Rainwater Harvesting Design for Minimalist Residential (House Types 36, 45, and 60) in Palembang City, Indonesia

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Abstract. The issue of clean water availability occurs not only in arid regions but also in areas with abundant rainfall, such Palembang City, Indonesia. This research aims to evaluate the performance of a rainwater harvesting (RWH) system simulated on a rain roof area (house roof) with areas of 36 m², 45 m², and 60 m². Furthermore, this research also serves as a development of the final de-sign of the RWH system for household scale. The method used in this research is forward engineering and a combined development model: definition – design – simulation - development. From the results of the study, it is concluded that the RWH system with a filtration pipe (8-inch diameter and 90 cm long) has a harvesting capacity of 0.65 m³/day. The simulation results indicate that the RWH system on roofs with areas of 36 m², 45 m², and 60 m² yields water harvests of 62.8%, 55.4%, and 46.4%, respectively. The designed RWH system for residential buildings includes main components such as an L-shaped sedimentation pipe (4 m long PVC pipe with a 4-inch diameter), a filtration pipe (PVC 8-inch, 0.9 m long), an overflow pipe (PVC pipe with a 2-inch diameter and 2 m long), and is equipped with a water storage tank.

Keywords: Rainfall, rainwater harvesting, RWH, rain roof area, filtration.

1 Introduction

Water has always been a basic necessity for everyone and is irreplaceable, as it is closely related to health, the economy, and the environment. However, many people in large cities still lack sufficient access to clean water to meet their daily needs.

The issue of clean water availability occurs not only in arid regions but also in areas with abundant rainfall. One example is Palembang, Indonesia, where more than 50% of the area consists of wetlands (peatlands), which naturally serve as water retention and absorption areas **[1]**. The groundwater is located deep below the surface, while the surface water has high acidity levels, making it unsuitable for consumption. This phenomenon is largely due to natural factors, commonly occurring **[2]** due to Palembang's hydrological conditions, being located downstream and influenced by the tidal fluctuations of the Musi River. This situation is exacerbated by the increasing conversion of wetland areas into built-up areas, such as residential and housing developments **[3]**. Several studies **[4], [5], [6],** have shown that efforts to reclaim or fill wetlands are common in areas of Indonesia, such as Palembang, Pekanbaru, Jambi, Pontianak, and Banjarmasin.

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fill wetlands are common in areas of Indonesia, such as Palembang, Pekanbaru, Jambi, Pontianak, and Banjarmasin.

Residential and housing developments on converted wetland land usually face issues related to the availability of clean water **[7]**. The provision of clean water through dug wells or boreholes often fails to provide adequate amounts, and the water quality is typically murky, rusty, and sometimes foul-smelling, making it unsuitable for use, especially for drinking.

The Palembang city government, through the local water utility company responsible for organizing and managing the clean water supply system, has not been able to provide comprehensive and sustainable service coverage. On one hand, the quality of raw water from the Musi River, which is the main source of clean water, is deteriorating due to pollution from household waste, industrial waste, and other human activities **[8]**. According to **[9]**, industrial activities such as mining and household activities are contributing to the decline in river water quality, including contamination by heavy metals such as mercury. Additionally, there are issues related to poor management of existing water resources and the unequal distribution of water to the community, due to limited funds and resources. Moreover, some residents feel that the water usage fees charged by the local government are relatively high, leading to inconsistent participation.

This research aims to evaluate the performance of a rainwater harvesting (RWH) system simulated on a rain catchment area (house roof) with areas of 36 m², 45 m², and 60 m². Furthermore, this research also serves as a development of the final design of the RWH system for household scale, which will later be used to create a prototype for testing the system's performance and its application in residential buildings.

2 Data and Methodology

The research was conducted in Palembang City, South Sumatra, Indonesia. The tools used in this study include a measuring tape, MS Office 2019, Quantum GIS (QGIS3), and Sketchup 2024. The data utilized consists of daily rainfall data from 2007 to 2023 in Palembang City, the standard water demand for urban areas of 120 (liters/person/day), and the roof area of minimalist houses (types 36, 45, and 60 m²) as rainwater catchment areas.

The method used in this research is forward engineering and a combined development model consisting of definition – design – simulation - development. The similar method namely the Four-D model (define, design, develop, and disseminate, previously used by **[10]** in his experiments and research the aim was to produce a product in the form of a water purification device design and test its effectiveness.

Based on the steps of the 4-D development model mentioned above, the research procedure consists of the following 4 stages:

2.1 Step of Define

The definition stage is useful for determining and defining the requirements in the process of gathering various information related to the product that will be developed. This stage is divided into several steps:

1. Literature Analysis

The initial analysis is conducted to understand the fundamental issues in developing a rainwater harvesting system for residential buildings. In this step, the author examines the basic problems and reviews the benefits and advantages of the rainwater harvesting system.

2. Preliminary Analysis

In this stage, an analysis is conducted on the potential of rainwater as an alternative source of clean water. A more specific review is also carried out regarding the issues of clean water availability, particularly in certain areas.

3. Case Analysis

The case analysis involves a comprehensive and detailed case study to assess the development of the rainwater harvesting system for residential buildings. Model designs and simulations are conducted to further explore the potential of the rainwater harvesting system to be developed

2.2 Design of Model

The selection of the developed design is based on the results of the previous analysis. The initial design of the RWH system for residential buildings is a device designed to be installed on houses, functioning to collect, store, and filter rainwater, making it ready for use or stored as a clean water reserve. The initial design of the RWH system components consists of: the roof of the residential building (with areas of 36, 45, and 60 m²), sedimentation components (4-inch PVC pipe) and filtration pipe (8-inch), storage components (2 m³ underground water tank and 1 m³ tower tank), and overflow/infiltration components.

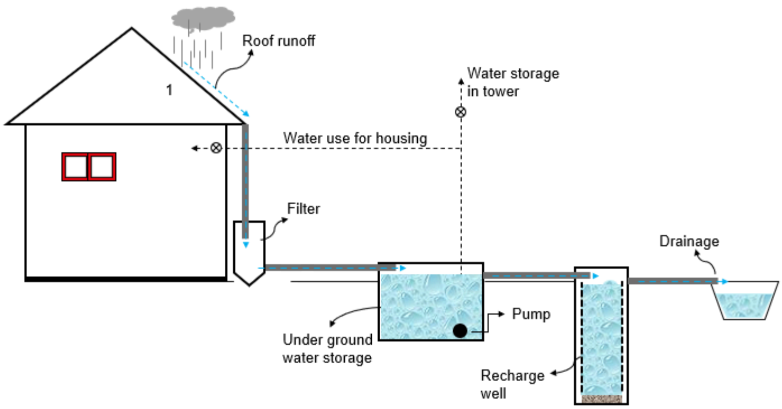

Fig.1. Rainwater harvesting scheme for household

2.3 Prototipe Develope

The prototype design development stage involves designing a more detailed and complete rainwater harvesting system prototype at a 1:1 scale, ready for construction. The components to be developed for the rainwater harvesting system prototype consist of rainwater collection components, filtration components, and storage components (water tank).

2.4 Calculation dan Analysis

1. Calculation of Runoff Discharge

The runoff discharge from the roof of the house (rain catchment area) in this study is calculated using the modified rational method. **[11]** stated that the rational method can be used to calculate runoff discharge in areas with small coverage.

$$Q_R = C \,.\, R \,.\, A_R \quad (1)$$

Dimana:

Q_R = Runoff rate from the catchment area (m^3/day)

C = Runoff coefficient for the catchment area

R = Rainfall (mm)

A_R = Rain roof area (m^2)

2. Calculation of Input Discharge

RWH system uses a filtration component consisting of a combination of gravel, coarse sand, and fine sand. The filtration capacity follows the hydraulic conductivity model of mixed media **[12]**, which is 5 m/day. The volume of harvested water and the amount of overflow from the RWH design are calculated using the following equation model:

$$Q_{RWH} = Q_L - C_f - OF \quad (2)$$

$$C_f = V_f \,.\, 3{,}14 \,.\, r^2 \quad (3)$$

Dimana:

Q_{RWH} = Volume of harvested rainwater (m^3/day)

Q_R = Rainwater runoff rate (m^3/s)

C_f = Filtration capacity (m^3/day)

V_f = Hydraulic conductivity of the filtration (m/hari)

r = Radius of the filtration pipe (4 inch = 0,2032 m)

Oveflow = Rainwater that overflows from the RWH (m^3/day)

3 Results and Discussion

3.1 Simulation dan Analysis

Rainwater falling on the roof of the house is collected through gutters and downpipes, then directed into the sedimentation pipe before entering the filtration pipe. The filtered rainwater can then be used directly as clean water or stored in an underground water storage tank. The RWH simulation results, using daily rainfall data over 16 years (approximately 6,200 days), a rain catchment roof area (36 m²), and an RWH filtration capacity (Cf = 0.65 m³/day), are presented in Figure 2.

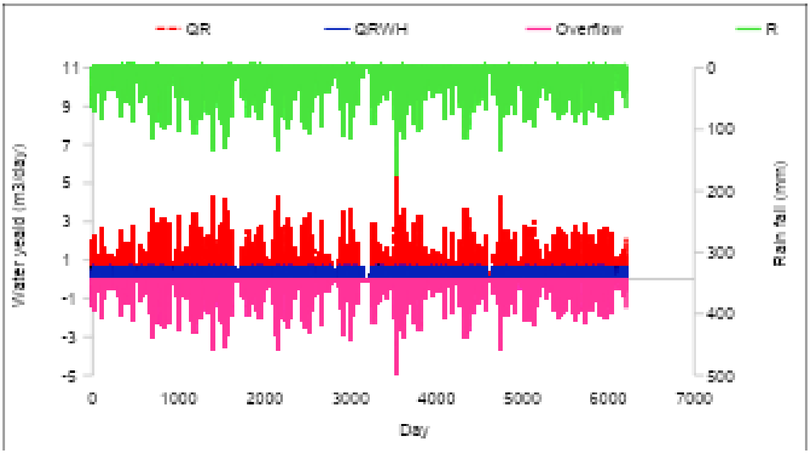

Fig. 2. RWH Simulation water yield (rain roof area 36 m^2)

Information:
Q_L: Rainwater runoff rate (m^3/day)
Q_{RWH} = Volume of rainwater harvested (m^3/day)
Overflow: Rainwater overflows from RWH (m^3/day)
R: Rainfall (mm)

The data shows that the number of rainy days over 16 years in the study area was 3,030 days, with an average daily rainfall of 7.2 mm and a maximum rainfall of 172.4 mm. The results of the analysis, as shown in Table 1, indicate that the larger the rain roof area, the more daily and monthly rainwater is harvested by the RWH system. However, in contrast, when comparing the amount of rainwater that can be harvested to the total runoff from the roof, the RWH system's ability to harvest water decreases as the roof runoff discharge increases. This occurs because the RWH system has a maximum harvesting capacity of 0.65 m³/day. This means that if the runoff entering the RWH system exceeds this value, the amount of rainwater that can be harvested will be equal to its maximum capacity.

Table 1. Water yield RWH system

Roof area (m^2)	Average of roof runoff (Q_L)		Average of rainwater harvested (Q_{RWH})		Average Overflow		% Q_{RWH}
	(m^3/day)	(m^3/month)	(m^3/day)	(m^3/month)	(m^3/day)	(m^3/month)	
36	7.5	90.2	0.15	4.7	0.086	2.8	62.8 %
45	9.4	112.7	0.16	5.2	0.13	4.2	55.4 %
60	12.5	150.3	0.18	5.8	0.21	6.7	46.4 %

In practice, the dimensions and harvesting capacity of the RWH system should be adjusted according to the size of the rain catchment area used for collecting rainwater. According to the Regulation of the Minister of Environment No. 12 of 2014, for every 50 m² of developed land, one RWH system unit with a harvesting capacity of 1.5 m³ is required. For every additional 25–50 m² of developed land, an additional RWH unit with the same harvesting capacity is needed **[13].**

3.2 Rainwater Harvesting Design

The rainwater harvesting system is designed for application in residential houses (types 36/45/60 m²) that function to collect, store, and filter rainwater, making it ready for use or storing it as a clean water reserve at the household scale. Figure 3 below is an example of the design of the RWH system component for a house 36 m² type.

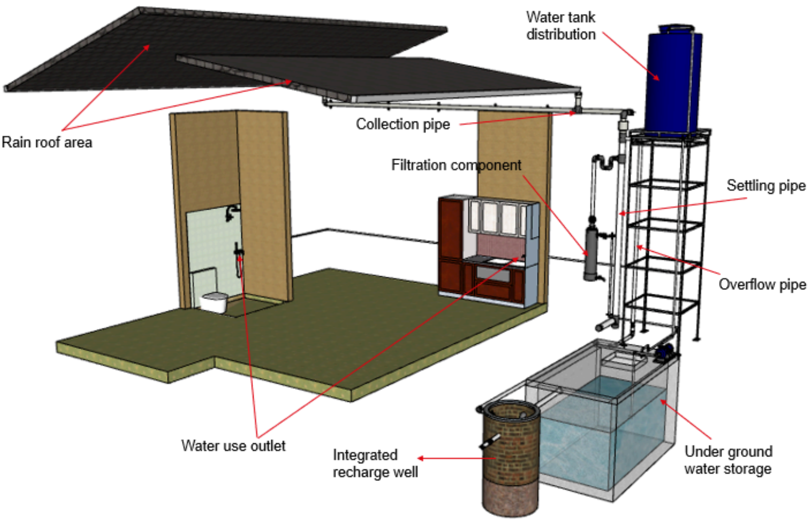

Fig. 3. RWH design for household (type 36/45/60 m^2)

From Figure 3, it is noted that the design of the RWH system consists of several components as follows:

1. Rain Roof Component

The rain catchment component functions as the collector of rainwater (catchment area) to be channeled to the collection system. Types of components that can be used include clay tiles, ceramic tiles, metal multi-roof, galvalume, and concrete. Research by **[14]**, **[15]**, and **[16]** indicates that materials such as asphalt, concrete, ceramic tiles, metal, and clay used for rain catchment roofs in RWH systems produce clean water that meets the hygiene water quality standards for household needs.

2. Main Components of RWH

Main components consist of a sedimentation pipe, filtration pipe, overflow pipe, and water storage tank. This design aligns with the views of **[17], [18],** and **[19]** in their research on the main components and essential units in rainwater harvesting buildings. The sedimentation pipe uses a 4-inch PVC pipe, approximately 3 m long in a straight section, and an L-shaped pipe that is 1 m long, which can be opened and closed to remove sediment or solid waste that accumulates. The overflow pipe uses a 2-inch PVC pipe, approximately 3 m long.

In Figure 4 the filtration component is designed using an 8-inch diameter PVC pipe, 90 cm long, which functions as the casing or container for the filtering stones. The selected PVC pipe should be of at least medium quality (type D) or the highest quality (level AW) because it is stronger and more resistant to breakage. The inlet section of the filtration pipe, where rainwater enters, is equipped with a 1 inch water mur to facilitate installation and routine maintenance. A strainer is installed at the bottom of the ¾-inch pipe as the final filter before the water is discharged. The filtered rainwater is discharged by gravity as clean, ready-to-use water through the outlet pipe (½-inch diameter).

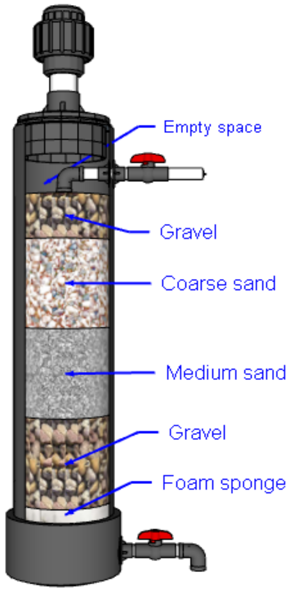

Fig. 4. Filter rocks arrangement

The filtration material used consists of natural rocks arranged vertically from bottom to top in the order of sponge foam, gravel, medium sand (silica), coarse sand, and gravel. Each material has a thickness of 10-20 cm, and the bottom of the filtration pipe is lined with approximately 10 cm of sponge foam, while the top section is left empty without stones. Related research conducted by **[20]** and **[21]** indicates that natural stones are excellent materials for clarifying, eliminating odors, and removing taste from turbid water.

In general, rainwater meets quality standards that are already close to the clean water quality standards, so the natural stone materials used to filter rainwater into clean water are sufficient without the need for additional chemicals. Research by **[22]** and **[23]** shows that gravel functions to filter out coarse particles dissolved in water, while medium and coarse sand (silica sand) serves to filter out medium particles and reduce the hardness of rainwater to meet the clean water quality standards for safe use. Furthermore, **[24]** revealed that silica sand can reduce the levels of TSS (Total Suspended Solids) and TDS (Total Dissolved Solids) in water.

4. Conclusion

From the results of the study, it is concluded that the RWH system with a filtration pipe (8-inch diameter and 90 cm long) has a harvesting capacity of 0.65 m^3/day. The simulation results indicate that the RWH system on roofs with areas of 36 m^2, 45 m^2, and 60 m^2 yields water harvests of 62.8%, 55.4%, and 46.4%, respectively. It is noted that the area of the rain catchment roof has a negative correlation with the percentage of harvested water; this occurs because the RWH system used for simulation has the same dimensions and capacity for each type of roof area.

The designed RWH system for residential buildings includes main components such as an L-shaped sedimentation pipe (4 m long PVC pipe with a 4-inch diameter), a filtration pipe (PVC 8-inch, 0.9 m long), an overflow pipe (PVC pipe with a 2-inch diameter and 2 m long), and is equipped with a water storage tank.

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