JSSEW
Journal of Sustainability, Society, and Eco-Welfare
JSSEW 2(2): 94–110
ISSN 3025-1254

Institute for Advanced Science, Social and Sustainable Future
MORALITY BEFORE KNOWLEDGE

Rainwater as an alternative to saving urban clean water which has economic value: Interaction human and conservation

Edison Reinkarnasi Gulo[1*], Annisa Fitri Mustafa[1]
[1] *School of Environmental Science, Universitas Indonesia, DKI Jakarta 10430, Indonesia.*
*Correspondence: edison.reinkarnasi@ui.ac.id

Received Date: October 30, 2024 Revised Date: January 25, 2025 Accepted Date: January 25, 2025

ABSTRACT
Background: Rainwater Harvesting System (RHS) is an alternative solution that can overcome the problem of demand of urban water with high population density and as a prevention of potential flooding due to lack of catchment areas. Central Jakarta's high population density triggers a large demand for clean water, causing excessive groundwater exploitation and a long impact on groundwater scarcity and seawater intrusion. The implementation of RHS in Indonesia is still relatively rare, especially in Jakarta. Therefore, the purpose of this research is to planning RHS design as an alternative to meet the urban water demands. This research innovates on RHS designs based on water demands and aspects of the feasibility in economics. **Methods**: This research was conducted quantitatively and data collection was carried out by mix method, the number of occupants data was collected through observation and literature review of previous RHS research. The analysis of RHS is carried out mathematics and descriptive. **Findings:** The result showed that the implementation of RHS at X Boarding House succeeded in saving clean water bills by up to 58% with benefit value of IDR 8,093,176. This shows that the RHS is an effective solution in reducing water costs for PDAM bills. The design of the RHS uses roof as catchment area and the tank system is placed above ground taking into ease of operation and maintenance. Benefit Cost Ratio (BCR) analysis shows that the RHS at X Boarding House is feasible to be built with a value of 1,388>1 which shows that the value of the benefits exceeds the costs. **Conclusion** The importance of using rainwater as an alternative to saving clean water by economic value shows that RHS can be an alternative solution to overcome problems, especially water availability during the dry season when the supply of clean water is decreasing. **Novelty/Originality of this article:** This research makes a novel contribution by presenting an RHS design tailored to urban water demand and its economic feasibility, as well as considering operational aspects under Jakarta's unique climatic and environmental conditions.

KEYWORDS: rainwater harvesting system; economic value; clean water; rainwater.

1. Introduction

Water is an essential necessity for life on earth. Humans need water for daily needs, such as drinking, bathing, washing and cooking. In addition, water is also used in various sectors, such as agriculture and industry. Urban water systems in many cities worldwide face significant stress due to factors such as environmental degradation, socio-economic crises, and climate change. Over time, population growth and urbanization have led to a drastic increase in urban clean water consumption, making clean water availability one of the most critical and challenging problems in urban areas. It is imperative to take appropriate and effective steps to ensure sustainable availability of urban clean water to

Cite This Article:
Gulo, E. R., Mustafa, A. F. (2025). Rainwater as an alternative to saving urban clean water which has economic value: Interaction human and conservation. *Journal of Sustainability, Society, and Eco-Welfare, 2*(2), 94-110. https://doi.org/10.61511/jssew.v2i2.2025.1279

support environmental, economic, and social development in cities (Ali & Sang, 2023; Zang, et al, 2018).

Indonesia, with its tropical climate has two seasons, the rainy season and the dry season. This leads to flooding in some areas during the rainy season and drought during the dry season. In 2023, BNPB (2023) predicts a higher dry season in Indonesia than in 2022, 2021 and 2020. Climate change has a significant impact on the availability of environmental services that support life on Earth. Changes in precipitation patterns and increasing extreme weather events have lasting effect on droughts and floods, resulting in water scarcity in several countries around the world (Almeida et al., 2023; Furtak & Wolinska, 2023). Jakarta, as a densely populated capital city, experiences significant population growth, particularly in Central Jakarta, which is home to 1.093.440 people (BPS Kota Jakarta Pusat, 2022) experiencing significant population growth every year which has an impact on various sectors, including the water sector, especially groundwater. Population growth also has an impact on increasing the demand for water resources and changing the pattern of the hydrological cycle in a region. Water shortages will continue to increase, followed by an increase in population and economic activity, while the maintenance of water quality and quantity will decrease. The high use of groundwater has resulted in land subsidence in Jakarta. The water and sanitation crisis in Jakarta is one of the issues discussed in the sustainable development goals. The UN states that there are 785 million people who still have difficulty accessing clean water. The current clean water crisis in Jakarta is a complex problem and requires serious attention from various parties. According to PT. X Jakarta stated that in 2018 Jakarta's annual water needs amounted to 547,5 million m3 and the clean water supply that could be met was only 296,65 million m3 or only about 54% of the existing clean water demand. This triggers the exploitation of groundwater to meet the lack of water demands, resulting in an imbalance between groundwater extraction and recovery. The emptiness of groundwater causes seawater intrusion and land subsidence (Taftazani et al, 2022; Ismahyanti et al., 2021; Sahana & Waspodo, 2020).

Rainwater Harvesting is defined as the concentration, collection, storage and use of rainwater runoff for both domestic and agricultural purposes. Domestic rainwater harvesting refers to the utilization of rainwater for household needs and garden watering. The implementation of the RHS is one of the most promising and effective measures to address the clean water crisis in urban areas. RHS is used to collect and store rainwater in tanks drained from roofs for use instead of tap water or as drinking water. The use of RHS can be an alternative to save clean water costs that tend to be expensive in urban areas (Ali & Sang, 2023). In regions with seasonal rainfall, the RHS helps increase water supply during the dry season and can serve as the primary water source when other sources are limited. Since the 20th century, the implementation of RHS systems and techniques has been widely implemented in several countries as a strategy to reduce dependence on surface and groundwater. Several countries have analysed the water-saving efficiency of RHS utilization (Lebek & Krueger, 2023). A study conducted in Brazil stated that the potential saving of clean water by using the RHS increase from 12% to 79%. In Jordan, the RHS saves approximately 14.5 million m3/year for domestic use, 7.5 m3/100 m2 per year in many cities in Saudi Arabia, 250-550 m3 depending on the catchment area in Dhaka, Bangladesh and the water saving efficiency of the RHS changes from 2% to 20% in arid regions in China, depending on location and water demand. Additionally, an analysis of the financial benefits of RHS in several Australian cities highlights considerable financial advantages (Ali & Sang, 2023; Zhang et al, 2019, Bashar et al, 2018).

Despite Indonesia's high potential for rainfall, the presence of RHS is still relatively rare, particularly in Jakarta. This discrepancy between potential and utilization does not align with the climatic conditions. Rainfall in Indonesia is quite a lot, ranging from 2500 mm to 3500 mm/year with the rainy season typically occurring from October to March. Some islands, such as Sumatra, Java, Kalimantan, and Papua, experience high rainfall, while others like Sulawesi and Nusa Tenggara receive less rainfall. The utilization of rainwater in Indonesia is carried out for various purposes, including irrigation, plantations, domestic use, etc. In addition, rainwater supplies water for the needs of shallow wells used for domestic purposes for Indonesian. In general, the use of rainwater has not been done wisely, so that existing rainwater only becomes runoff water that flows into urban drainage systems (Lestari et al, 2020; Susilo & Prayogo, 2019).

The limited availability of clean water due to the high rate of physical development that eliminates water catchment areas, the high population and the high frequency of flood events in the city of Jakarta, especially Central Jakarta and the successful implementation of RHS that has been carried out in several cities in Indonesia and the world shows the potential for increasing economic value and shows that RHS can be an alternative solution to overcome these problems, especially during the dry season when the supply of clean water is getting less and less. Based on these descriptions, it is considered necessary to plan a RHS design as an alternative to meet the urban clean water demands. This research innovates on rainwater harvesting designs that are in accordance with the clean water demand of the research location and aspects of the feasibility of implementing RHS in terms of economics.

2. Methods

2.1 Case study, data collection, and analysis

This research was conducted at X Boarding House, Central Jakarta, DKI Jakarta. Central Jakarta is the city with the highest population density in DKI Jakarta. Central Jakarta with a high population density has the potential to increase the demand for water resources, resulting in water scarcity. In general, drinking water sources used in the Jakarta area are sourced from drinking water companies. In addition, the research location is an area that has not used rainwater as a source of water to meet daily needs. Then, data collection is carried out primary and secondary. Primary data was obtained through interviews with boarding house owners related to data on the number of residents and clean water needs of boarding house residents. Secondary data was obtained through a literature study about Central Jakarta rainfall data (2017 - 2021) obtained through the website of BPS Provinsi DKI Jakarta (2023) with data sources coming from the Meteorology, Climatology and Geophysics Agency (BMKG). The rainfall data used for the Central Jakarta administrative area is sourced from the Kemayoran monitoring station. Data analysis was carried out with mathematical calculations related to rainwater harvesting planning and economic value analysis of rainwater utilization as a source of clean water at the research site. The characteristics of boarding house are presented in Table 1.

Table 1. The Characteristics of x boarding house, Central Jakarta

Category	Description
Number of Occupants	45
Garden Area	24.5 m^2
Roof Material	Clay tile
Roof Area	504 m^2

Roof sketch to describe the boarding house and serves to describe the catchment area for RHS design purposes. X Boarding House roof sketch shown in Fig. 1. The building layout of X Boarding House, Central Jakarta is needed to describe the allocation of rooms and toilets with their size in the building, as well as the location of the garden depicted in the form of a building layout. X Boarding House shown in Fig. 1. The building characteristic of X Boarding House consist of two floors. Based on Fig. 1. X table 1 presents the characteristics of a boarding house in Central Jakarta, which includes information related to the number of occupants, garden area, roofing material, and roof area. The boarding house is occupied by 45 people, with a garden area of 24.5 m^2, which can contribute to the greening aspect of the environment. The roof of the building uses clay tile material, which generally has heat-resistant and environmentally friendly properties. In addition, the total roof area reaches 504 m^2, which can be an important factor in rainwater management or potential solar energy utilization. This information can be used for further analysis of the condition of the dwelling and its environmental management potential.

Boarding House has a total of 50 rooms which are divided into bedroom and kitchen. Each room has a toilet. Garden is located in front and side of the building, and there is supporting infrastructure, security office. Some mathematical analysis used in this research. Mathematics analysis used to calculated total clean water demand of boarding house each room has a toilet.

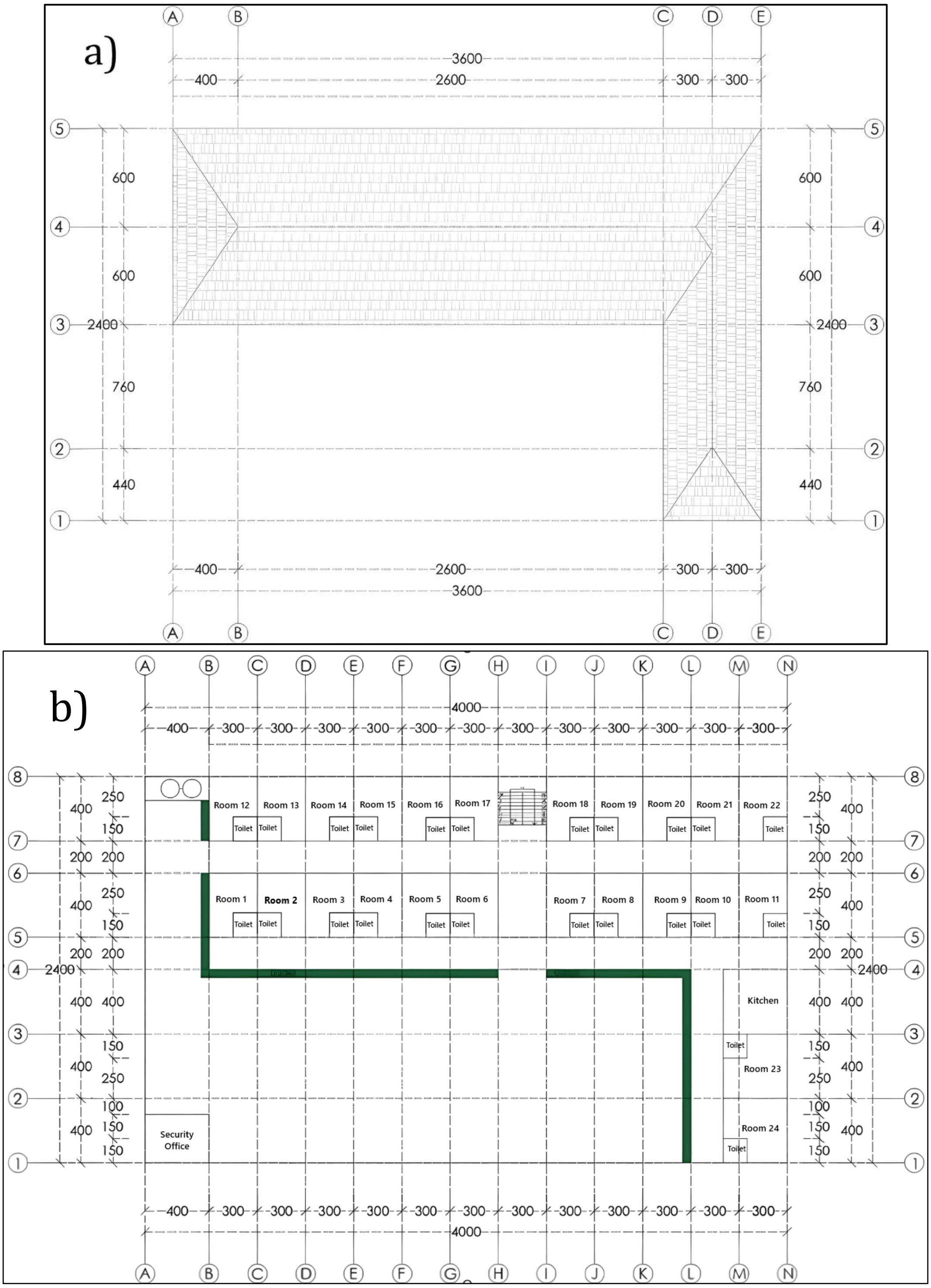

Fig. 1. X Boarding house sketch, Central Jakarta: a) Roof sketch; b) Layout

Garden is located in front and side of the building, and there is supporting infrastructure, security office. Some mathematical analysis used in this research.

Mathematics analysis used to calculated total clean water demand of boarding house residents according to the Equation 1.

$$Qwater\ Demands = (Occupants\ x\ Water\ demands) + (Garden\ Area\ x\ Garden\ water\ demands) \quad \text{(Eq. 1)}$$

Qwater Demands is the discharge of water demands of occupants and water demands for gardening. Qwater Demands will be used for further analysis related to economic value aspect by implementing RHS. Furthermore, mathematical analysis is needed to calculate the volume of RHS. Calculation of rainwater discharge according to the Equation 2.

$$QRHS = P\ x\ A\ x\ C \quad \text{(Eq. 2)}$$

QRHS is the amount of rainwater that is provided by RHS, P is the amount of rainfall, A is the roof area or catchment area in m2 to be used in RHS, and C is the surface roughness value or called as runoff coefficient according to the materials of the catchment areas. Runoff coefficient used in this research is 0.95 according to the characteristic of the roof. Percentage of main rainfall is required to chances of rainfall occurs. The percentage of main rainfall calculate with the Equation 3.

$$P\ (\%) = \frac{m}{(n+1)} \times 100\% \quad \text{(Eq. 3)}$$

P (%) is the minimum chance of rainfall occurring that can be used to determine the probability that it can occur in one month, m is the ranking order of rainfall data, and n is the amount of rainfall data used. The equation for calculating the volume of rainwater storage is determined based on the largest mainstay rainfall data, thus showing the largest volume of rainwater. The rainwater tank capacity calculate with the Equation 4.

$$Vtank = \frac{m\text{QRWHMw}}{n} \quad \text{(Eq. 4)}$$

Vtank is the capacity of rainwater tanks that are needed as a rainwater storage area before being distributed to each room in the boarding house. QRWMw is the rainwater discharge available in the wet months and n is the amount of rainwater data. Analysis of the value of economic benefits of implementing RHS is necessary for the economic feasibility analysis of the application of RHS. The economic calculation of RHS is carried out by calculating the Benefit Cost Ratio (BCR). The calculation of BCR adopted from Odhiambo et al. (2021) as follows Equation 5.

$$\text{BCR} = \frac{\sum_1^n Bt(1+r)^t}{\sum_1^n Ct(1+r)^t} \quad \text{(Eq. 5)}$$

In this context, t serves as a time marker that allows the calculation of benefits and costs in each period to be calculated cumulatively by considering a discount factor. This means that the value of benefits and costs obtained in each period t will be adjusted by a set discount factor of 10%. In simple terms, t is the time span in which investments or expenditures are made and the benefits of the RHS are accumulated, allowing the calculation of the present value of these benefits and costs.

3. Results and Discussion

3.1 Water demands analysis

Results and discussion in this research include analyses carried out for RHS planning at the research site. These analyses include, analysis of water demand, analysis of rainwater availability, planning of RHS, analysis of economic savings in the use of RHS, RHS system design, and the cost of RHS design. Meeting water demand in the residential environment is indeed a top priority to maintain daily life and the residents well-being. Water is the most important raw material and is widely used in the lives of both plants, animals, and humans rely heavily on water as the main necessity (Society, 1941). The water will be used for drinking, cooking, and washing. The demand for clean water is driven by the increasing necessity for clean water for consumption in various sectors of daily life, such as industrial activities, agricultural fields, food production, and sanitation purposes. In addition, consumption and demand for clean water are controlled by the socioeconomic conditions of the community because they affect consumption patterns. (Alsulaili et al., 2022). This means that people with middle to upper income levels tend to consume high amounts of water, especially for the purposes of facilities such as irrigating home gardens, swimming pools, and the use of additional water devices, both indoors and outdoors (Savelli et al., 2023). Table 2 shows the standards for clean water demand of the Department of Public Works in the book Wardana (1999) in Damayanti et al. (2018).

Table 2. Results of standard data processing for household clean water use in indonesia

Activity	Water Demands (litre/person/day)
Bathing, Toilet	12
Laundry	10.7
Ablution	16.2
Vehicle Washing	21.1
Garden	11.8
Others	21.7
Total	93.5

(Wardana, 1999 in Damayanti et al., 2018)

The requirements depends on occupants using water, average clean water consumption per person and needs according to its utilization (Musa et al., 2022). Population growth and urbanization have an impact on the high demand for clean water. In addition, the potential for water scarcity is increasing due to climate change which causes changes in the hydrological cycle that can threaten resources and environmental welfare, such as accessibility to drinking water (Alsulaili et al., 2022). Based on statistical analysis that has been carried out by considering the characteristics of X Boarding House and the number of occupants, the results of the water demand of X Boarding House residents are 3946 L/day or 3,946 m^3/day. The source of clean water X Boarding House's comes from PDAM (Regional Drinking Water Company). PDAM is a provider of clean water used to meet daily needs such as bathing, washing, and consuming drinking water. The use of rainwater harvesting in this research is planned to be used in non-potable water, for bathing, latrine, laundry, etc.

3.2 Rainfall availability analysis

The rainfall data used in this research is secondary data sourced from the website of BPS DKI Jakarta Province, (2023) which is based on BMKG monitoring of Kemayoran monitoring station which covers the administrative area of Central Jakarta. Based on rainfall data by month of Kemayoran Station, it is known that the Central Jakarta Area has maximum rainfall in February (270.10 to 1043.20 mm), while the minimum rainfall is in August (0 to 101 mm) which is the category of dry months in a year. The amount of rainfall that occurs affects the availability of rainwater that can be collected for rainwater harvesting analysis.

Table 3. Rainfall by month Kemayoran Station

Months	Rainfall by Month (mm)				
	2017	2018	2019	2020	2021
January	214.10	215.10	383.90	618.00	332.80
February	520.80	431.20	270.10	1043.20	604.40
March	138.70	188.60	327.30	220.70	244.10

April	156.50	159,10	194.60	182.80	213.90
May	135.00	16.70	47.80	50.40	203.60
June	138.50	12.60	23.10	21.10	79.10
July	119.90	14.50	0.00	12.10	35.80
August	0.80	33.00	0.00	101.00	79.70
September	165.80	62.00	1.00	151.90	113.40
October	112.40	133.80	1.00	208.30	182.10
November	195.30	140.90	50.10	87.30	134.10
December	254.10	52.30	263.80	134.70	171.60

(BPS DKI Jakarta Province, 2023)

The amount of rainfall that exists can be an alternative to meet domestic demands of clean water. This statement is reinforced by Zabidi et al. (2020) which states that for developing countries, rainwater harvesting systems with roof as catchment areas have the ability to meet domestic water demands between 30% and 80% with tank sizes ranging between 5 and 76 m3. The rainfall data obtained is used for mainstay rainfall analysis. Mainstay rainfall is the result of an analysis of the minimum amount of rain that is guaranteed to occur within a certain period of time which shows the magnitude of the chance of rain to occur again by (80%). Based on the analysis, the ranking of mainstay rainfall opportunities is shown in Table 4.

Table 4. Mainstay rainfall rating

Category	Year				
	2017	2018	2019	2020	2021
Average Rainfall/year (mm)	179.33	121.65	130.23	235.96	199.55
Rate	3	5	4	1	2
P (%)	50.00	83.33	66.67	16.67	33.33

Table 4 shows the mainstay rainfall rating based on annual data from 2017 to 2021. The data in the table includes the average annual rainfall (mm), the rainfall rating for each year, and the probability of rainfall occurrence (P%) in the study area. The average annual rainfall shows significant fluctuations, with the lowest value of 121.65 mm in 2018 and the highest of 235.96 mm in 2020. In addition, the probability of rainfall events also varies from year to year, with the highest value of 83.33% in 2018 and the lowest of 16.67% in 2020. This information can be used to understand year-to-year rainfall patterns and assist in water resources planning and mitigation of drought or flood risk in the region.

Based on the results of the analysis shown in Table 4, the data that is considered to be representative is the data of 2017, 2018, and 2019 because it has a greater probability value among others. The largest mainstay rainfall chance is in 2018, which is 83,33% and the lowest mainstay rainfall chance is in 2020, which is 16,67%. Rainfall odds rating closest to 80% shown in Table 5.

Table 5 presents data on the chance of rainfall occurring close to 80% in three different years, namely 2017, 2018 and 2019. In this table, there is information on the amount of rainfall (in millimeters) and the percentage chance of rain in each year. In 2018, the chance of rain reached 83.33% with 121.65 mm of rainfall, which is the highest value compared to other years. Meanwhile, in 2017 and 2019, the chance of rain was 50% and 66.67%, respectively, with 179.33 mm and 130.23 mm of rainfall. This data can be used to analyze rainfall patterns and possible climate change in the studied area.

Table 5. Chance of rainfall that closest to 80%

Year	Rainfall (mm)	Chance of Rainfall (%)
2017	179.33	50
2018	121.65	83.33
2019	130.23	66.67

Table 6 displays the main rainfall data per month from 2017 to 2019, which was then averaged to produce the main rainfall value per month in millimeters (mm). This data was used in the design analysis of the rainwater harvesting system, focusing on calculating the tank capacity required to store rainwater in the boarding house area. The average of the main rainfall per month is important because it illustrates the seasonal fluctuations that affect rainwater availability throughout the year, which will be used as the basis for planning the optimal storage capacity.

Table 6. Main Rainfall

Months	2017	2018	2019	Main Rainfall (mm)
January	214.10	215.10	383.90	271.03
February	520.80	431.20	270.10	407.37
March	138.70	188.60	327.30	218.20
April	156.50	159.10	194.60	170.07
May	135.00	16.70	47.80	66.50
June	138.50	12.60	23.10	58.07
July	119.90	14.50	0.00	44.80
August	0.80	33.00	0.00	11.27
September	165.80	62.00	1.00	76.27
October	112.40	133.80	1.00	82.40
November	195.30	140.90	50.10	128.77
December	254.10	52.30	263.80	190.07

The results of the mainstay rainfall analysis shown in Table 7 will be used as a guideline for rainwater harvesting planning analysis. The description of the month's mainstay rainfall is shown in Fig. 1. Based on the graph shown in Fig. 2. below, the highest rainfall was in February at 407.37 mm and the lowest was in August at 11.27 mm.

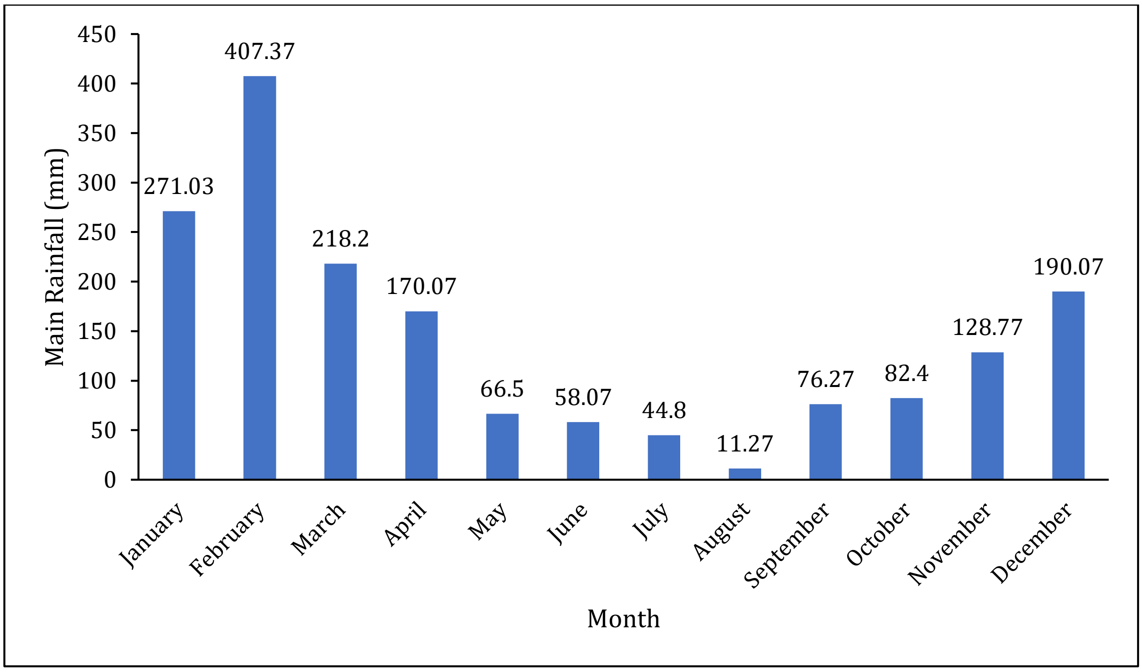

Fig. 2. Main Rainfall (mm)

The mainstay rainfall classification based on Schmidt-Ferguson consists of Dry Months (Md) with the amount of rainfall < 60 mm, Humid Months (Mh) with the amount of rainfall 60 to 100 mm, dan Wet Months (Mw) with the amount of rainfall > 100 mm (Yasa et al., 2022). Fig. 3. shows that Md present in June to August, Mh consists of May, September, and October, and Mw started from November to April. Based on the mainstay rainfall analysis, the amount of rainwater that can be harvested is shown in Table 7 below.

Table 7. The amount of rainwater

Months	QRHS (L/day)
January	4325.69
February	6501.57
March	3482.47
April	2714.26
May	1061.34
June	926.74
July	715.01
August	179.82
September	1217.22
October	1315.10
November	2055.12
December	3033.46

Table 7 shows the monthly amount of rainwater that can be collected in liters per day (L/day) based on the QRHS calculation. The results show considerable variation between months, with the highest peak in February (6501.57 L/day) and the lowest in August (179.82 L/day). Months with high rainfall occur early in the year, especially January to March, while months with lower rainfall occur in the middle of the year, such as June to August. Rainfall starts to increase again in the later months of the year, such as November (2055.12 L/day) and December (3033.46 L/day). This data shows a seasonal pattern that can be used as a reference for rainwater management and utilization throughout the year.

3.3 Rainwater harvesting system planning

The high potential of rainwater in Mw can potentially meet the water demands of urban communities, Central Jakarta, DKI Jakarta. In addition, the implementation of rainwater harvesting can reduce the chances of urban flooding, especially for areas with high building density, such as cities that have low catchment areas (Custódio & Ghisi, 2023; Istachuk & Ghisi, 2022; Gerafi & Ghisi, 2017). These characteristics are in accordance with the conditions of the Central Jakarta area with high building density and diverse space utilization. Thus, rainwater harvesting systems can be an alternative to prevent flooding due to high rainfall, especially in wet months. The calculation of storage capacity in the RHS is adjusted to the amount of rainfall. This statement is supported by Kim et al. (2021) which states that the RHS system has a significant correlation with the amount of annual rainfall. The calculation of tank capacity is based on data on maximum rainwater, which is the largest rainfall that occurs in January and February which is Mw.

$$\text{Vtank} = \frac{QRWH\ January + QRWH\ February}{2}$$

$$= \frac{4325.69 + 6501.57}{2}$$

$$= 5413.63 \text{ L}$$

Based on analysis, the tank capacity required for rainwater harvesting design is 5413.63 L. Then, this research will be used tanks with a capacity of 8000 L considering the availability of tanks on the market and preventing spill over due to excess rainfall. Based on tank capacity, rainwater filling time in the tank shown in Table 8.

The 8000 L capacity water storage shown in Table 8 shows that the most water availability is found in February with a tank filling time of once and in January and March with the number of tank fillings twice. The lowest amount of water available in tanks takes place in July and August with 10 and 38 fills. This is because the amount of rainfall in both months is the lowest rainfall throughout the year and falls into the Dry Months (Md) category based on the Schmidt-Ferguson month classification.

Table 8. Rainwater filling time

Months	QRHS (L/day)	Rainwater filling (Tank: 8000 L/day)
January	5088.52	2
February	7648.12	1
March	4096.60	2
April	3192.92	3
May	1248.51	6
June	1090.17	7
July	841.10	10
Augustus	211.53	38
September	1431.87	6
October	1547.02	5
November	2417.53	3
December	3568.41	2

3.4 Economic analysis of rainwater harvesting system (RHS) utilization

The analysis of economic savings with by using RHS is based on the availability of rainwater that can be collected and the total water demand for various purposes at the research site. Economic benefit value analysis by using RHS at the research location shown in Table 9. In the table below can be seen that comparison of water demand and water availability in January to February exceeding water demand, showing a surplus of water volume.

Table 9. Benefit value

Months	Water Demands (L/H)	Harvested Rainwater (L/H)	% Fulfilments of Demands	Benefit Value IDR
January	3946	4325.69	109.622	IDR 1,271,753
February	3946	6501.57	164.764	IDR 1,911,462
March	3946	3482.47	88.253	IDR 1,023,847
April	3946	2714.26	68.785	IDR 797,994
May	3946	1061.34	26.897	IDR 312,034
June	3946	926.74	23.486	IDR 272,463
July	3946	715.01	18.120	IDR 210,212
Augustus	3946	179.82	4.57	IDR 52,866
September	3946	1217.22	30.847	IDR 57,862
October	3946	1315.10	33.328	IDR 386,641
November	3946	2055.12	52.081	IDR 604,204
December	3946	303346	76.874	IDR 891,838
Total	47.352	27.528		IDR 8,093,176

The surplus can be used as an alternative to meet clean water demands in the dry months, especially in March to December. Thus, rainwater harvesting in months with water surplus can be an effective solution in overcoming water deficit in the next period. Reduced water demand can result in reduced operational and capital costs for water utilization (Coombes et al., 2016). By utilizing rainwater through rainwater harvesting systems, it can reduce water demand from PDAMs which in turn can reduce monthly water bills. Currently, X Boarding House Central Jakarta uses 118.38 m^3 PDAM water per month or 1,420 m^3 every year. The tariff charged for Group IVA group in Central Jakarta is IDR 9,800 m^3 based on DKI Governor Regulation No. 91 of 2017 concerning automatic tariff adjustment of drinking water. This means that every month X Boarding House spends IDR 1,160,214 or IDR 13,921,488 every year to pay water bills from PDAM. With the utilization of RHS, X Boarding House significantly reduces PDAM's water bill. In each year, X's Boarding House saves IDR 8,093,176 or around 58% of the total bills. This shows that the use of RHS provides an effective solution in reducing the costs that must be incurred for PDAM. This is supported by Zabidi et al. (2020) which states that the ability of the RHS can meet domestic clean water demands and reduce dependence on groundwater, and can reduce monthly expenses by up to 50%. These savings depending on the volume of rainwater that can be collected and used efficiently.

3.5 rainwater *harvesting system design*

Rainwater Harvesting System (RHS) design applied to X Boarding House, Central Jakarta is a roof harvesting system that utilizes the roof as a catchment area of rainfall. The concept of roof harvesting system is used in several country (Italy, Australia, Spain, Ireland, Jordan, Ireland, dan Malaysia) (Zabidi et al., 2020). Kim et al. (2021) also emphasized that RHS with a roof as a catchment area is the most common type of RHS system and has minimal maintenance costs. The rainwater will be collect from the catchment area (roof) and stream to rainwater tank before distribution. Roof material in this rainwater harvesting system is clay tile. This is in accordance with the statement of Zabidi et al. (2020) which states that clay tile and flat roofs are the common types of roofs in Mediterranean landscapes which indicate that clay tiles are suitable for use as catchment area materials. Rainwater harvesting system design shown in Fig. 3.

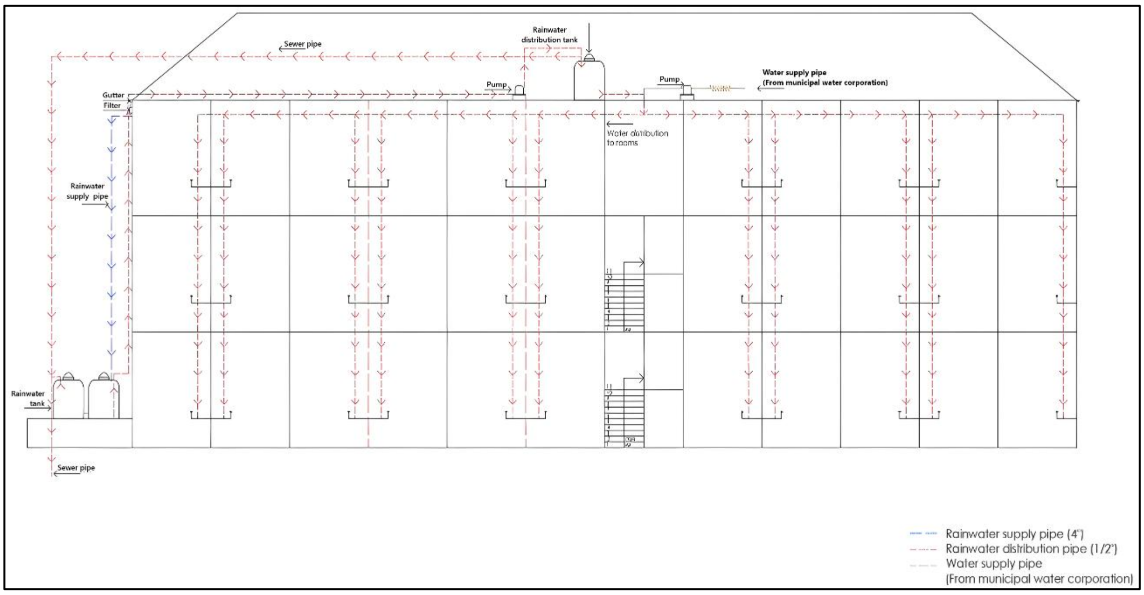

Fig. 3. Rainwater harvesting system design

Rainwater storage applied in this study is using an aboveground system with consideration of ease of accessibility for maintenance and ease of material selection for the rainwater harvesting system to be applied. This is supported by the statement of Musa et al. (2022) which states that the failure rate of the rainwater harvesting system that is placed underground is higher than the rainwater harvesting system aboveground. Rainwater storage tanks are placed close to the catchment area with the aim of facilitating the gravity system (Tsanov et al, 2024; Zabidi et al., 2020). Basic element of rainwater harvesting system shown in Fig. 4.

The rainwater distribution system is connected to the PDAM pipe using a storage tank and water pump. The water distribution process begins with RHS. RHS use the roof as a surface designed to collect rainwater. Rainwater catchment area using roof with clay tile as a base material. The designed roof surface is recommended to have a slope so that rainwater can flow easily into the storage. Rainwater collected on the surface is flowed through drainage channels. This channel is a gutter that direct the flow of water to a storage area or storage tank. Before rainwater enters the storage tank or RHS, filtration is carried out. The purpose of filtration is to remove dirt, leaves and other particles that can enters in rainwater tanks. Rainwater that has gone through the filtration process is then channeled using pipes and stored into rainwater storage tanks. This water tank should not be higher than the roof of the rainwater harvester. The water tank is located parallel to the elevation of the height of the first floor. There are two rainwater tanks used with a capacity of 8000 L/tank. Rainwater stored in water tanks is then distributed to 8000 L transit storage tanks through distribution pipes, then flowed to each room using a water pump. This tank is equipped with a sewer pipe that serves as a drain to urban drainage in case of excess water in the tank.

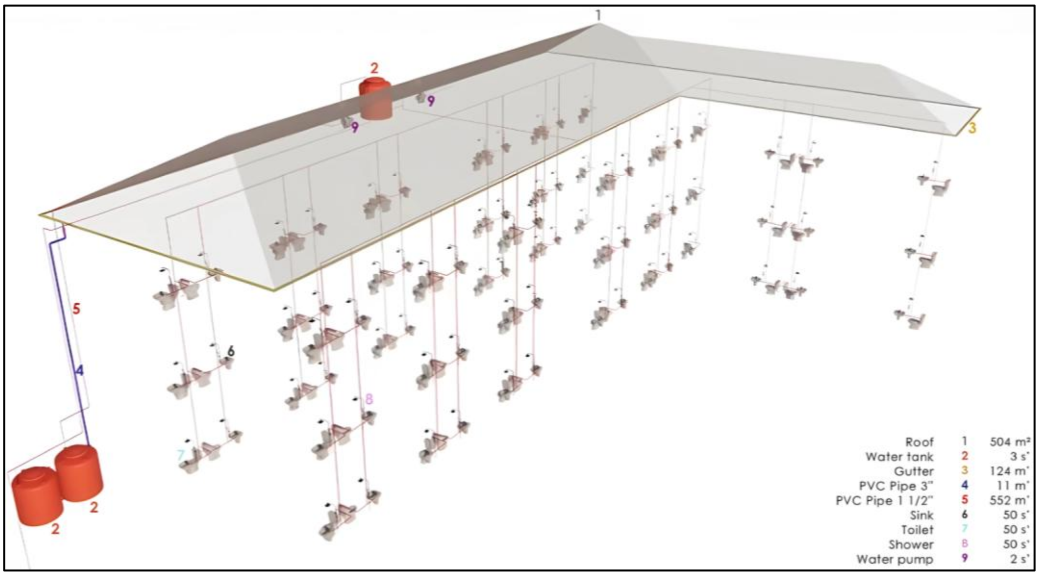

Fig. 4. Water distribution system design

Based on observations, there has been an installation of piping system at the research location. The total piping that has been installed in the installation of Boarding House X, Central Jakarta is 483.5 m so that the pipe length requirement that needs to be added for the rainwater harvesting system is 69.5 m for PVC pipes measuring 1/2 inch. Catchment area of RHS using building roof of Boarding House X, Central Jakarta (504 m2) dan QRHS in every year is 27,528 L.

3.6 Cost of rainwater harvesting system design

In planning a RHS, various material components are needed to build a RHS. The cost budget plan in this research uses unit price from the DKI Jakarta building materials catalogue. Keep in mind that these are only rough estimates and may change depending on the size of the project, specific needs, and price fluctuations. Estimated construction cost of rainwater harvesting shown in Table 10.

Table 10. Estimated Construction Cost of Rainwater Harvesting System

Construction Components	Volume	Unit	Unit Price		Total
Investment					
Gutter	124	m′	IDR	92,750	IDR 11,501,000
PVC 3” pipe	11	m′	IDR	53,300	IDR 586,300
PVC ½” pipe	69.5	m′	IDR	6. 800	IDR 472,600
3” pipe accessories	3	Unit	IDR	25.875	IDR 77,625
½” pipe accessories	11	Unit	IDR	6.640	IDR 73,040
Pump	1	Unit	IDR	1.286.900	IDR 1,286,900
Tank construction cost (K100)	6	m^3	IDR	770.000	IDR 4,620,000
Cost of construction	204.5	m′	IDR	15,000	IDR 3,067,500
Total cost of investment					IDR 3,084,964
Operational & Maintenance (O &M)					
The cost of cleaning gutters, pipes, and tank (once/month)	12	oh	IDR 100,000		IDR 1,200,000
Total operational costs					IDR 1,200,000
Total cost of investment + O & M Cost					IDR 34,284,965

 https://doi.org/10.61511/jssew.v2i2.2025.1279

Table 10 presents the estimated construction cost of a rainwater harvesting system, covering initial investment as well as operation and maintenance costs. In the investment section, the table details the various construction components such as gutters, PVC pipes of various sizes, pipe accessories, pumps, as well as the construction cost of storage tanks. Each component is listed with the volume, unit, price per unit, and total cost required. The total construction cost calculated reached IDR 3,084,964. In addition, there are details of operational and maintenance (O&M) costs, including the cost of cleaning gutters, pipes, and tanks carried out monthly, totaling IDR 1,200,000 per year. Overall, the total investment and operational costs of this rainwater harvesting system amounted to IDR 34,284,965. This information can be used to assess the economic feasibility as well as the long-term benefits of the rainwater harvesting system in the planned location.

Based on Table 10, from an economic, the initial cost used to implement a RHS is a form of investment. Therefore, it is important to evaluate whether the value of the investment is proportional to the profit to be obtained. The initial design of the RHS at X Boarding House requires an initial investment cost of IDR 33,804,964. Meanwhile, the estimated operational and maintenance costs are IDR 1,200,000/year. In the maintenance of these RHS, emphasis is placed on the maintenance of gutters, pipes, and water tanks. In this calculation, it is assumed that rainwater harvesting will be used for 10 years. Therefore, the monthly costs that will be incurred for RHS investment are as much as IDR 285,708/10 Years x 12 months. Optimal utilization of RHS must be proven both technically and economically. This optimization can be done with investment analysis. Investment analysis carried out includes Benefits Cost Ratio (BCR) (Odhiambo et al., 2021). Based on the analysis of benefit value and total investment costs, as well as operational and maintenance, the Benefit Cost Ratio (BCR) can be calculated to determine the economic feasibility of implementing this rainwater harvesting. BCR analysis shown in Table 11.

Table 11. Benefit Cost Ratio Analysis

Years	Investment IDR	O&M Cost IDR	Total Cost IDR	Benefit IDR	Net Benefit IDR	D.F 10%	PV Benefit IDR	PV Cost IDR
0	34,284,965		34,284,965		-34,284,965	1	8,093,175,552	34,284,965
1		1,200,000	1,200,000	8,093,176	6,893,176	0.9091	7,357,432.32	1,090,909.09
2		1,200,000	1,200,000	8,093,176	6,893,176	0.8264	6688574.836	991,735.54
3		1,200,000	1,200,000	8,093,176	6,893,176	0.7513	6,080,522.579	901,577.76
4		1,200,000	1,200,000	8,093,176	6,893,176	0.6830	5,527,747.799	819,616.15
5		1,200,000	1,200,000	8,093,176	6,893,176	0.6209	5,025,225.271	745,105.59
6		1,200,000	1,200,000	8,093,176	6,893,176	0.5645	4,568,386.61	677,368.72
7		1,200,000	1,200,000	8,093,176	6,893,176	0.5132	4,153,078.737	615,789.74
8		1,200,000	1,200,000	8,093,176	6,893,176	0.4665	3,775,526.124	559,808.86
9		1,200,000	1,200,000	8,093,176	6,893,176	0.4241	3,432,296.477	508,917.14
10		1,200,000	1,200,000	8,093,176	6,893,176	0.3855	3,120,269.524	462,651.95
			Total				57,822,235.83	41,658,445.53

In this calculation, it is assumed that rainwater harvesting will be used for 10 years. The calculation of BCR is as follows.

Benefit value = IDR 57,822,235.83
Cost value = IDR 41,658,445.63

$$\text{BCR} = \frac{\text{PV Benefit}}{\text{PV Cost}}$$

$$\text{BCR} = \frac{\text{IDR } 57{,}822{,}235.83}{\text{IDR } 41{,}658{,}445.63}$$

$$\text{BCR} = 1{,}388 > 1$$

From the results, it is obtained that the BCR value is greater than one, so the construction of the X Boarding House rainwater harvesting system is feasible to build and can be economically beneficial for the local community, as stated by Joleha et al. (2019) The application of RHS can be one of the best methods to restore the hydrological cycle in the concept of sustainable urban development. In addition, technically and economically, the application of RHS can be the right solution because it is affordable and can be adapted to hydrological, social, and cultural conditions. The advantages of implementing RHS are simple, economically profitable, efficient, sustainable and adaptable, can be applied on a small scale, easy to operate, and cost-effective in its operational processes.

4. Conclusions

Rainwater has considerable potential to meet water demands. Applying the right RHS design, rainwater can be collected from the roof and stored in water storage tanks. The rainwater will be used for various purposes such as bathing, washing, ablution, watering the garden and other daily needs, and can be an alternative for urban flood prevention. With the implementation of RHS at X Boarding House, water bill savings reach 58% with a benefit value of IDR 8,093,176.

RHS design applied in this research using the roof as a catchment area and the placement of the water storage system placed above ground was chosen by considering the ease of operation and maintenance. From the calculation of the Benefit Cost Ratio (BCR), it shows that the construction of the RHS system in X Boarding House is feasible to build with a value of 1,388 > 1 which proves that the value of the benefits derived from saving water through the RHS system is greater than the cost incurred to build the RHS. Further research is needed by considering the quality of rainwater at the study site and the analysis of chemical contaminants from the use of materials in RHS. In addition, RHS design can consider water treatment systems to be used as potable water in urban areas.

Acknowledgement
This research was conducted to qualify for the Human Life and Environmental Systems course, School of Environmental Sciences, University of Indonesia by involving X Boarding House owners, Central Jakarta, DKI Jakarta Province, which is the target area for the implementation of RHS. The author appreciates the support that has been given by any parties who participated in this research, owners and officers of X Boarding House, and also for the lecturers for all the knowledge, and experience that have been given.

Author Contribution
E. R. G., & A. F. M as the proposer of ideas. All authors compile and discuss theories and results, as well as analysis of rainwater harvesting systems and contribute to the final manuscript.

Funding
This research received no external funding.

Ethical Review Board Statement
Not available.

Informed Consent Statement
Not available.

Data Availability Statement
Not available.

Conflicts of Interest

The authors declare no conflict of interest.

Open Access

References

[BNPB] *Badan Nasional Penanggulangan Bencana/*National Disaster Management Agency. (2023). Long Drought Potential in 2023, BNPB Prepares Prevention Strategy: https://bnpb.go.id/berita/potensi-kemarau-panjang-pada-2023-bnpb-siapkan-strategi-pencegahan-karhutla-). Retrivied April 13, 2023.

Ali, S., & Sang, Y. F. (2023). Implementing rainwater harvesting systems as a novel approach for saving water and energy in flat urban areas. *Sustainable Cities and Society, 89*(August 2022), 104304. https://doi.org/10.1016/j.scs.2022.104304

Almeida, A. P., Liberalesso, T., Silva, C. M., & Sousa, V. (2023). Combining green roofs and rainwater harvesting systems in university buildings under different climate conditions. *Science of The Total Environment, 887*(December 2022), 163719. https://doi.org/10.1016/j.scitotenv.2023.163719

Alsulaili, A., Alkandari, M., & Buqammaz, A. (2022). Assessing the impacts of meteorological factors on freshwater consumption in arid regions and forecasting the freshwater demand. *Environmental Technology & Innovation, 25*, 102099. https://doi.org/10.1016/j.eti.2021.102099

Bashar, M. Z. I., Karim, M. R, Imteaz, M. A. (2018). Reliability and economic analysis of urban rainwater harvesting: A comparative study within six major cities of Bangladesh, *Resources, Conservation and Recycling, 133,* 146-154. https://doi.org/10.1016/j.resconrec.2018.01.025

BPS Kota Jakarta Pusat. (2022). Central Jakarta City in Numbers, https://jakpuskota.bps.go.id/publication/2022/02/25/c609651e46568d34090e4022/kota-jakarta-pusat-dalam-angka-2022.html)

BPS Provinsi DKI Jakarta. (2023). *Rainfall at Kemayoran Station by Month (mm).* https://jakarta.bps.go.id/indicator/151/373/1/curah-hujan-di-stasiun-kemayoran-menurut-bulan.html)

Coombes, P. J., Smit, M., & MacDonald, G. (2016). Resolving boundary conditions in economic analysis of distributed solutions for water cycle management. *Australian Journal of Water Resources, 20*(1), 11–29. https://doi.org/10.1080/13241583.2016.1162762

Custódio, D. A., & Ghisi, E. (2023). Impact of residential rainwater harvesting on stormwater runoff. *Journal of Environmental Management, 326*(November 2022), 116814. https://doi.org/10.1016/j.jenvman.2022.116814

Damayanti, A., Mulki, G. Z., & Ayuningtyas, R. A. (2018). Analysis of domestic clean water needs in Kedamin Darat Village and Kedamin Hilir Village. Muara Journal of Science, Technology, *Medical and Health Sciences, 2*(1), 1–11. https://jurnal.untan.ac.id/index.php/JMHMS/article/view/27594/75676577916

Furtak, K., & Wolińska, A. (2023). The impact of extreme weather events as a consequence of climate change on the soil moisture and on the quality of the soil environment and agriculture – A review. *Catena, 23.* https://doi.org/10.1016/j.catena.2023.107378

Geraldi, M. S., Ghisi, E. Influence of the length of rainfall time series on rainwater harvesting systems: A case study in Berlin. *Resources, Conservation and Recycling, 125*, 169-180. https://doi.org/10.1016/j.resconrec.2017.06.011

Ismahyanti, F., Saleh, R., & Maulana, A. (2021). Planning the Utilization of Rainwater Harvesting System (PAH) in supporting the implementation of ecodrain on campus B of State University of Jakarta. *Tower: Journal of Civil Engineering, 16*(1), 18–25. https://doi.org/10.21009/jmenara.v16i1.19328

Istachuk, R. N., & Ghisi, E. (2022). Influence of rainfall time series indicators on the performance of residential rainwater harvesting systems. *Journal of Environmental Management, 323*. 116163. https://doi.org/10.1016/j.jenvman.2022.116163

Joleha, Mulyadi, A., Wawan, & Suprayogi, I. (2019). Application of Rainwater Harvesting Technology to Supply Sustainable Domestic Water. International Journal of Electrical, *Energy and Power System Engineering, 2*(1), 10–14. https://doi.org/10.31258/ijeepse.2.1.10-14

Kim, J. E., Teh, E. X., Humphrey, D., & Hofman, J. (2021). Optimal storage sizing for indoor arena rainwater harvesting: Hydraulic simulation and economic assessment. *Journal of Environmental Management, 280*. https://doi.org/10.1016/j.jenvman.2020.111847

Lebek, K., & Krueger, T. (2023). Conventional and makeshift rainwater harvesting in rural South Africa: exploring determinants for rainwater harvesting mode. *International Journal of Water Resources Development, 39*(1), 113–132. https://doi.org/10.1080/07900627.2021.1983778

Lestari, E., Pranoto, W., & Makarim, C. A. (2020). Utilization of rainwater harvesting installation to fulfil water needs in educational buildings. *IOP Conference Series: Materials Science and Engineering, 852,* 1-8. https://doi.org/10.1088/1757-899X/852/1/012054

Musa, S. M. S., Mostaffa, M. F., Manap, N., Yassin, A. M., & Zainal, R. (2022). Small Scale Rainwater Harvesting Design for External Usage. *Environment and Ecology Research, 10*(2), 267–274. https://doi.org/10.13189/eer.2022.100216

Odhiambo, K. O., Iro Ong'Or, B. T., & Kanda, E. K. (2021). Optimization of rainwater harvesting system design for smallholder irrigation farmers in Kenya: A review. Aqua Water Infrastructure, *Ecosystems and Society, 70*(4), 483–492. https://doi.org/10.2166/aqua.2021.087

Sahana, M. I., & Waspodo, R. S. B. (2020). Mapping of Seawater Intrusion into Coastal Aquifer: A Case Study of Pekalongan Coastal Area in Central Java, *Journal of The Civil Engineering Forum, 6*(2), 183-182. https://doi.org/10.22146/jcef.53736

Savelli, E., Mazzoleni, M., Baldassarre, G. Di, Cloke, H., & Rusca, M. (2023). Urban water crises driven by elites' unsustainable consumption. Nature Sustainability. https://doi.org/10.1038/s41893-023-01100-0

Society, T. H. E. N. (1941). Proceedings Of The Nutrition Society. *British Medical Journal, 2*(4214), 516. https://doi.org/10.1136/bmj.2.4214.516

Susilo, G. E., & Prayogo, T. B. (2019). Rainwater Harvesting As an Alternative Source of Domestic Water in Lampung Province - Indonesia. *Tataloka, 21*(2), 305. https://doi.org/10.14710/tataloka.21.2.305-313

Taftazani, R., Kazama, S., Takizawa, S. (2020). Spatial Analysis of Groundwater Abstraction and Land Subsidence for Planning the Piped Water Supply in Jakarta, Indonesia. *Water, 14*(20). https://doi.org/10.3390/w14203197

Tsanov, E., Valchev, D., Ribarova, I., & Dimova, G. (2024). Quality of Harvested Rainwater from a Green and a Bitumen Roof in an Air Polluted Region. *Civil Engineering Journal, 10*(5). https://doi.org/10.28991/CEJ-2024-010-05-015

Yasa, I. W., Sulistiyono, H., Saadi, Y., & Hartana, H. (2022). Spatial Climate Forecasting for Climatology Disaster Mitigation. *Environment and Ecology Research, 10*(6), 786–796. https://doi.org/10.13189/eer.2022.100613

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 (Switzerland), 12*(11), 1–22. https://doi.org/10.3390/w12113163

Zhang, S., Zhang, J., Jing, X., Wang, Y., Wang, Y., & Yue, T., (2018). Water saving efficiency and reliability of rainwater harvesting systems in the context of climate change. *Journal of Cleaner Production, 196,* 1341-1355. https://doi.org/10.1016/j.jclepro.2018.06.133

Zhang, S., Zhang, J., Xue, T, & Yue, T. (2019). Impacts of climate change on urban rainwater harvesting systems. *Science of The Total Environment, 665*, 262-274. https://doi.org/10.1016/j.scitotenv.2019.02.135

Biographies of Authors

Edison Reinkarnasi Gulo, School of Environmental Science, Universitas Indonesia DKI Jakarta 10430, Indonesia.

- Email: edison.reinkarnasi@ui.ac.id
- ORCID: N/A
- Web of Science ResearcherID: N/A
- Scopus Author ID: N/A
- Homepage: N/A

Annisa Fitri Mustafa, School of Environmental Science, Universitas Indonesia, DKI Jakarta 10430, Indonesia.

- Email: annisa.fitri21@ui.ac.id
- ORCID: N/A
- Web of Science ResearcherID: N/A
- Scopus Author ID: N/A
- Homepage: N/A