

# Integrating mosquito control and drinking water quality standards (DWQS) in urban rainwater harvesting systems

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**Abstract.** This study investigates the integration of advanced rainwater harvesting systems in urban residential buildings, focusing on their effectiveness in meeting Drinking Water Quality Standards (DWQS) and implementing effective mosquito control measures. As global challenges such as water scarcity and climate change intensify, sustainable water management practices have become critical. Rainwater harvesting, a time-tested approach, is increasingly recognized for its potential to reduce reliance on municipal water supplies and enhance the resilience of urban environments. The research addresses significant gaps in the current literature by evaluating a comprehensive system that not only harvests and filters rainwater for potable use but also manages grey water for non-potable applications. Through simulation and laboratory testing, the study assesses the system's ability to meet DWQS while preventing mosquito breeding, which is vital for public health, particularly in regions prone to vector-borne diseases. The results indicate that the system is highly effective in maintaining water quality and controlling mosquito populations. The water collected consistently met DWQS, and no mosquito larvae were detected in the final storage tanks. These findings highlight the system's suitability for integration into urban residential designs, supporting both sustainability and public health objectives.

## 1 Introduction

Water scarcity and the increasing demand for freshwater resources are among the most pressing global challenges of the 21<sup>st</sup> century. According to the United Nations, nearly two billion people live in areas experiencing water stress, a situation that is projected to worsen with the impacts of climate change. As urbanization intensifies and populations grow, the

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strain on existing water resources escalates, necessitating innovative and sustainable water management solutions [1], [2].

Rainwater harvesting, the practice of collecting and storing rainwater for future use, presents a promising solution to these challenges. Traditionally, rainwater harvesting systems have been implemented primarily in rural and agricultural settings, focusing on basic water collection and storage. However, with advancements in technology, there is growing interest in adapting these systems for urban environments and integrating them into green building designs. This approach not only reduces dependence on municipal water supplies but also supports the sustainability of urban water systems [3], [4].

Despite the potential of rainwater harvesting, significant gaps remain in the research and application of these systems, particularly in urban and residential contexts. Most existing studies have focused on the basic feasibility of rainwater harvesting and its impact on water conservation. However, less attention has been given to the comprehensive evaluation of modern rainwater harvesting systems that incorporate advanced filtration technologies, grey water reuse, and mosquito control measures—especially in densely populated urban areas [1], [5].

Moreover, while rainwater harvesting is increasingly recognized as a key component of green architecture and climate adaptation strategies, there is a lack of detailed analysis on its integration into residential buildings in various climatic conditions. Specifically, the effectiveness of these systems in providing potable water, managing grey water for non-potable uses, and controlling mosquito populations has not been extensively studied. This gap is particularly critical given the rising concern over waterborne diseases and the need for climate-resilient infrastructure [3], [4].

This study seeks to address these research gaps by developing and evaluating a rainwater harvesting system tailored for residential use, with a focus on its ability to meet drinking water standards, efficiently manage grey water, and implement effective mosquito control. The system's performance is assessed through simulation and laboratory testing, offering insights into its scalability, potential for replication, and relevance to both urban and rural settings. By bridging the existing gaps in research, this study aims to contribute to the broader understanding of sustainable water management practices and their role in mitigating the effects of climate change.

## 2 Rain water harvesting design

In designing a rainwater harvesting system, it is crucial to ensure that the system not only effectively collects rainwater but also prevents mosquito breeding and meets Drinking Water Quality Standards (DWQS). To achieve these objectives, various filtration components must be integrated into the system. The table below presents the key components necessary for mosquito control and water purification.

**Table 1.** Filtration (key component) specification

Filtration Component	Specification
Primary Screen	304 SS mesh, 0.5 mm pore size
First Flush Diverter	PVC/HDPE, auto-flush, 2 mm diversion
Sediment Filter	Polypropylene, 5-micron rating
Activated Carbon Filter	Carbon block, 1-micron rating
RO Membrane	TFC, 0.0001-micron rating

These components work together to ensure that the harvested rainwater is safe from contamination and health risks posed by mosquitoes [5], [6]. The primary screen and first flush diverter serve as initial barriers, preventing insects and large debris from entering the system, thus reducing potential mosquito breeding grounds. The sediment and activated carbon filters further refine the water by removing smaller particles and organic compounds before the water passes through the RO membrane [7], which filters out dissolved solids and pathogens, ensuring the water meets DWQS [8].

**Table 2.** Filtration components (supplementary) specification

Filtration Component	Specification
Post-Carbon Filter	Inline carbon, final polish
UV Sterilizer	Quartz UV lamp, disinfection
Storage Tank	Air-tight, food-grade, 5-10 gallons
Monitoring System	TDS meter, pressure gauge
Booster Pump	60-100 psi rating

These supplementary components ensure that the filtered water remains safe until it is consumed. The post-carbon filter improves the taste of the water and removes any remaining contaminants. The UV sterilizer adds an extra layer of protection by deactivating any residual microorganisms. The air-tight storage tank prevents recontamination, while the monitoring system and booster pump ensure the system operates at maximum efficiency. Together, these elements create a reliable rainwater harvesting system that is free from mosquito threats and meets drinking water quality standards.

To optimize the rainwater harvesting system and ensure it meets the desired performance metrics, the following modeling equations are utilized [9]. These equations are designed to calculate water flow, filtration efficiency, and system capacity to ensure optimal operation while maintaining mosquito control and adherence to DWQS [1,2], [10]. The water collection rate is determined by the amount of rainfall captured over a specific catchment area, accounting for runoff efficiency:

$$WCR = P \times A \times C \quad (1)$$

Where:

WCR = Water Collection Rate (m<sup>3</sup>/day)

P = Precipitation (m/day)

A = Catchment area (m<sup>2</sup>)

C = Runoff coefficient (dimensionless)

The filtration efficiency is calculated as the percentage reduction in contaminant concentration after filtration:

$$FE = (1 - (C_{out} / C_{in})) \times 100 \quad (2)$$

Where:

FE = Filtration Efficiency (%)

C<sub>out</sub> = Contaminant concentration after filtration (mg/L)

C<sub>in</sub> = Contaminant concentration before filtration (mg/L)

The size of the storage tank is calculated based on the water collection rate, the number of dry days, and the system's efficiency:

$$STS = (WCR \times D) / E \quad (3)$$

Where:

STS = Storage Tank Size (m<sup>3</sup>)

WCR = Water Collection Rate (m<sup>3</sup>/day)

D = Number of dry days (days)

E = System efficiency (dimensionless)

Effective management of a rainwater harvesting system that divides collected water into drinking water (DWQS Tank) and grey water requires a robust control strategy. This strategy is essential to ensure that water is directed to the appropriate storage based on its quality, optimizing the use of available resources while maintaining safety standards. The control strategy relies on mathematical modeling to manage the flow rates, filtration efficiency, and overall distribution between the two tanks.

The key equations that govern the flow and distribution of water between the DWQS Tank and Grey Water Tank are as follows:

$$Q_{DWQS} = (V_{Total} \times E_{Filtration}) / T_{Total} \quad (4)$$

Where:

Q<sub>DWQS</sub> = Flow rate to DWQS Tank (m<sup>3</sup>/day)

V<sub>Total</sub> = Total volume of water collected (m<sup>3</sup>)

E<sub>Filtration</sub> = Filtration efficiency (dimensionless)

T<sub>Total</sub> = Total time for water collection (days)

Equation 1 calculates the flow rate of water that meets the Drinking Water Quality Standards (DWQS) and is directed to the DWQS Tank. This equation takes into account the total volume of water collected, the efficiency of the filtration system, and the duration of the collection period.

$$Q_{Greywater} = V_{Total} - Q_{DWQS} \quad (5)$$

Where:

Q<sub>Greywater</sub> = Flow rate to Grey Water Tank (m<sup>3</sup>/day)

Equation 2 determines the amount of water that does not meet the DWQS and is therefore directed to the Grey Water Tank. This is the residual volume after the DWQS Tank has been allocated its share.

The control strategy relies on real-time monitoring of water quality parameters, with sensors feeding data into the system that governs these flow equations. By dynamically adjusting E<sub>Filtration</sub>, the system can optimize how much water is stored as potable versus grey water, ensuring that resources are utilized effectively while maintaining safety and regulatory compliance.

### 3 Result

The following table presents the results of a simulation for a house with a surface area of 120 square meters. The simulation assumes a precipitation rate, filtration efficiency, and a collection period to estimate the water distribution between the DWQS Tank and Grey Water Tank.

**Table 3** Key stages of implementation

Parameter	Value
Total Volume Collected ( $V_{Total}$ )	$V_{Total} = A \times P \times T_{Total} = 120 \text{ m}^2 \times 0.01 \text{ m/day} \times 30 \text{ days} = 36 \text{ m}^3$
Flow to DWQS Tank ( $Q_{DWQS}$ )	$Q_{DWQS} = (V_{Total} \times E_{Filtration}) / T_{Total} = (36 \text{ m}^3 \times 0.85) / 30 \text{ days} = 1.02 \text{ m}^3/\text{day}$
Flow to Grey Water Tank ( $Q_{Greywater}$ )	$Q_{Greywater} = V_{Total} - Q_{DWQS} = 36 \text{ m}^3 - (1.02 \text{ m}^3/\text{day} \times 30 \text{ days}) = 4.4 \text{ m}^3$

To assess the effectiveness of the mosquito control measures implemented in the rainwater harvesting system, water samples were collected from various points within the system and tested in a laboratory. The focus was on detecting the presence of mosquito larvae and assessing water quality parameters that could contribute to mosquito breeding.

**Table 4** Observation the presence of mosquito larvae

Parameter	Inlet	After First Flush Diverter	DWQS Tank	Grey Water Tank
Mosquito Larvae Presence	Detected	None	None	None
Turbidity (NTU)	12.5	5.2	0.8	2.4
Organic Matter (BOD in mg/L)	18.2	8.7	1.2	5.8
pH Level	6.8	7.0	7.2	7.1

Mosquito larvae were observed at the inlet before the primary screen, but none were detected after the first flush diverter or within either the DWQS Tank or Grey Water Tank. These results suggest that the mosquito control measures implemented in the system are highly effective in preventing larvae from entering and proliferating in the stored water. Additionally, the turbidity of the water decreased significantly after passing through the first flush diverter and was further reduced within the DWQS Tank. This reduction in turbidity indicates that the filtration system effectively removes particles that could contribute to mosquito breeding [2,4]. The amount of organic matter, measured by Biological Oxygen Demand (BOD), was also significantly lower in the DWQS Tank, which suggests that the system successfully reduces the potential nutrients that could support the growth of mosquito larvae. The pH levels across all samples remained within a neutral range, indicating that the water environment is less likely to support mosquito breeding. These findings collectively demonstrate the effectiveness of the rainwater harvesting system's design in controlling mosquito populations and maintaining water quality.

## 4 Discussion

The simulation results, which detail the performance of the rainwater harvesting system in a household setting with a 120-square-meter roof area, offer valuable insights into its effectiveness, technical capabilities, and broader implications for sustainable development, particularly in the context of green architecture and climate adaptation.

The Total Volume Collected ( $V_{Total}$ ) of 36 cubic meters over a 30-day period, derived from a precipitation rate of 10 mm/day, underscores the system's capability to harvest significant volumes of water even under moderate rainfall conditions. This is particularly notable when considering areas that experience seasonal rainfall or those facing increasingly unpredictable weather patterns due to climate change. The ability to capture and store water

on-site aligns with the principles of green architecture, where the integration of sustainable water management systems into building designs is crucial for reducing reliance on external water supplies.

The Flow to the DWQS Tank (Q\_DWQS), calculated at 1.02 cubic meters per day, reflects the system's high filtration efficiency of 85%. This figure is indicative of the system's robust capacity to produce potable water that meets drinking water quality standards [10], even from rainwater sources that may initially contain various impurities. This level of filtration efficiency is essential for ensuring safe drinking water in areas with limited access to clean water supplies, making this system particularly valuable in rural or underserved urban environments [11].

From a technical perspective, the system's ability to consistently achieve high filtration efficiency highlights its potential for integration into green building designs. The use of advanced filtration technologies, such as reverse osmosis and UV sterilization, not only ensures water quality but also contributes to the overall sustainability of the building by reducing its environmental footprint [12]. In the context of green architecture, this system supports the concept of decentralized water management, where buildings are designed to be more self-sufficient in their water needs, reducing the demand on municipal water systems and decreasing the energy required for water treatment and distribution.

The Flow to the Grey Water Tank (Q\_Greywater), which totals 4.4 cubic meters over the 30-day period, represents the portion of collected water that does not meet the stringent requirements for potable use but is still suitable for non-potable applications. This dual-use approach not only maximizes the utility of the collected rainwater but also aligns with sustainable water management practices by reducing the demand for treated water for activities such as irrigation, toilet flushing, and other household uses.

The grey water generated by this system can be seamlessly integrated into green architecture designs, where water conservation is a key objective [13]. By incorporating grey water systems into buildings, architects and engineers can reduce the overall water consumption of the structure, thereby enhancing its sustainability credentials. This is particularly relevant in regions facing water scarcity, where the reuse of grey water can significantly decrease the strain on local water resources [12, 13-15]

Moreover, the ability to harvest and utilize grey water supports broader climate adaptation strategies. As climate change leads to more frequent and severe droughts, the capacity to effectively manage and recycle water within buildings becomes increasingly important. By reducing the reliance on external water sources, this system contributes to the resilience of buildings and communities, helping them to better withstand the impacts of climate variability.

The results from the laboratory tests demonstrate the effectiveness of the rainwater harvesting system in both maintaining water quality and controlling mosquito populations, which are critical for preventing vector-borne diseases [13]. The absence of mosquito larvae in the water stored in both the DWQS Tank and the Grey Water Tank indicates that the integrated mosquito control measures—such as the primary screen, first flush diverter, and airtight tank design—are highly effective. This outcome is particularly important in regions prone to mosquito-borne diseases like malaria and dengue fever, suggesting that the system could be replicated in similar environments with high disease prevalence.

The significant reduction in turbidity and organic matter content in the DWQS Tank highlights the effectiveness of the filtration system in ensuring that the water meets drinking water quality standards. The low turbidity levels indicate that the water is clear and free from particles that could harbor pathogens or contribute to the formation of biofilms, which are known to support mosquito larvae development. Additionally, the reduction in organic matter, as evidenced by the lower BOD levels, suggests that the water is less likely to provide

the nutrients necessary for mosquito breeding [13]. These findings underscore the system's suitability for areas where maintaining high water quality is critical.

Furthermore, the consistent pH levels across all samples, remaining within a neutral range, indicate that the water is chemically stable and less likely to support the acidic or alkaline conditions that some mosquito species prefer for breeding. This chemical stability is particularly advantageous in regions with variable water sources or where rainwater may be slightly acidic due to environmental factors.

The implications of these findings are significant for climate adaptation and mitigation efforts. As climate change continues to influence weather patterns and increase the frequency of extreme weather events, the need for resilient water management systems becomes more pressing. This rainwater harvesting system, with its dual focus on water quality and mosquito control, offers a sustainable solution that can be adapted to a wide range of environments. Its ability to provide a reliable source of clean water while simultaneously reducing the risk of mosquito-borne diseases makes it an ideal candidate for implementation in both urban and rural settings, particularly in areas experiencing water scarcity or facing public health challenges related to climate change [3, 9, 12].

Moreover, the system's scalability and relatively low cost make it suitable for replication in developing regions where resources for large-scale water infrastructure are limited. By integrating this system into existing community frameworks, it can contribute to local resilience against climate-induced water shortages and health crises. The potential for this system to be part of broader climate mitigation strategies is also worth noting, as it can reduce reliance on groundwater and other stressed water sources, thereby promoting sustainable water use.

## 5 Conclusion

The rainwater harvesting system examined in this study demonstrates significant potential as a sustainable and effective solution for water management in both residential and commercial settings. The system's ability to efficiently collect and filter rainwater, ensuring that a substantial portion meets Drinking Water Quality Standards (DWQS), underscores its suitability for areas with limited access to clean water. Additionally, the allocation of non-potable water to a grey water tank for reuse in activities such as irrigation and flushing toilets reflects the system's alignment with best practices in water conservation and sustainability.

The simulation results highlight the system's effectiveness, with a total volume of 36 cubic meters of water collected over a 30-day period, of which 1.02 cubic meters per day was directed to the DWQS Tank. The remaining 4.4 cubic meters was appropriately allocated to the Grey Water Tank, showcasing the system's ability to maximize the utility of available water resources. The successful control of mosquito larvae through the use of advanced filtration and storage solutions further demonstrates the system's capacity to contribute to public health, particularly in regions prone to vector-borne diseases.

In the context of green architecture, this rainwater harvesting system offers a scalable and adaptable solution that can be integrated into a wide range of building designs. Its potential for replication in both urban and rural environments makes it a valuable tool for promoting sustainable water management practices and enhancing the resilience of communities to climate change. Furthermore, by reducing the demand for externally supplied water and minimizing the environmental footprint of buildings, the system contributes to broader climate mitigation efforts.

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