameworks.

II Experimental Methods

Vadodara is a major industrial city in Gujarat, India. The city lies in the fertile region between the Narmada and Mahi rivers, along the banks of the Vishwamitri River, at $22°17'59''$ N latitude and $73°15'18''$ E longitude. The terrain of Vadodara is mostly flat, in line with the Vishwamitri river basin. The Vishwamitri River, passes through the center of the city and divides it into two parts. The city is also home to several attractive lakes that contribute to the Vishwamitri catchment area. Another tributary, the Jambuva River, flows along the southern edge of Vadodara and joins the Vishwamitri River. The Vishwamitri extends approximately 27km within the VUDA boundary and around 16.5km within the VMC boundary. The river's width ranges from about 60m to 130m, while its depth is roughly $8 - 10$m. The general elevation of the city varies between 20m and 40m above mean sea level. Vadodara receives an average yearly rainfall of nearly 900mm, mainly during the monsoon season from June to September. During the rule of Maharaja Sayajirao Gaekwad III, a well- planned storm water drainage system was established. However, after 1960, rapid industrial expansion and inadequate urban planning resulted in irregular growth and encroachment on natural drainage systems such as rivers, ponds, and lakes. Construction of residential areas in the Vishwamitri floodplain has also contributed to increased flooding concerns [18].

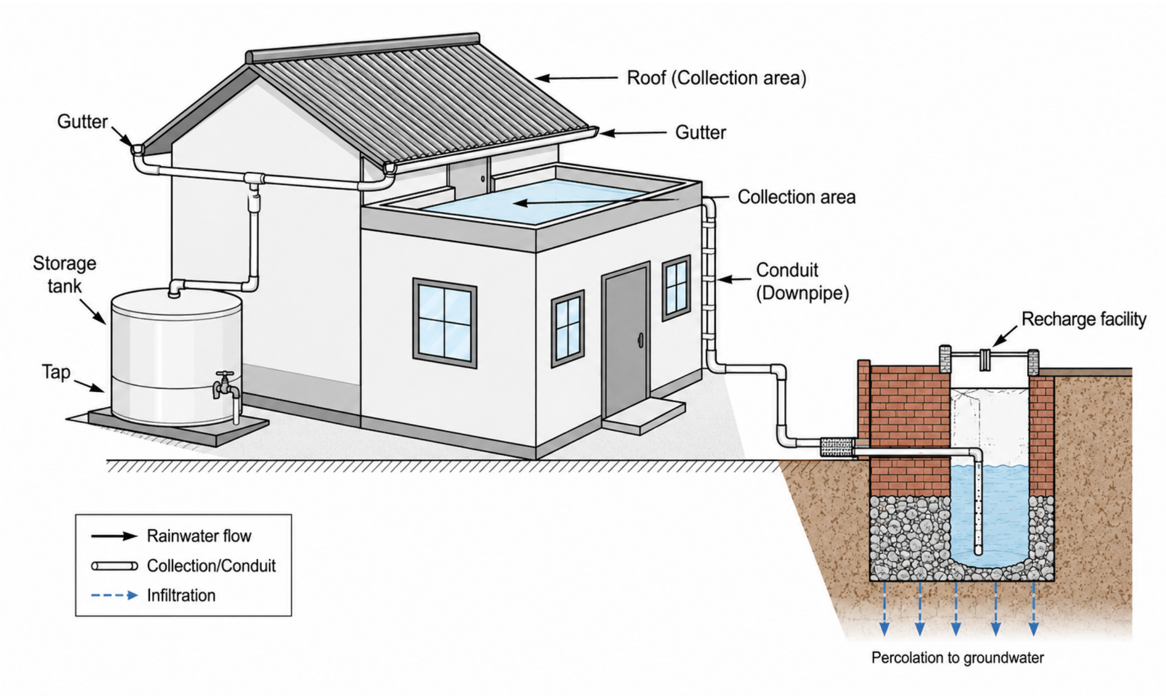


Figure 1: Typical rainwater harvesting system either a storage tank or a recharge [21]

After conducting the survey, several issues related to borewells were identified, like visual issues such as: borewells drying up during the summer season, red or yellow coloured water, bad odour in the water, rainwater logging within premises and some issues such as chemical contamination [19, 20] such as pH, TDS (Total Dissolved Solids), total hardness as $CaCO_3$, Alkalinity, Ammonical Nitrogen Sulphate as SO_4, etc, in the water and unpotable (unsafe) water after laboratory test of borewells water. Efforts were made to convince citizens about the importance of rainwater harvesting will be the permanent solution for above problem. The typical rain water harvesting (Figure 1) system is oldest, time consuming and costlier process. With the advancement of technology over time, modern rainwater harvesting systems (Figure 2) have been developed using compact and efficient devices. This device is easy to install and easy to maintain with very low running cost and electricity free and affordable by any common people.

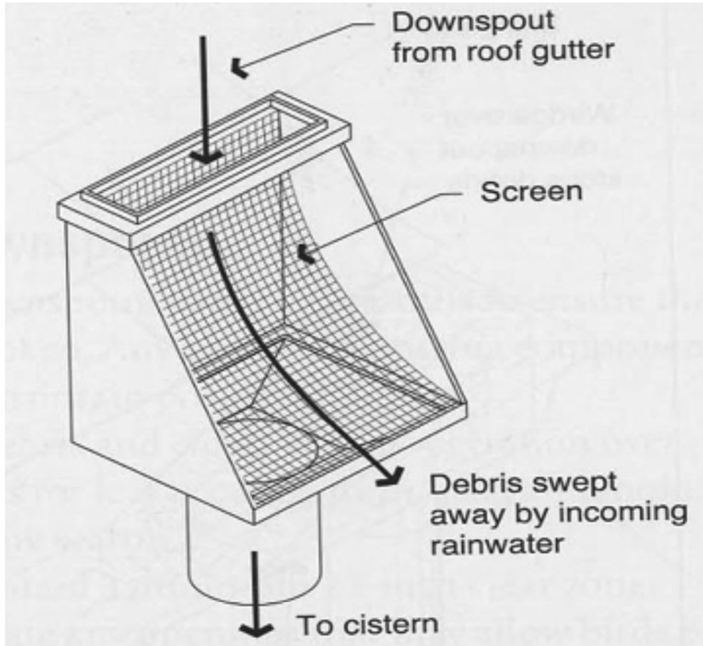


Figure 2: Modern Rain Water Harvesting System

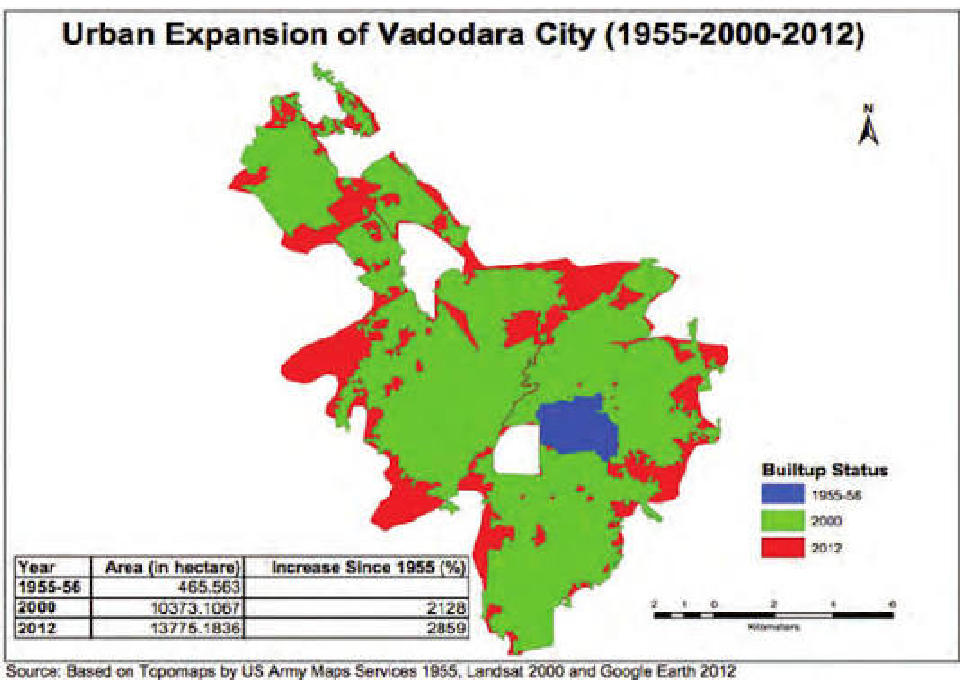
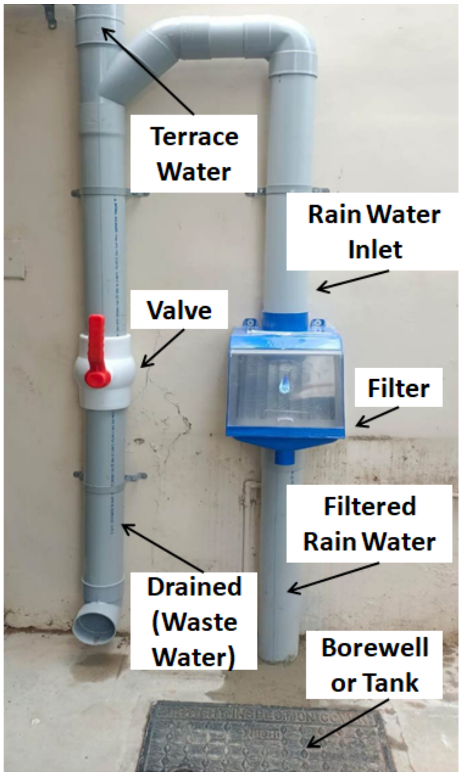


Figure 3: Urban Expansion of Vadodara City [6]

These Rainwater Harvesting systems (RWH) were installed at many houses (Figure 4a), flats (Figure 4b), industries, schools, and hospitals. Before installing RWH, the sample of water collected from different borewells were tested in laboratories. After successful installation and recharge of RWH throughout the monsoon season, borewell water samples were tested in the laboratory after monsoon season for comparison.



(a) Actual RWH system installed in a house

(b) Actual RWH system installed in a flat

Figure 4: Installed rooftop rainwater harvesting (RWH) systems in different residential buildings: (a) individual house and (b) apartment/flat.

III Results and Discussion

1. **Mitigating Water Scarcity:** Water scarcity represents a significant challenge encountered in numerous areas, primarily due to inconsistent rainfall patterns, excessive groundwater extraction, and a growing population. The practice of rainwater harvesting facilitates the collection and storage of rainwater, which can subsequently be utilized for household purposes, agricultural irrigation, and various other requirements. Utilizing harvested rainwater diminishes reliance on municipal water systems and groundwater sources, thereby contributing to the alleviation of water shortage problems, particularly during the summer months.

2. **Flood Control:** The practice of rainwater harvesting significantly contributes to mitigating flooding. In instances of heavy rainfall, substantial volumes of water accumulate on roadways and open areas, leading to waterlogging and flooding. By implementing rooftop harvesting systems, recharge pits, and percolation tanks to collect rainwater, the runoff is considerably diminished. When individuals and communities engage in rainwater harvesting collectively, the strain on drainage systems is alleviated, thereby enhancing the effectiveness of flood control.

3. **Revival of Tubewells / Borewells:** In numerous regions, borewells and tubewells become dry in winter or summer due to a decline in groundwater levels. The practice of rainwater harvesting contributes to the replenishment of groundwater by facilitating the infiltration of rainwater into

the soil via recharge pits and recharge wells. Consequently, groundwater levels increase following the monsoon season, leading to the reactivation of previously dried borewells. This enhances the long-term viability of groundwater resources.

4. **Enhancement of Borewell Water Quality:** In certain areas, the quality of borewell water may be compromised due to factors such as salinity, hardness, or contamination. The practice of rainwater harvesting enhances groundwater quality by diluting the polluted water present and replenishing the aquifers with fresh rainwater [22]. Ongoing recharge via rainwater harvesting can progressively diminish the levels of harmful minerals, thereby improving the taste and usability of borewell water.

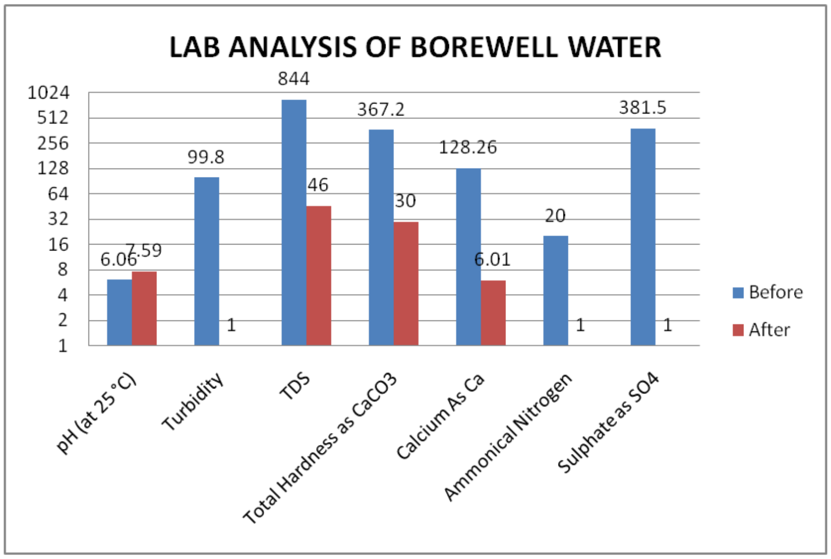


Figure 5: Lab analysis of Borewells (Before RWH & after RWH)

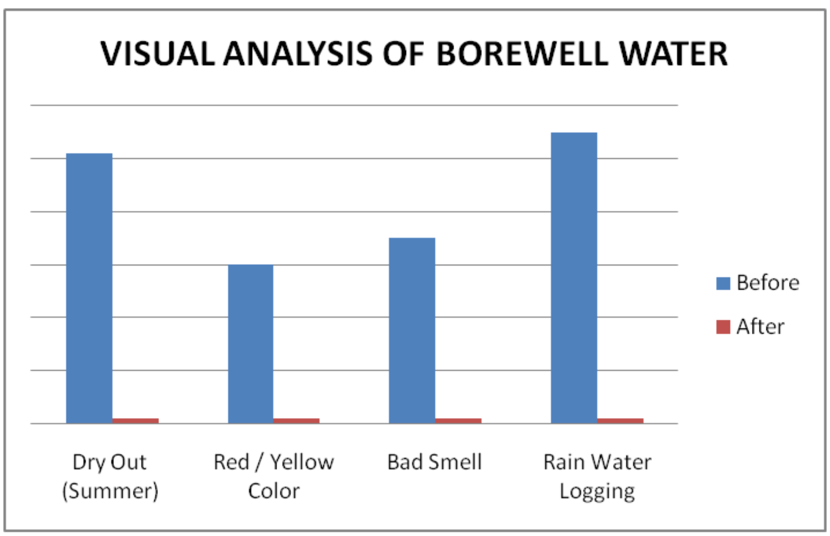


Figure 6: Visual analysis of Borewells (Before RWH & after RWH)

5. **Dedicated Rainwater Storage Tank:** Building an independent rainwater storage tank offers

significant advantages, particularly for potable and domestic purposes. The rainwater collected is typically clean and devoid of numerous contaminants present in groundwater. With the installation of adequate filtration systems, the harvested rainwater can yield high- quality drinking water year- round. Additionally, this practice guarantees water accessibility during emergencies, arid periods, and instances when the municipal water supply is inconsistent.

IV Conclusion

Rooftop rainwater harvesting serves as an efficient and sustainable strategy to confront the rising challenges associated with water scarcity and management. With a growing population, swift urban development, and unpredictable rainfall trends, the need for freshwater resources is perpetually increasing, while groundwater supplies are diminishing at a troubling rate. Under these circumstances, rooftop rainwater harvesting presents a feasible solution to gather and utilize rainwater that would otherwise be wasted as surface runoff.

This method is crucial in alleviating water scarcity by capturing rainwater and reserving it for household use, gardening, and various other applications. Additionally, it aids in replenishing groundwater via recharge pits and percolation systems, which subsequently elevates the groundwater table. As the levels of groundwater rise, borewells and tubewells that typically run dry in the summer may regain functionality following the monsoon season. Furthermore, rainwater harvesting enhances groundwater quality by diluting detrimental salts and pollutants, leading to cleaner and safer water for everyday consumption.

In addition to addressing water- related challenges, rooftop rainwater harvesting aids in flood mitigation by lessening stormwater runoff during periods of intense rainfall. This reduction alleviates waterlogging in urban environments and diminishes the strain on drainage systems, thereby helping to mitigate flooding issues. Overall, rooftop rainwater harvesting represents an environmentally friendly, economically viable, and sustainable strategy that fosters water conservation and guarantees the availability of water resources. Consequently, the implementation of rooftop rainwater harvesting at both individual and community levels is crucial for safeguarding natural water resources and ensuring a secure and healthy future for future generations.

Acknowledgement

We would like to acknowledge the residents of Vadodara who have shown their trust in us, facilitating the establishment of the Rainwater Harvesting system on their premises. This initiative not only motivates other residents but also boosts the availability of groundwater for all citizens of Vadodara, without regard to any religious, caste, or community boundaries. I would like to convey my sincere appreciation to Vedansh Envirotech, Vadodara for their significant support and assistance throughout these projects. Their help during the installation phase and their continuous guidance have made this achievement possible. I am truly grateful for their time, effort, and encouragement.

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