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A Portable Biofiltration System Utilizing Local Organic Waste for Rainwater Treatment

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Abstract

Low rainwater collection in some campus areas of the Indonesian Institute of Technology campus creates unnecessary surface runoff and high municipal water usage. Rainwater coming from roofs was not treated and sent directly to drainage channels. A community service program was carried out to offer an alternative solution by producing a portable biofiltration system made of local organic material as the filter media. Implementation of the program was done in multiple steps, which included: examination of partner needs, technical system design phase, physical device construction and production, installation on-site at the fielding location, initial operational testing, and user support. The system that had been created is intended to be straightforward, mobile, and low-maintenance, making it possible for its use to go beyond just the campus setting. Depending on design specifications and regional rainfall patterns, the system can handle roughly 100 to 300 liters of rainwater with each rainfall, decreasing surface runoff by approximately 20 to 35 percent, and providing about 15 to 25 percent of the non-drinkable water needs in the nearby region. The findings suggest that using suitable technology made from local resources can promote sustainable water management and raise awareness about rainwater use within the educational community.

Keywords: *portable biofiltration, rainwater harvesting, water conservation*

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Introduction

In a real campus setting, water is usually considered a resource that is readily accessible. This is not entirely true in a real sense, since water availability is very much dependent on supply levels and activities. In the Indonesian Institute of Technology (ITI), clean water is usually sourced from the municipal water supply and groundwater. At some point in time, especially when campus activities become high or when there is a shortage in supply, this may not be enough. Considering the physical condition of the campus, most of the buildings in ITI have extensive roofs that are exposed to rainfall all year round. The current situation is that the rainwater collected from the roofs is simply directed to the drainage system without being utilized. The rainwater collected from the roofs of buildings in the campus can be reused through a very simple system that is able to satisfy the demand. Filtration is essential in ensuring that the collected rainwater is not used immediately. From the initial observation made within the community service learning program, it is clear that there is a lack of filtration facilities in the rainwater harvesting system at the campus. Rainwater from the rooftops drains directly to the drainage channels. On the contrary, organic materials at the campus have not been utilized to their full potential, even though their use in water filtration is well known. The use of locally available organic materials in community-scale biofilters has been shown to support affordable and context-appropriate water treatment solutions, particularly in community service settings (Yuliasari et al., 2020).

Taking all these factors into consideration, the objective of the community service was the conceptualization and actual implementation of a portable biofiltration system using locally available organic materials. The biofiltration system was conceptualized to be easily set up, portable, and inexpensive in terms of operation costs. It was also hoped that the biofiltration system would help in creating awareness among the academic fraternity about the need for effective water conservation. The biofiltration system can be easily transported from one location to another; hence, it can be used not only in ITI but also in other places where the problem of rainwater conservation is a challenge. This approach is consistent with findings by Zhang et al. (2022), who demonstrated that properly designed rainwater harvesting systems can significantly reduce surface runoff while improving water utilization efficiency in urban environments (Zhang et al., 2022). Recent studies also show that rainwater harvesting can function as part of sponge city infrastructure, where collection systems support both stormwater attenuation and decentralized water reuse (Li et al., 2022). Urban rainwater harvesting has increasingly been recognized not only as an alternative water supply approach but also as part of integrated urban water management strategies that contribute to runoff mitigation and water security (Campisano et al., 2017; Zabidi et al., 2020).

Methods

The methods used in this community service program emphasize the application of applied engineering knowledge. This method also emphasizes a strategic combination of technical design, appropriate technology, and collaborative support from stakeholder groups, aimed at meeting the partners' real needs for alternative water sources. All community service program activities take place at the Indonesian Institute of Technology (ITI). The technique employed also takes sustainability elements into account to guarantee that the system developed may be used in other surroundings with similar characteristics, in addition to concentrating on resolving problems at the project location. The biofiltration system in this project utilizes readily available organic materials from markets or agricultural and plantation waste, such as rice husks, coconut fiber, and coconut shell charcoal. These materials were selected based on several pragmatic factors, such as their effectiveness in filtering water, local availability, affordability, and ease of replacing the filter media when necessary. The incoming rainfall is allowed to go through a progressive filtration process beginning with coarse filtration and progressing to finer filtration when the filtration media is then arranged into several layers. These materials were selected based on several pragmatic factors, such as their effectiveness in filtering water, local availability, affordability, and ease of replacing the filter media when necessary.

Before the water is recycled for non-drinkable purposes, the structured arrangement aims to lessen the number of suspended particles, reduce cloudiness of the water, and lower the amount of organic materials. The quality of the water that has been filtered is predicted to stabilize and be fit for fundamental operational needs inside the campus context via a slow filtering process. Commencing on July 3, 2025, the execution of this service task was conducted in phases. This process initiated with technical preparation, followed by the assembly phase, preliminary testing, and operational support during the system's actual implementation.

Partner Needs Assessment and Identification

The first phase of the program focuses on identifying the partners' actual conditions and needs. This phase includes direct field observations and informal conversations with facility managers and technical personnel on campus. The purpose of the observations is to examine the existing drainage system at the project site. This phase then involves finding a biofilter tester suitable for roof space runoff, suitable for rainwater harvesting, and determining the practicality of installing a portable biofiltration system on campus.

Information gathered in this phase includes estimating the roof catchment area, assessing gutter conditions, evaluating the slope and accessibility of possible installation sites, and analyzing current water usage habits for clean water needs, excluding drinking water. The findings from this needs assessment would serve as the basis for determining the storage tank size, supporting structure measurements, and the type and quantity of filtration media needed to ensure efficient system function. Figure 1 provides an overview of the campus sites where the program is partnering. To improve reproducibility and analytical transparency, the estimation of system performance was supported by simplified hydrological calculations based on roof catchment characteristics. The potential volume of harvested rainwater (V) was approximated using:

$$\boldsymbol{V = C \cdot A \cdot R}$$

where C represents the runoff coefficient (dimensionless), A is the effective roof catchment area (m^2), and R denotes rainfall intensity (mm/event). Based on field observations, the runoff coefficient for metal roofing surfaces ranges between 0.8 and 0.9 (Fewkes, 2000). With an estimated catchment area of approximately 50–80 m^2 and rainfall events ranging from 5–10 mm, the resulting harvested volume falls within the observed operational range of 100–300 liters per event.

The rainfall intensity values used in this estimation (5–10 mm/event) are based on typical short-duration rainfall characteristics observed in the South Tangerang region. The estimated runoff reduction (20–35%) was derived by comparing the portion of roof runoff diverted into the system against the total discharge entering the drainage network. Similar runoff estimation approaches have been applied in Indonesian rainwater harvesting feasibility studies, including in industrial and residential settings (Kurniawan et al., 2023; Zuliarti & Saptomo, 2021).

In terms of water quality targets, the system is designed for non-potable applications. Therefore, the performance criteria refer to general guidelines for non-drinking water use, where acceptable conditions include neutral pH (6–8), reduced turbidity, and absence of visible suspended solids. These criteria provide a practical benchmark for evaluating system functionality in the absence of laboratory testing.

Furthermore, preliminary field measurements indicated that the filtration rate within the biofiltration drum remained within a low-flow regime (<0.1 L/s), which is consistent with slow filtration principles aimed at maximizing contact time between water and filter media (Li et al., 2010). Although laboratory-grade measurements were not conducted, these approximations provide a reasonable basis for validating the observed system performance.

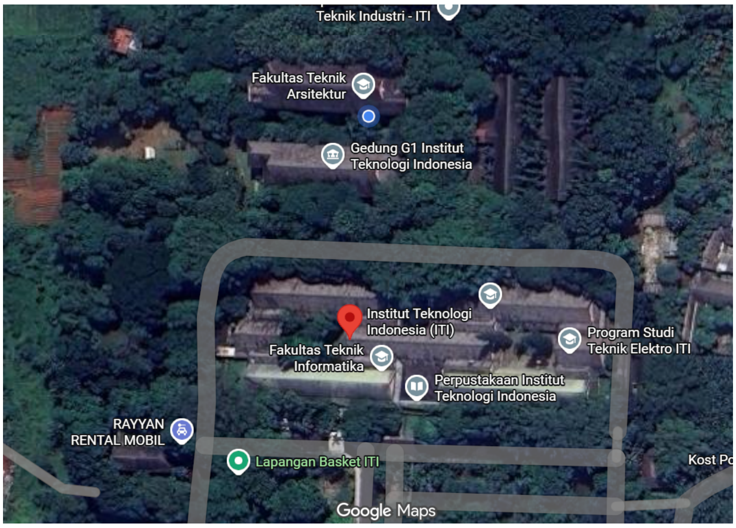

Fig. 1. Location of the Indonesian Institute of Technology area as the installation site for the portable biofiltration system (source: Google Maps, 2025)

Portable Biofiltration System Design

This portable biofiltration system was designed to adapt to the physical characteristics of the building and operational patterns within the Indonesian Institute of Technology campus. Therefore, this portable biofiltration system was created based on identified needs in the area. The main factors to be taken into account in the design process are the structural stability, the simplicity of system installation, and the system's capacity to run independently without using more power. The system therefore has one 550-liter rainwater storage tank, one 200-liter filtration drum, and a lightweight steel supporting frame meant to guarantee stable system operation as well as enough elevation to enable gravitational water flow. The system therefore has one 550-liter rainwater storage tank, one 200-liter filtration drum, and a lightweight steel supporting frame meant to guarantee stable system operation as well as enough elevation to enable gravitational water flow. Such decentralized water infrastructure systems have been recognized as an effective approach to improving urban water resilience and sustainability, particularly in areas with fluctuating water supply conditions (Palla et al., 2023).

Layers of fiber mesh, coconut husk, rice hulls, coconut shell charcoal, silica sand, and gravel make up the filtration media. Rice husk and coconut-shell-based carbon have been widely reported as effective low-cost adsorptive media due to their high silica content and porous carbon structure, enabling removal of suspended solids and selected contaminants (Foo & Hameed, 2009). The design helps to enable a slow filtration process in which finer particles and organic material go through more filtration in the next layers, while bigger particles are caught by the initial ones. This system makes use of the adsorption capability of organic materials in addition to physical filtering, therefore greatly improving the clarity of the filtered water. Using a simple flow balance approach, the flow pattern of water inside the system is predicted in order to preserve the stability of system performance during operation. Using this method as a guide helps to guarantee that the rate of rainwater entering does not go over the capacity of the filtering medium, therefore lowering the danger of blockage. The flow control also aims to guarantee that during rainstorms, rainwater can pass uniformly throughout all media layers, enabling a continuous and successful filtering process.

To ensure replicability of the system, several implicit design parameters are explicitly defined. The filtration drum (200 L capacity) operates under a gravity-driven flow system with an estimated hydraulic head difference of 0.8–1.2 meters between the storage tank outlet and filtration outlet. The filtration media were arranged in a vertical stratified configuration with approximate thicknesses as follows:

a. Gravel layer (bottom support): 10–15 cm (particle size: 10–20 mm)
b. Silica sand layer: 15–20 cm (effective size: 0.3–0.6 mm)
c. Coconut shell charcoal: 10–15 cm (adsorptive layer)
d. Rice husk layer: 10–15 cm (fine particulate filtration)
e. Coconut fiber (top layer): 5–10 cm (coarse screening)

The estimated porosity of the layered system ranges between 0.35 and 0.50, influencing flow resistance and retention time. The hydraulic retention time (HRT) is approximated to be between 15 and 30 minutes under normal operating conditions, allowing sufficient interaction between water and filter media for turbidity reduction and organic adsorption.

The general filtration process flow can be expressed by the following equation:

$$Q_{\text{out}} = Q_{\text{in}} - \sum_{i=1}^{n} R_i$$

where Q_{out} represents the discharge of the filtered water, Q_{in} is the inflow entering the system, and $R_i$denotes the flow loss caused by resistance in each filtration layer. This equation is used as an analytical approximation to ensure stable flow and to prevent clogging within the system. The selected hydraulic retention time is consistent with performance recommendations for small-scale gravity-driven rainwater treatment systems reported in prior evaluations (Toronto and Region Conservation Authority, 2011).

Procurement of Materials and System Fabrication

Once the system design is confirmed to be ready, one must get supplies in line with the authorized community service program's budget plan. Technical requirements, local market availability, and ease of construction and maintenance procedures all guide the material choices. Then, involving the skills of lecturers and students, the assembly process of the portable biofiltration drum was carried out in a concrete laboratory on the Indonesian Institute of Technology campus. This procedure not only discussed the final design and manufacturing process of the portable biofiltration but also provided information and learning resources for group study for students wishing to deepen their knowledge of the applied science of water conservation and serve as a starting point for applied engineering ideas in the field.

Among the key processes in production are assembling the lightweight steel frame, getting the rainwater collecting tank and filtration drum ready, and running the piping system, valves, and other support connectors. The fabrication process is precisely as follows:

a. Construction a lightweight steel frame to support the rooftop rainwater storage tank and biofiltration drum to maintain the stability of the drainage system.
b. Assembling the filter components in a 550-liter HDPE tank, which serves as the primary water source for filtration or supply.
c. Preparation of a 200-liter filter drum equipped with pipe connections and a flow control valve to maintain flow control from the temporary water storage tank to the biofiltration drum.
d. Arrangement of the filter media according to the design layout, which is determined based on the needs analysis.

e. Prior to installation, rice husk and coconut fiber materials underwent basic pre-treatment to enhance filtration performance and prevent contamination. The materials were washed using clean water to remove adhering dust and fine particulates, followed by air-drying under sunlight for 24–48 hours to reduce moisture content. This step is essential to minimize the introduction of organic residues that may contribute to microbial growth during early system operation.
f. During extended dry periods, when the system is not regularly exposed to rainwater flow, preventive maintenance becomes critical. It is recommended that the filtration drum be partially drained and ventilated to avoid prolonged moisture retention within the organic layers. Periodic drying of the upper layers (every 2–4 weeks) and inspection for fungal growth should be conducted. If visible mold or odor is detected, partial replacement of the affected media is advised to maintain system hygiene and performance.

After fabrication was complete, the biofiltration unit wass transported to its designated installation location on campus. The installation procedure includes placing the storage tank and filtration drum on their respective support frames, connecting the system to the building's roof gutters using PVC pipes, and adjusting the pipe positions and slopes to ensure smooth water flow. To ensure the system is ready for operation, a preliminary inspection must be conducted before testing to ensure the stability of the support frame and the tightness of the pipe and valve connections. Figures 2 and 3 illustrate the complex design of the biofiltration mechanism.

Figure 2 presents the overall system layout, illustrating the sequential flow of rainwater from rooftop collection to storage and filtration units. The elevation difference between the storage tank and filtration drum enables a gravity-driven flow mechanism, eliminating the need for external energy input.

Figure 3 illustrates the layered arrangement of filtration media. Each layer performs a specific function: coconut fiber acts as a coarse filter, rice husk removes finer suspended particles, coconut shell charcoal provides adsorption of organic compounds, silica sand enhances turbidity reduction, and gravel supports structural stability and flow distribution. The number of these layers is designed to optimize filtration efficiency while maintaining low operational complexity.

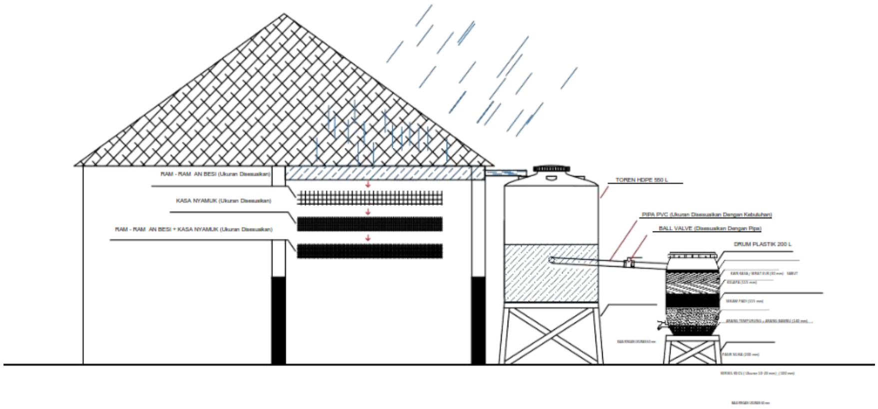

Fig. 2. Layout scheme of the portable biofiltration system

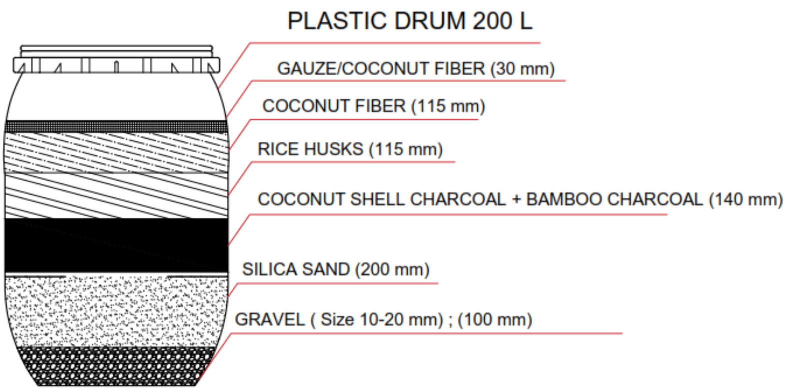

Fig. 3. Schematic of filtration media layer arrangement in the portable biofiltration system

Table. 1. Filtration media characteristics

Media	Thickness	Function	Role
Coconut fiber	5–10 cm	Coarse filtration	Debris removal
Rice husk	10–15 cm	Fine filtration	Suspended solids
Charcoal	10–15 cm	Adsorption	Organic removal
Sand	15–20 cm	Fine filtration	Turbidity reduction
Gravel	10–15 cm	Support	Flow stability

Table 1 summarizes the characteristics and functional roles of each filtration medium used in the portable biofiltration system. The selection and arrangement of the media are designed to achieve a gradual filtration process, transitioning from coarse to fine filtration while incorporating adsorption mechanisms. The uppermost layer, consisting of coconut fiber, functions as a coarse filter that captures large debris and prevents clogging in the underlying layers. This is followed by the rice husk layer, which plays a significant role in removing finer suspended particles due to its relatively high surface area and porous structure. The coconut shell charcoal layer serves as an adsorption medium, contributing to the removal of dissolved organic compounds and improving water clarity. Beneath the organic layers, silica sand provides fine filtration by trapping smaller particles that pass through the upper layers, thereby enhancing turbidity reduction. Finally, the gravel layer at the bottom acts as a structural layer, maintaining media stability and ensuring uniform distribution of flow throughout the filtration column. The arrangement and thickness of each layer were determined based on a balance between filtration efficiency, hydraulic resistance, and ease of maintenance. This layered configuration supports a low-flow filtration regime, allowing sufficient contact time between water and media, which is essential for improving overall treatment performance in decentralized, small-scale systems. The layered arrangement follows a multi-barrier treatment principle combining screening, adsorption, and sediment retention, which is commonly recommended in decentralized filtration technologies (Crini & Lichtfouse, 2019; Wulandari & Sentosa, 2023).

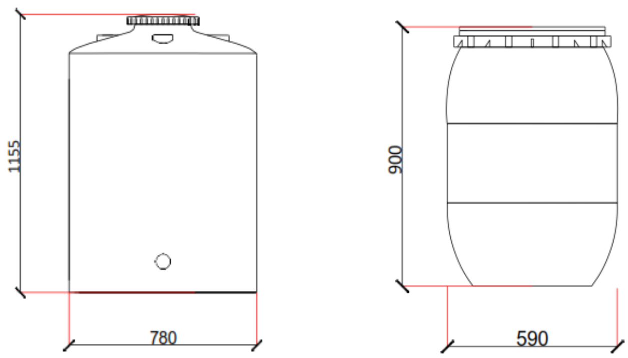

Fig. 4. Geometric dimensions and physical configuration of the rainwater storage tank and biofiltration drum in the portable biofiltration system

To enhance the technical clarity of the system design and facilitate reproducibility, the geometric configuration of the main components is explicitly defined, as presented in Figure 4. The rainwater storage tank, with a height of approximately 1.155 m and a diameter of 0.78 m, serves as the primary collection unit with a nominal capacity of 550 liters. Positioned above the filtration unit, this configuration generates a sufficient hydraulic head to drive gravity-induced flow without the need for external energy input.

The biofiltration drum, with a height of 0.90 m and a diameter of 0.59 m, is designed as a vertical filtration column that accommodates multiple layers of organic and granular media. The dimensional relationship between the storage tank and filtration unit establishes an elevation difference that enables stable flow conditions, as previously described by the simplified flow balance approach ($Q_{out} = Q_{in} - \Sigma R_i$).

This configuration supports a low flow filtration regime, where water percolates downward through the media layers under gravitational force. The vertical arrangement is critical in ensuring sufficient contact time between water and filter media, thereby improving the removal efficiency of suspended solids and organic contaminants. Furthermore, the ratio between tank capacity and filtration volume was determined to prevent overflow during peak rainfall events while maintaining continuous filtration under moderate inflow conditions. By explicitly presenting the physical dimensions and spatial arrangement of system components, the design moves beyond a purely conceptual framework toward an engineering-based specification. This level of detail enables replication in similar settings and provides a clearer basis for future optimization, particularly in relation to hydraulic performance, media configuration, and scaling considerations.

System Installation and Testing

The water source for a rainwater harvesting system project requires rainy weather conditions during the initial testing of the portable biofiltration system to assess its effectiveness under actual operating conditions. Rather than a comprehensive laboratory water quality analysis, this assessment emphasizes fundamental functional components. Initial baseline testing includes water quality testing, pH levels determined using water test indicator paper, visual clarity of the filtered water, indication of leaks at pipe connections, and smooth water flow in and out of the system. Findings gathered from all testing phases provide initial indications for verifying the system's intended operational design for subsequent phases.

The next action following the conclusion of the first testing stage was a guidance and outreach session for academic community representatives. This exercise aimed to familiarize the operating principles of the biofiltration system, describe daily operational processes, and offer instructions for regular maintenance, including the steps for replacing the filtration media. It is anticipated that the partners would obtain enough knowledge through this support process to handle and maintain the system on their own, free from the implementation team's need.

The portable biofiltration system was formally given over to the partners as the last stage in this run of activities under the community service program. According to its operational demands, this transfer indicates that the campus is ready for direct use and management.

Several phases of system testing guaranteed that every component works as expected. The testing phases comprised pH measurements using indicator paper, visual clarity observations of the filtered water, inspections of possible pipe joint and valve leaks, and incoming water flow rate inspections.

Dissemination, Assistance, and Handover

Once the portable biofiltration system was fully installed and operating effectively, an outreach and support event was held for members of the campus community, particularly staff from specialized units involved in facility maintenance and day-to-day operations. This outreach event aims to ensure that partners fully understand how the system works, its processes, and the maintenance required for the portable biofiltration system. The project team presented and explained how rainwater flows from the rooftop collection area to the storage tank, and explained the process of the piping system until it reaches the filtration material. It began with an explanation of the role of each component in the system: the storage tank, filtration drum, pipe connections, and filter material layers. Then, practical components such as checking the condition of the water inlet and outlet pipes, identifying potential blockages, and basic troubleshooting methods were emphasized.

Hands-on lectures and guided exercises helped the partners to run and keep the system on their own by means of support activities. Instructions were also provided on how to replace and clean the filter components, with tips on how frequently to replace them depending on system performance and visual inspection. The community service program had as one of its main outcomes the formal handover of the portable biofiltration system to the campus administration at the conclusion of this event. This movement meant the change of operating responsibilities for the system from the implementation team to the partners.

In addition to receiving training, the partners actively contributed to the implementation process. During installation, campus technical staff assisted in site preparation, positioning of system components, and ensuring alignment with existing drainage infrastructure.

Furthermore, partners were involved in initial system testing and provided feedback regarding operational practicality.

In the post-installation phase, designated personnel were assigned responsibility for routine monitoring and maintenance activities, including inspection of flow conditions and periodic cleaning of filter media. This level of involvement reflects a collaborative implementation approach and strengthens the sustainability of the program outcomes.

Evaluation and Activity Documentation

Given that the portable biofiltration system was in its first stage of use when it was introduced, the community service program was assessed descriptively. Thorough numerical examination of water quality parameters and evaluation of system efficiency over a long period had not yet been carried out. Therefore, the evaluation focused on the fundamental operation, system preparedness, and expected influence based on design specifications and field observations.

To enhance the analytical depth of the evaluation, several performance indicators were conceptually defined to assess system effectiveness. These include turbidity reduction efficiency, volumetric efficiency, and flow consistency. Although detailed laboratory measurements have not yet been conducted, an initial quantitative approximation can be formulated. Turbidity reduction efficiency (η) is expressed as the relative difference between influent and effluent turbidity. Based on visual comparison, the system indicates a noticeable reduction in suspended particles after filtration. Furthermore, volumetric efficiency—defined as the ratio between collected water volume and theoretical runoff potential—was estimated to range between 60–75% under typical rainfall conditions. These values provide a preliminary quantitative framework for evaluating system performance and highlight the need for further experimental validation.

The portable biofiltration system is expected to manage roughly 100 to 150 liters of rainwater during typical rainfall events and up to 250 to 300 liters during more intense rainfall, subject to the design of the system and its installation arrangement, as long as rainwater from the roof is effectively diverted into the system. The estimates given indicate potential reductions in surface runoff of around 20–35% and the capacity to meet approximately 15–25% of the non-potable water needs in the immediate campus area, which comprises activities like gardening and washing.

Activities were documented at every stage of the program: site surveys, fabrication techniques, system installation, testing, social interactions, and ultimate transfer. Evidence, such as field notes and photographic documentation, helps demonstrate program implementation and promote transparency and accountability. The evaluation results and documentation are used to establish benchmarks for monitoring the operational effectiveness of the portable biofiltration system in the future, as well as for the continued development of the portable biofiltration system once it is fully operational. For long-term operation, a structured maintenance and monitoring plan was proposed. Routine inspection is recommended every two weeks to ensure stable flow conditions and to detect potential clogging within the filtration media. Organic filter materials should be partially replaced every 2–3 months, depending on system usage and environmental exposure.

Additionally, simple monitoring logs are recommended to document system performance over time, including water clarity, flow rate consistency, and the presence of odor. This approach enables early detection of performance degradation and supports data-driven system improvement in future applications.

Results and Discussions

This project was implemented at the Indonesian Institute of Technology (ITI) from July to December 2025. All activities followed a planned phase, including site evaluation, system development, construction, assembly, testing, outreach, and system transfer. The installation site selected for this project is near the Civil Engineering Laboratory building. This location was deemed appropriate due to the availability of adequate roof rainwater flow as planned, easy access for equipment installation, and operational safety.

Fig. 5. Implementation site of the community service program in the civil engineering building area of the Indonesian Institute of Technology

Figure 5 shows documentation of the location where the portable biofiltration system was installed. This image illustrates the actual conditions of the selected site, including proximity to drainage for roof rainwater runoff, open area for the system, and accessibility for maintenance and operation. This location was chosen to ensure efficient roof rainwater drainage to the storage tank, while providing sufficient space for the filtration drum and its supporting structures. The site selection also took into account ease of routine inspection and maintenance by campus management staff without disrupting educational activities.

After the site was prepared, the project team, consisting of lecturers and students, began building and assembling the portable biofiltration system. Figure 6 illustrates the initial assembly procedure of the system, which includes the construction of a lightweight steel frame and the arrangement of the portable biofiltration system components. This stage demonstrates the process of using the portable biofiltration system in a real-world application and highlights the teamwork aspect of this project, where lecturers and students actively participated in the biofiltration system construction process. The activity of assembling the portable biofiltration system is also expected to be a valuable learning experience for several parties, allowing the beneficiary user participants to gain practical skills in implementing appropriate technology with materials available in their local environment.

Fig. 6. Fabrication process of the lightweight steel frame and procurement of system components

After assembly, the system was installed at the selected location and connected to a pre-installed roof gutter system. During rainfall events, rainwater flowing from the rooftop collection source was directed to a storage tank and then passed through a filtration drum filled with layers of organic and mineral materials. Initial field observations during testing of the biofiltration system indicated that the system performed as expected, maintaining stable inlet and outlet flow conditions, with no visible leaks at the pipe connections. Visual inspections also indicated improved water clarity after passing through the filtration media, suggesting that the multi-layer filtration setup was successful for non-potable water use. This indicates that the system performs as a preliminary treatment unit, primarily targeting the reduction of suspended solids and organic impurities rather than full potable water treatment. This improvement in water clarity can be directly associated with the multi-layer filtration mechanism. The upper organic layers function as primary filters for larger particles, while the finer sand layer enhances turbidity reduction. In addition, the presence of charcoal contributes to the adsorption of dissolved organic substances, thereby improving the overall visual quality of the filtered water.

This performance can be attributed to the combined effect of mechanical filtration and adsorption mechanisms within the layered media. The gradual change in particle size through each layer enhances sediment retention, while the presence of charcoal contributes to the adsorption of dissolved organic compounds, thereby improving overall water quality. Similar synergistic mechanisms have been reported in low-cost wastewater and rainwater treatment systems utilizing natural filtration media (Crini & Lichtfouse, 2019).

Although comprehensive laboratory testing has not yet been conducted, the system's performance can be reasonably evaluated based on design capacity and field observations. The system was capable of collecting approximately 100–300 liters of rainwater per rainfall event. The variation in collected volume reflects differences in rainfall intensity, duration, and effective runoff conditions during each event and up to 250–300 liters during higher intensity events, contributing to a reduction in surface runoff of about 20–35% and supporting water conservation efforts on campus. The estimated runoff reduction was derived by comparing the proportion of rooftop rainwater diverted into the storage system with the total potential runoff volume. This approximation reflects the system's ability to intercept and utilize a portion of rainwater that would otherwise be directly discharged into the drainage network.

From a quantitative perspective, the system performance can be interpreted through simplified efficiency indicators based on field observations and design estimations. The ratio between the estimated harvested volume (100–300 L per rainfall event) and the theoretical runoff potential indicates that the system is capable of capturing a substantial portion of rooftop rainwater. This performance corresponds to an estimated volumetric efficiency in the range of 60–75%, depending on rainfall intensity and duration. In addition, the observed reduction in outlet flow velocity suggests the presence of effective hydraulic resistance within the filtration media, which plays a critical role in controlling flow stability. The observed storage utilization and runoff interception are consistent with performance ranges reported for small-scale rooftop rainwater harvesting systems (Toronto and Region Conservation Authority, 2011; Zabidi et al., 2020).

This observed system behavior is consistent with the design parameters defined in the methodology. The relatively low-flow condition at the outlet indicates that the estimated hydraulic retention time (approximately 15–30 minutes) is likely achieved during operation. Such conditions allow sufficient contact time between rainwater and the layered filtration media, thereby enhancing sedimentation and adsorption processes. The progressive reduction in particle size across each filtration layer, combined with the adsorptive properties of charcoal, contributes to the improvement of water clarity and the reduction of suspended solids under practical field conditions.

It is important to note that the performance indicators presented in this study are based on field observations and simplified estimations. While these results provide a reasonable representation of system behavior under practical conditions, further laboratory-based measurements and controlled testing are required to obtain more precise and validated performance data.

In addition to the main filtration performance, the system also incorporates a preliminary treatment stage to improve overall effectiveness. A preliminary filtration stage had been implemented at the gutter level using a steel mesh screen to retain coarse debris before entering the storage tank. However, as a first flush diverter has not yet been incorporated, finer contaminants from the initial runoff may still enter the system. Future improvements should therefore consider the inclusion of a simple bypass or first flush mechanism to divert the initial 1–2 mm of rainfall, thereby enhancing influent quality and overall hydraulic performance.

Despite the promising results, several limitations should be acknowledged. The evaluation of system performance was primarily based on short-term observations without comprehensive laboratory testing of water quality parameters. In addition, variations in rainfall patterns and environmental conditions were not systematically controlled, which may influence system performance. These limitations highlight the need for further experimental studies to strengthen the reliability of the findings. These findings suggest that the proposed system can serve as a practical reference for the development of small-scale decentralized water treatment systems, particularly in areas with limited access to clean water infrastructure.

From a community service perspective, the implementation yielded both technical and non-technical outcomes, particularly in increasing user awareness and capacity for system operation and maintenance. Overall, the findings demonstrate that locally sourced materials can be effectively utilized for decentralized water management. Nevertheless, further monitoring and quantitative analysis are required to evaluate long-term filtration efficiency and system performance. Strengthening the engineering basis of the system also requires integration with broader scientific references, including rainwater harvesting modeling, biofiltration mechanisms, hydraulic performance, and the utilization of agricultural waste materials. Future evaluation should include physicochemical water quality testing and long-term monitoring, as recommended in previous rainwater harvesting performance studies (Campisano et al., 2017). practical and scalable solution

Conclusion

This study successfully addressed the initial objective of developing a simple, portable, and low-cost rainwater treatment system utilizing locally available organic materials. The project, conducted at the Indonesian Institute of Technology (ITI), demonstrated the feasibility of designing and implementing a portable biofiltration system using readily available materials derived from food and beverage, textile, pulp and paper, as well as agricultural processing waste streams. The system provides an affordable alternative for rainwater utilization, improving the conventional practice of directly discharging untreated rooftop runoff into drainage systems.

In terms of technical performance, the system is capable of treating approximately 100–300 liters of rainwater per rainfall event, contributing to a reduction in surface runoff by approximately 20–35% and fulfilling around 15–25% of the non-potable water demand within the campus environment. These findings indicate that the system performs effectively as a preliminary treatment unit, particularly in improving water clarity and reducing suspended solids under practical field conditions.

Beyond its technical contribution, the program has also enhanced awareness regarding rainwater utilization and appropriate water treatment technologies within the campus community, where reliance on groundwater remains dominant. The involvement of project partners in installation, operation, and maintenance activities further supports knowledge transfer and encourages long-term system adoption.

To ensure sustainability, routine monitoring and periodic maintenance by designated personnel are essential, particularly in maintaining filtration efficiency and system functionality. In addition, continued evaluation by researchers is necessary to assess long-term performance, optimize system design, and strengthen quantitative validation of treatment effectiveness.

Overall, this study demonstrates that the integration of simple engineering design with locally available materials can provide a practical and scalable solution for improving water resource management. The portability and replicability of the system make it suitable for broader application in similar institutional or community settings, contributing to environmental sustainability and reducing pressure on conventional water resources. This finding supports broader evidence that decentralized rainwater harvesting coupled with simple treatment systems can contribute to resilient urban water management (Campisano et al., 2017; Li et al., 2022).

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References

American Public Health Association. (2017). *Standard methods for the examination of water and wastewater* (23rd ed.). https://www.standardmethods.org

Campisano, A., Butler, D., Ward, S., Burns, M. J., Friedler, E., DeBusk, K., Fisher-Jeffes, L. N., Ghisi, E., Rahman, A., Furumai, H., & Han, M. (2017). Urban rainwater harvesting systems: Research, implementation and future perspectives. *Water Research, 115*, 195–209. https://doi.org/10.1016/j.watres.2017.02.056

Crini, G., & Lichtfouse, E. (2019). Advantages and disadvantages of techniques used for wastewater treatment. *Environmental Chemistry Letters, 17*, 145–155. https://doi.org/10.1007/s10311-018-0785-9

Fewkes, A. (2000). Modelling the performance of rainwater collection systems: Towards a generalised approach. *Urban Water, 1*(4), 323–333. https://doi.org/10.1016/S1462-0758(00)00026-1

Foo, K. Y., & Hameed, B. H. (2009). Utilization of rice husk ash as novel adsorbent: A judicious recycling of the colloidal agricultural waste. *Advances in Colloid and Interface Science, 152*(1–2), 39–47. https://doi.org/10.1016/j.cis.2009.09.005

Kurniawan, E. A., Ramadani, R. N., & Wijaksana, I. K. (2023). Kajian penyediaan air bersih alternatif melalui pemanenan air hujan di kawasan industri Citatah. *Jurnal Inovasi Pertambangan dan Lingkungan, 3*(1). https://doi.org/10.15408/jipl.v3i1.31844

Li, Z., Boyle, F., & Reynolds, A. (2010). Rainwater harvesting and greywater treatment systems for domestic application in Ireland. *Desalination, 260*(1–3), 1–8. https://doi.org/10.1016/j.desal.2010.05.035

Li, W., Wang, H., Zhou, J., Yan, L., Liu, Z., Pang, Y., Zhang, H., & Huang, T. (2022). Simulation and evaluation of rainwater runoff control, collection, and utilization for sponge city reconstruction in an urban residential community. *Sustainability, 14*(19), 12372. https://doi.org/10.3390/su141912372

Palla, A., Gnecco, I., & Lanza, L. G. (2023). Decentralized stormwater management and sustainable urban drainage systems: A review. *Infrastructures, 8*(6), 103. https://doi.org/10.3390/infrastructures8060103

Toronto and Region Conservation Authority. (2011). *Performance evaluation of rainwater harvesting systems* (Revised ed.). Sustainable Technologies Evaluation Program. https://sustainabletechnologies.ca/app/uploads/2013/01/FINAL-RWH-2011_EDIT3.pdf

Wulandari, N., & Sentosa, R. (2023). Penerapan teknologi tepat guna penyaringan air hujan untuk masyarakat perkotaan. *Jurnal Rekakarya Itenas, 11*(2), 87–96. https://ejurnal.itenas.ac.id

Yuliasari, M., Prasetyo, D., & Lestari, A. (2020). Penerapan biofilter berbasis limbah organik lokal pada kegiatan pengabdian kepada masyarakat. *Jurnal Pengabdian Sains dan Teknologi, 5*(1), 14–22. https://ejurnal.ung.ac.id/index.php/jpst

Zabidi, H. A., Goh, H. W., Chang, C. K., Chan, N. W., & Zakaria, N. A. (2020). A review of roof and pond rainwater harvesting systems for water security: The design, performance and way forward. *Water, 12*(11), 3163. https://doi.org/10.3390/w12113163

Zhang, X., Li, Y., & Wang, Z. (2022). Performance evaluation of rainwater harvesting systems for runoff reduction and water supply. *International Soil and Water Conservation Research, 10*(4), 586–596. https://www.sciencedirect.com/journal/international-soil-and-water-conservation-research/vol/10/issue/4

Zuliarti, A., & Saptomo, S. K. (2021). Perancangan dan pemanfaatan penampung air hujan dengan filtrasi sederhana skala unit perumahan Villa Citra Bantarjati. *Jurnal Teknik Sipil dan Lingkungan, 6*(3), 159–176. https://doi.org/10.29244/jsil.6.3.159-176