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Innovative Rainwater Collection System for Alternative Home Water Supply

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Abstract

This project introduces an innovative rainwater harvesting system designed to provide a sustainable alternative water supply for residential applications. By addressing challenges of water scarcity and urbanization, the proposed system incorporates dual storage tanks, efficient filtration, and an automatic irrigation mechanism. One tank serves indoor applications, such as washing machines and kitchen sinks, while the other supports outdoor uses like car washing and plant watering. The system features multi-layer filtration to ensure water quality, removing impurities, sediments, and odors. Testing includes water collection efficiency, filtration performance, and water quality evaluation based on pH, ammonia nitrogen, turbidity, and suspended solids standards. Results showed improvements in pH, turbidity, and suspended solids across filtered samples, with Filter 2 demonstrating superior flow rate and water clarity, making it a practical option for real-world applications. Although some inconsistencies were observed in ammonia nitrogen testing, the results were generally favorable for non-potable applications such as irrigation. Additionally, the automatic irrigation system promotes efficient water use, minimizing waste while maintaining plant health. This project contributes to sustainable water management by optimizing rainwater use and reducing reliance on traditional water sources, aligning with global efforts to combat water scarcity and promote environmental sustainability.

1. Introduction

Water is a crucial resource for human sustainability, especially in countries like Malaysia that experience varying rainfall patterns throughout the year. As an equatorial country, Malaysia is characterized by a tropical climate, leading to high annual rainfall and seasonal water scarcity, particularly during the dry season. The rapid urbanization and growing population have intensified the demand for clean water, thus increasing pressure on treated water sources [1]. In response, rainwater harvesting (RWH) has emerged as a practical and sustainable solution for alternative water supply systems in residential areas.

Rainwater harvesting involves collecting, storing, and utilizing rainwater for non-potable purposes such as washing, irrigation, and flushing. The conventional RWH systems vary from simple barrels to complex systems integrating multiple filtration stages and automation. By utilizing rooftop surfaces and filtration units, these

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systems can significantly reduce the dependency on municipal water supply and contribute to water conservation efforts [2].

Despite its advantages, several issues remain in ensuring the quality and usability of harvested rainwater. Rainwater may contain contaminants such as dust, animal droppings, and dissolved gases, which necessitate a proper multi-stage filtration process before use. Past studies have indicated the effectiveness of using layered media filters, such as gravel, sand, activated carbon, and cotton, in improving water quality by reducing turbidity, ammonia nitrogen levels, and suspended solids [3].

Besides storage and filtration, integrating smart irrigation systems is essential to maximize the benefits of rainwater usage in household gardening. Automatic irrigation systems equipped with moisture sensors and timers ensure water is delivered efficiently to plants without wastage. These systems also enhance plant growth while reducing labor and water consumption [4].

This study proposes the development of an innovative rainwater collection system designed for residential applications. It combines dual storage tanks (indoor and outdoor), a multi-stage filtration system, and an automated irrigation setup. The objective of this project is to design, develop, and evaluate an innovative rainwater collection system prototype for alternative home water supply. With this prototype, the study aims to contribute toward sustainable urban water management and eco-friendly practices, supporting Malaysia's long-term environmental goals.

2. Literature Review

Innovative rainwater storage systems (IRSSs) are becoming crucial as global water resources decline due to population growth and climate change. By 2025, nearly 1.8 billion people may face absolute water scarcity, with another 4 billion facing severe shortages [5]. Urban areas like Lembah Klang, Pulau Pinang, and Johor Bahru have significantly higher water demand compared to rural regions [6].

Traditional rainwater systems often lack advanced filtration and water quality control. This project addresses these limitations by developing a modern residential system featuring dual storage, advanced filtration, and automated irrigation. It offers a practical, sustainable solution to urban water scarcity through efficient water use and improved quality.

2.1 Rainwater Harvesting System

Rainwater harvesting systems (RHS) are sustainable solutions for mitigating water scarcity, especially in urban settings where water demand is high. These systems range from simple rain barrels to advanced setups incorporating pumps, dual tanks, and filtration mechanisms, which allow for broader applications such as irrigation, cleaning, and even potable use after treatment. There are mainly two types of harvesting systems: Pond Harvesting Systems (PHS) for agriculture and Roof Harvesting Systems (RHS) for residential applications. Innovations in RHS include collapsible tanks, modular components, and integration with green technologies like smart irrigation and rain gardens [7]. In Malaysia, such systems are gaining traction due to rising water demand and frequent supply disruptions. Studies from various Malaysian regions have shown up to 40% water savings when RHS is implemented. Moreover, these systems reduce urban flooding by managing runoff effectively, especially in regions with high annual rainfall like Sarawak and Pahang [8]. Despite high awareness, practical adoption remains limited, suggesting the need for improved governance, training, and policy support for broader implementation [9].

2.2 Water Quality

The quality of harvested rainwater depends on environmental conditions, roofing material, storage cleanliness, and regular maintenance. While rainwater is naturally clean, contaminants from rooftops, bird droppings, and industrial air pollution often degrade its quality. Critical water quality indicators include pH, turbidity, heavy metals, and microbial contamination like E. coli and coliforms [10]. In Malaysia, water quality standards for non-potable use are established under the National Water Quality Standards (NWQS), while WHO guidelines apply for potable applications. Effective filtration systems, including pre-filtration screens, sediment filters, and activated carbon, can improve water quality significantly, making the water safe for household and agricultural use [11]. Other influencing factors include the type of catchment surface, rainfall intensity, and surrounding pollution sources. Proper design—such as incorporating first-flush diverters—and regular system upkeep are essential to maintain water safety [12]. Health risks from untreated rainwater include gastrointestinal illness, chemical exposure, and skin irritation. Thus, disinfection methods like UV treatment or chlorination, and regular testing are recommended for higher-risk uses [13].

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2.3 Automatic Plant Watering

Automatic plant watering systems integrated with RHS present a practical and eco-friendly approach to urban agriculture and landscaping. These systems use stored rainwater, distributed via moisture sensor-based irrigation setups managed by microcontrollers like Arduino, to ensure optimal watering without waste [14]. The benefits are both economic and environmental—reducing labor, improving crop yields, conserving freshwater resources, and minimizing pollution from agricultural runoff. In Malaysian contexts, such systems have been applied in rooftop gardens and urban farms, particularly where access to water is limited. Studies demonstrate up to 12.7% improvement in water-use efficiency using automation [15]. With rising interest in smart farming, modern systems now incorporate IoT, neural networks, and wireless sensor networks (WSN) to optimize irrigation and reduce energy use [16]. For example, leaf sensors can now adjust irrigation based on real-time plant health data, saving up to 50% of water in overhead systems [17]. These innovations align with Malaysia's broader goals of sustainable agriculture and climate resilience.

3. Methodology

This methodology explained the method used to achieve the project's objectives in a systematic and well-organized way. After studying the system, a working prototype was created that demonstrated how to collect, filter, and store rainwater. Three main objectives were identified for the methodology. The prototype was initially create with a filtration system using COOHOM software. To replicate a functional rainwater harvesting system, the prototype was constructed with materials. Third, the prototype's performance was assessed through testing, particularly with regard to its capacity to gather and hold water. To evaluate the efficacy of the system, the test results were documented and examined. To improve future implementation, recommendations for enhancements were made based on this analysis. Fig. 1 below shows flowchart of methodology for this study.

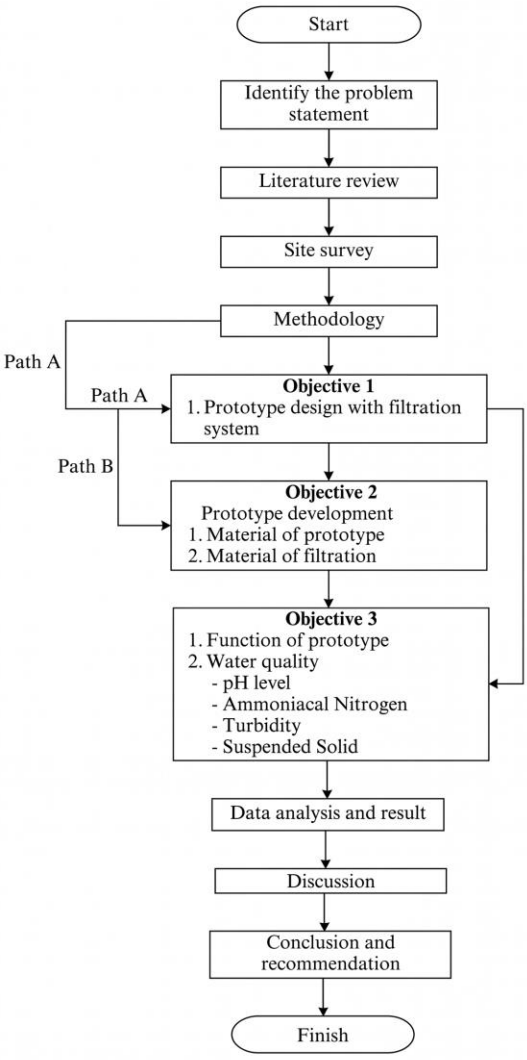

Fig. 1 *Flowchart of the study*

3.1 Prototype Design

The project's prototype was created with COOHOM, a 3D modeling program frequently used in engineering and design domains. Despite being primarily designed for interior design, COOHOM was helpful in the early planning and presentation phases of the project because it helped visualize layouts and optimize designs.

Appendix A shows two prototype models were compared in the study; (a) had two independent tanks, while (b) had a single, larger tank. The single-tank design required careful water management but simplified the structure and saved space. In contrast, the dual-tank design divided water use for irrigation and general purposes. Water efficiency was the goal of both designs. A crucial component of both was the filtration system, which purified rainwater to make it suitable for cleaning, car washing, and plant watering while advancing the project's objective of sustainable and useful water management.

3.2 Material

The main filter body of the prototype was a 3-liter plastic container because it was lightweight and simple to modify. The water impurities were gradually eliminated by the filtration system's multiple layers. The filter prototyp as shown in Appendix B. Coarse aggregate, which was used to remove larger particles, made up the first layer. Fine aggregate came next, capturing smaller suspended particles. After that, charcoal was used to absorb potentially hazardous chemicals and offensive smells. Lastly, a layer of cotton was applied to ensure a clearer water output by filtering out the smallest particles. Table 1 shows the amount of material in the filter. These materials were chosen with care because they improve filtration performance and are in line with practical and sustainable methods that are frequently employed in actual water purification systems. This design approach was validated by prior research that demonstrated the high efficacy of multi-layer filters in purifying rainwater.

Table 1 *Material in the filter*

Material	Filter 1	Filter 2
Coarse aggregate	400 g	400 g
Fine aggregate	300 g	500 g
Charcoal	150 g	150 g
Cotton	35 ply	20 ply

3.3 Sampling preparation

Three types of samples were prepared for the test: Sample A, Sample B, and Sample C as shown in Appendix C. Sample A was left unfiltered to represent raw rainwater. Sample B and Sample C were filtered using two different types of filters Filter 1 and Filter 2, respectively. All samples were then tested and compared based on several water quality parameters, including turbidity, pH, suspended solids, and ammonia nitrogen. This was done to evaluate the effectiveness of each filtration method in improving rainwater quality compared to the raw (unfiltered) sample.

4. Result and Discussion

4.1 Development Of Prototype

A simple prototype of a home rainwater harvesting system was displayed in Appendix D. A gutter was used to collect rainwater, which was subsequently filtered to get rid of dirt and debris. The water was filtered and stored in a plastic tank. A timer at the bottom of an automated irrigation system made watering plants more efficient and hands-free. Water waste was decreased, and sustainable living was encouraged by this arrangement.

4.2 Development of Filtration

The basic water filters (1 and 2) constructed from plastic bottles were displayed in Appendix E. Four layers were present in each filter to purify rainwater. The large stones (coarse aggregate) at the top caught large dirt particles and leaves. Little stones, or fine aggregate, were found beneath that, trapping sand and dirt particles. Charcoal, the next layer, assisted in eliminating chemicals and unpleasant odors. Cotton at the bottom gathered any remaining dirt particles and clarified the water. With this configuration, rainwater was converted into cleaner water that could be used for cleaning or plant watering.

4.3 Prototype Functionality

4.3.1 Filtration system test

The filtration system test was conducted to compare the water flow efficiency between two different filter designs, Filter 1 and Filter 2. Each filter was tested by measuring the time taken to pass 3 liters of water through, and the flow rate was then calculated. Based on Table 2, Filter 2 demonstrated a significantly faster flow rate of 0.500 L/min compared to Filter 1, which had a slower flow rate of 0.188 L/min. This indicates that Filter 2 is more efficient in allowing water to pass through, completing the 3-liter filtration in just 6 minutes, whereas Filter 1 required 16 minutes. The difference in performance could be attributed to variations in filter material density, layer thickness, or overall design that may restrict water movement in Filter 1. Therefore, Filter 2 is more suitable for applications requiring quicker water processing, making it a more practical choice for the rainwater collection system where time and efficiency are critical.

Table 2 *Result of filtration flow rate*

	Filter 1	Filter 2
Time For Water Passing (3 L)	16 minutes	6 minutes
Flow Rate	0.188 L/Min	0.500 L/Min

4.3.2 pH Test

pH levels are critical in determining the suitability of water for various applications, including irrigation, domestic use, and industrial processes. For plant irrigation, maintaining an appropriate pH range is essential for nutrient availability and healthy plant growth. For general water quality, the standard pH range is 6.5 to 8.5, standard for irrigation is 6.0 to 7.5 and risk of corrosion is below 6.0 [11]. Table 3 explains the pH values derived from the outcomes of laboratory tests.

All three water samples have pH values within the acceptable range of 6.0 to 7.5 for general use and plant irrigation, indicating they are safe and non-corrosive. Sample A, which is unfiltered, has a near-neutral pH of 6.37, showing that the rainwater is already balanced and free from acidity issues. Samples B and C, which are filtered, show slightly higher pH levels of 7.25 and 7.43, likely due to the presence of alkaline materials like charcoal in the filters. This mild increase in alkalinity is common and can be beneficial, as it helps buffer acidic soils and reduce metal toxicity. Therefore, no pH adjustment is needed, and the filtered water may even support better soil health in acidic conditions.

Table 3 *Results of pH test*

Sample	A	B	C
pH	6.37	7.25	7.43

4.3.3 Suspended Solid

The suspended solids (TSS) test revealed significant differences in water clarity between the unfiltered and filtered samples. Sample A, which is unfiltered, showed a high average TSS value of 310 mg/L, well above the recommended safe limit of 25–50 mg/L. This indicates that the collected rainwater in its raw form contains a substantial amount of particulate matter, making it unsuitable for direct use. In contrast, Sample B showed a complete removal of suspended solids, with a TSS value of 0 mg/L, while Sample C had a low TSS average of 30 mg/L, both within acceptable limits. These results demonstrate the effectiveness of the filtration system, especially Filter 2, in significantly reducing or eliminating suspended solids from the water. The superior performance of Filter 2 may be attributed to its higher amount of fine aggregate and reduced cotton layering, which enhances flow while still maintaining good filtration. Overall, the filtration process clearly improves water clarity, and both filters, particularly Filter 2, are effective for reducing suspended solids to safe levels for non-potable uses like irrigation. Table 4 explains the result of suspended solid derived from the outcomes of laboratory tests.

Table 4 *Result of suspended solid*

Sample	A1	A2	B1	B2	C1	C2
Volume of sample, mL	5	5	5	5	5	5
Weight of empty filter, g	0.0908	0.0908	0.0925	0.0913	0.0918	0.0918

Weight of filter + dried solids, g	0.0921	0.0926	0.0925	0.0913	0.0919	0.0920
Weight of solids, g	0.0013	0.0018	0.0000	0.0000	0.0001	0.0002
Total suspended solids, mg/L	260	360	0	0	20	40
Averange total suspended solid, mg/L	310		0		30	

4.3.4 Turbidity

According to Table 5, the turbidity test results showed Sample A had the highest turbidity (10.90 NTU), indicating that it was the most contaminated with visible particles, most likely because of inadequate or nonexistent filtration. The water was the clearest and the filtration method had been the most successful, as Sample B had the lowest turbidity (3.38 NTU). Sample C's turbidity of 4.48 NTU, which was higher than Sample A's but lower than Sample B's, indicated that it had undergone partial or ineffective filtration. All things considered, the results demonstrated that the filtration system had assisted in lowering turbidity, particularly in Sample B.

Table 5 *Result of turbidity test*

Sample	A	B	C
Turbidity (NTU)	10.90	3.38	4.48

4.3.5 Ammonia test

Ammonia nitrogen (NH_3-N) in water typically originates from decomposing organic matter or external pollutants and poses risks to both plants and aquatic ecosystems. Concentrations should not exceed 1.0 mg/L to ensure water remains safe for use and handling. Based on Table 6, the unfiltered Sample A showed an ammonia concentration of 5 mg/L, significantly surpassing the recommended limit. Filtration effectively reduced these levels to 0.3 mg/L in Sample B and 0.5 mg/L in Sample C, indicating the efficacy of the filters likely due to the charcoal's adsorptive properties. Both filtered samples fall within the acceptable range, but Sample B demonstrated superior performance, making Filter B the most effective at removing ammonia nitrogen and improving the safety of the collected water.

Table 6 *Result of ammonia test*

Ammoniacal Nitrogen concentration of samples, mg/L NH3-N		
Sample A	Sample B	Sample C
5	0.3	0.5

5. Conclusion

This project successfully developed an innovative rainwater collection system designed for residential use, integrating dual storage tanks, a multi-stage filtration unit, and an automatic irrigation mechanism. The prototype demonstrated effective performance in water collection, filtration efficiency, and water quality enhancement, as evidenced by improvements in pH, turbidity, and suspended solids. Filter 2, in particular, showed superior flow rate and clarity, making it a practical option for real-world applications. While ammonia testing faced some inconsistencies, the overall system proved viable for non-potable uses such as plant watering and cleaning. By reducing reliance on treated water and promoting sustainable water use, this system offers a promising solution to address urban water challenges and supports environmentally responsible living.

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Conflict of Interest

Authors declare that there is no conflict of interests regarding the publication of the paper.

Author Contribution

The authors confirm contribution to the paper as follows: ***study conception and design:*** *Muhammad Muaz Saamri, Muhammad Nashrul Haiman Shaharrudin, Muhammad Afiq Farihin Nazri, Mardiha Mokhtar;* ***data collection:*** *Muhammad Muaz Saamri, Muhammad Nashrul Haiman Shaharrudin, Muhammad Afiq Farihin Nazri, Mardiha Mokhtar;* ***analysis and interpretation of results:*** *Muhammad Muaz Saamri, Muhammad Nashrul Haiman Shaharrudin, Muhammad Afiq Farihin Nazri, Mardiha Mokhtar;* ***draft manuscript preparation:*** *Muhammad Muaz Saamri, Muhammad Nashrul Haiman Shaharrudin, Muhammad Afiq Farihin Nazri, Mardiha Mokhtar. All authors reviewed the results and approved the final version of the manuscript.*

Appendix A



(a) **(b)**

Fig. 2 *(a) design with two independent tanks; (b) design with a single, larger tank*

Appendix B



Fig. 3 *Filter for the prototype*

Appendix C

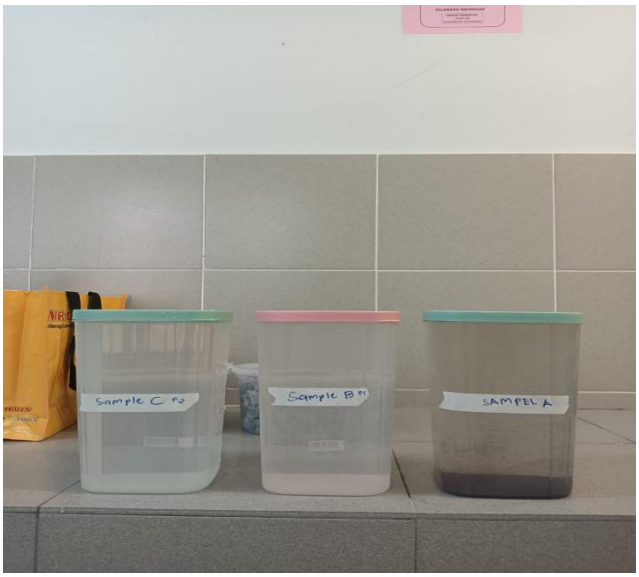

Fig. 4 *Sample A, B and C*

Appendix D

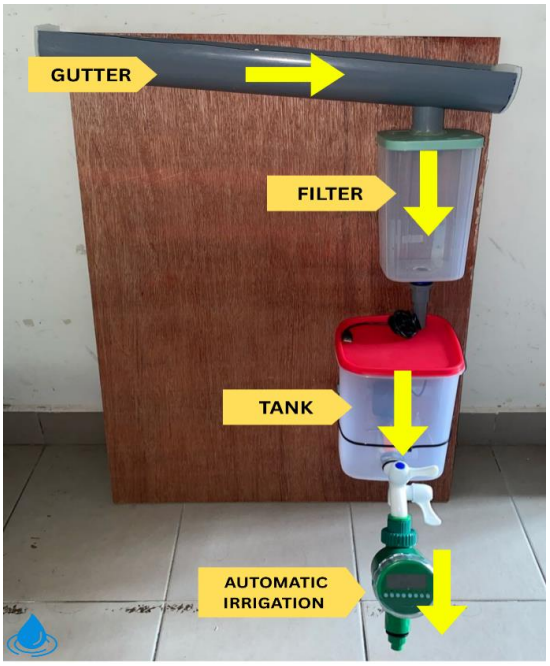

Fig. 5 *The design of prototype*

Appendix E



Fig. 6 *The design of filter*

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