Analysis of Rainwater Harvesting System for 36-Type House in Palembang City as an Alternative for Clean Water Supply

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Abstract. The increase in population resulted in an increased need for housing. Opening up land for housing development worsened runoff by reducing vegetation that covered the soil. The areas that underwent land clearing were at risk of experiencing a shortage of clean water supply for household needs during the dry season. The use of rainwater was employed as one of the efforts in conserving water resources. This research aimed to design a rainwater harvesting system for 36-square-meter houses in Palembang City as an alternative water supply solution. Data processing was carried out using rainfall data from the last 15 years (2008-2022) obtained from the Meteorological Station of Sultan Mahmud Badaruddin II in Palembang City. A 36-square-meter house had a roof area of 53.12 square meters. The availability of rainwater was obtained at 132.59 liters per day and could meet the daily water needs of one person, based on the average family size. The use of the rainwater harvesting system could save water cost of Palembang Local Water Company (Regional Water Supply Company) by IDR 165,920.2 per year.

Keywords: Rainwater, Rainwater Harvesting, Clean Water Needs

1 Introduction

Based on data from the Central Statistics Agency in 2021, Palembang City had a population of approximately 1,686,073 people with a population density of around 4,209 people per square kilometer. Furthermore, between 2010 and 2020, the population of Palembang City grew by 1.03 percent. With the significant population growth, there was also an increased demand for housing [1]. Developers and housing construction in Palembang City became highly relevant in fulfilling the basic human need for decent housing.

Opening up land for housing development worsened surface runoff by reducing vegetation that protected the soil and disrupted soil structure, especially in wetland and river areas [2], [3]. Excessive surface runoff could lead to flooding [4]. In addition to the potential for flooding, areas that underwent land clearing were also at risk of experiencing a shortage of clean water supply for households during the dry season [5].

To meet the household's clean water needs, the available rainwater source in the area could be utilized [6]. This rainwater could be collected in special containers with the

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aim of providing an additional supply of clean water that would be beneficial during the dry season [7]. Therefore, it was necessary to design a household-scale rainwater collection system to create the infrastructure that allowed for the utilization of rainwater [8].

Rainwater harvesting was a method used to collect rainwater during periods of high rainfall and to utilize it during dry seasons [9]. Rainwater harvesting was a simple and effective approach that could be done through building rooftops or ground surfaces [10]. Several studies had been conducted on rainwater harvesting to meet household's clean water needs. Besides fulfilling clean water needs, rainwater harvesting also helped reduce excessive runoff in drainage systems and supported water management in an agricultural context [11].

The objective of this research was to analyze of potential development of rainwater harvesting system that could be implemented in 36-type houses, serving as a reserve source of clean water during the dry season and as a groundwater conservation effort. This study was expected to serve as a technical guide for those interested in constructing a similar rainwater harvesting system. The system could serve as an example for the broader community looking to implement rainwater harvesting systems.

2 Data and Methodology

Preliminary survey was conducted to identify the conditions at the case study site. Based on the preliminary survey, the roof dimensions of the building were determined to obtain the rainwater catchment area. This catchment area became a factor for calculating runoff discharge. The calculation of runoff discharge on the rainwater harvesting system of the building's roof was performed in the following stages:

2.1 Rainfall Analysis

Rainfall analysis is needed to determine the intensity of rainfall in the city of Palembang. Daily maximum rainfall data obtained from Meteorological Station of Sultan Mahmud Badaruddin II in Palembang City was then analyzed using the normal distribution, log-normal distribution, Pearson Type III distribution, and Gumbel distribution analyses. The normal distribution function is represented by the following equation:

$$X_T = \bar{X} + K_{Tr} S \quad (1)$$

Where:

X_T : Design rainfall with a T-year return period.
$\bar{X}$: Mean value of the variance.
S : Standard deviation of the variance.
K_{Tr} : Frequency factor, a function of probability.

The log-normal distribution function is represented by the following equation:

$$Log\, X_T = log\bar{X} + K_{Tr}\, S_{logX} \quad (2)$$

$$Cv = \frac{S_{logx}}{log\ \bar{X}} \quad (3)$$

$$S_{logx} = \sqrt{\frac{\sum(log\ X - log\ X_i)^2}{(n-1)}} \quad (4)$$

Where:

X_T : Estimated value expected to occur with a T-year return period
$Log\ \bar{X}$: Mean value in logarithmic terms
S_{logx} : Standard deviation in logarithmic terms
K_{Tr} : Frequency factor of the log-normal distribution
Cv : Coefficient of variation of the log-normal distribution

The three crucial parameters in the log Pearson Type III distribution are the mean, standard deviation, and skewness coefficient. If the skewness coefficient equals zero, the distribution reverts to a log-normal distribution. Here is the equation for the log Pearson Type III distribution [12]:

$$Log\ X_T = log\bar{X} + K_{Tr}\, S_{logX} \quad (5)$$

$$Log\ \bar{X} = \frac{\sum_{i=1}^{n} log X_i}{n} \quad (6)$$

$$S = \left[\frac{\sum_{i=1}^{n}(log X_i - log\bar{X})}{n-1}\right]^{0,5} \quad (7)$$

$$Cs = \left[\frac{\sum_{i=1}^{n}(log X_i - log\bar{X})}{(n-1)(n-2)S^3}\right] \quad (8)$$

Where:

X_T : Estimated expected value to occur with a T-year return period
$Log\ \bar{X}$: Mean value in logarithmic terms
S_{logx} : deviasi standar dalam harga logaritmik
K_{Tr} : Frequency factor of the Log-Pearson Type III distribution
Cs : Skewness coefficient of the Log-Pearson Type III distribution

Rainfall or discharge with a return period of T years can be calculated based on the Gumbel distribution using the following equation [13]

$$X_T = \bar{X} + K_{Tr}\, S \quad (9)$$

The frequency factor Ktr for the Gumbel distribution can be expressed in the following equation

$$Ktr = \frac{(Y_{tr} - Y_n)}{Sn} \quad (10)$$

$$Y_{tr} = -In\left(-In\frac{Tr-1}{Tr}\right) \quad (11)$$

Where:

X_T : Estimated value expected to occur with a return period of T years
S : Sample standard deviation
Yn : *Reduced mean depending on the sample size*

Sn : *Reduced standard deviation also depending on the sample size*
Ytr : *reduced variate*

Furthermore, a goodness-of-fit test is conducted using the Kolmogorov-Smirnov methods to select the rainfall distribution that will be analysed to determine the rainfall intensity values [14].

2.2 Rainfall Intensity

Rainfall intensity (I) represents the degree of rainfall events over a specific time interval, where the accumulated precipitation is focused [15]. Rainfall intensity is differentiated from the calculation of daily rainfall intensity using the Mononobe Method [16].

$$I = \frac{R_{24}}{24}\left(\frac{24}{t}\right)^{\frac{2}{3}} Y_{tr} \tag{12}$$

Where:
I : Rainfall intensity (mm/hour)
R_{24} : Maximum daily rainfall (mm)
T : Duration of rainfall (hours)

2.3 Analysis of Planned Flood Discharge

In analyzing the planned flood discharge, the rational method is employed. The rational method has been widely used for the planning of drainage systems in relatively narrow catchment areas and for rivers with large catchment areas [17]. The Rational Method equation is formulated as follows:

$$Q = 0{,}278\ C\ I\ A \tag{13}$$

Where:
Q : Discharge of surface runoff (m^3/ second)
C : Runoff coefficient
I : Rainfall intensity (mm/hour)
A : Catchment area (km^2)

The coefficient (C) is expressed as the ratio of the peak surface runoff to the rainfall intensity and can be obtained from the Runoff Coefficient Table.

2.4 Probability of Rain

To calculate the probability of a reliable rainfall, you can use Equation (14):

$$(\%) = \frac{m}{(n+1)}\ x\ 100\% \tag{14}$$

Where:
P : Probability (%)
m : Sequential number of the data

n : Total number of data points used

2.5 Analysis of Harvestable Water Quantity

The quantity of harvestable rainwater is calculated based on the type of building. To analyze the quantity of rainwater that can be harvested:

$$\Sigma Q = a \ R_{24} A \tag{15}$$

ΣQ : Total of harvestable water (liters/day)
A : Roof area of the house (m^2)
a : Runoff coefficient (0,8)
R_{24} : Average daily maximum rainfall (mm/day)

3 Results

3.1 Rainfall

In analyzing rainfall, the data used was obtained from 15 years of rainfall data, specifically from the year 2008 to 2022, recorded at the SMB II Climatology Station in the city of Palembang.

Table 1. Maximum annual rainfall

No	Year	R_{max} (mm)
1	2008	142.29
2	2009	217.00
3	2010	234.26
4	2011	208.96
5	2012	233.00
6	2013	137.75
7	2014	143.67
8	2015	106.88
9	2016	235.15
10	2017	104.00
11	2018	93.68
12	2019	110.77
13	2020	99.04
14	2021	141.30
15	2022	193.11

Source: SMB II Climatology Station, Palembang City

3.2 Frequency analysis

Frequency analysis was used in the calculation of distributions, including the Normal distribution, Log Normal distribution, Gumbel distribution, and Log Pearson III distribution. Here is a table for rainfall calculations with these four distribution methods.

Table 2. The result of the analysis of the determination of planned rainfall

No	Return period (Tr)	Planned rainfall (mm)			
		Distribution type			
		Normal	Log Normal	Gumbel	Log Pearson Type III
1	2	160.06	145.46	152.73	172.47
2	5	205.60	186.88	217.45	210.74
3	10	229.45	214.44	260.30	232.72
4	25	252.23	248.42	314.45	258.02
5	50	271.20	281.08	354.61	287.40
6	100	286.38	304.91	394.49	300.80

Table 3. Summary of the Smirnov-Kolmogorov test calculation

No	Analysis of Planned Rainfall (mm)			
	Normal	Log normal	Log pearson III	Gumbel
1	2.11	16.12	11.44	67.52
2	14.34	15.59	13.11	31.56
3	25.81	34.01	27.53	11.12
4	20.62	37.56	29.94	3.92
5	23.00	43.18	35.06	4.43
6	16.56	36.45	27.99	0.49
7	24.14	6.48	15.19	42.13
8	17.77	2.98	11.87	37.65
9	9.63	6.52	6.52	27.72
10	4.48	5.01	5.01	24.46
11	22.59	27.41	27.41	45.28
12	17.12	27.12	27.12	43.55
13	7.24	26.15	26.15	41.26
14	2.79	27.55	27.55	41.43
15	17.12	29.60	29.60	42.34
Δ_{maks}	25.81	43.18	35.06	67.52
$\Delta_{criticism}$	41	41	41	41
Goodness of fit test	accepted	rejected	accepted	rejected

After conducting the goodness of fit analysis using the Smirnov-Kolmogorov test on four different types of frequency distributions, it was found that the normal distribution and Log Pearson III distribution were accepted. When comparing the results of both tests, the Log Pearson Type III distribution yielded the best calculation among the other three distributions. Therefore, for further analysis, the planned rainfall was obtained from the Log Pearson Type III distribution.

The determination of planned rainfall (R_{24}) in the analysis of rainfall frequency distribution was carried out for return periods of 2, 5, 10, 25, 50, and 100 years. The planned rainfall used in the calculation process was the planned rainfall with a 2-year return period, which amounted to 172.477 mm/day. This selection was based on the Regulation of the Minister of Public Works Number 12/PRT/M/2014 regarding the Implementation of Urban Drainage Systems, which stated that if the catchment area is less than 10 hectares, the return period used in the calculation of planned rainfall is 2 years.

Subsequently, rainfall intensity was calculated with a 2-hour rainfall duration using the mononobe method. Rainfall intensity is the height of rainfall within a unit of time. Based on the calculation, the rainfall intensity was found to be 37.668 mm/hour. The magnitude of rainfall intensity is required to calculate the peak flow or peak surface runoff discharge in the planning area, which consists of a roof area measuring 36 square meters. The peak flow was calculated using the rational method, resulting in a peak discharge of 0.30 liters/second.

3.3 Rainwater Availability

The size of the Type 36 house roof was 6 meters by 6 meters with a 1-meter overhang and a 30-degree slope, resulting in a roof area of 53.12 m^2 as the rainwater catchment area in this study. The average rainfall was determined from the result of reliable rainfall calculations with an 80% reliability level or an approximation to it.

Based on the calculations, the observation year for rainfall was 2018. The rainfall data for the year 2018 was used to calculate the average daily rainfall. The average daily rainfall for the year 2018 was determined to be 3.12 mm/day. By multiplying the average daily rainfall by the roof area and a runoff coefficient of 0.8, the availability of rainwater was obtained as 132.59 litters per day.

The volume of rainwater obtained was used to meet daily water needs. According to the SNI 03-7065-2005 regulation on Plumbing System Planning Procedures, water usage for a residential home was 120 litters per person per day. The average family size in Indonesia was 4 people (BPS 2019). Therefore, with a rainwater harvesting system from a 53.12 square meter roof area, the volume of water obtained, which was 132.59 liters per day, could only meet the daily water needs of one person from the average family size.

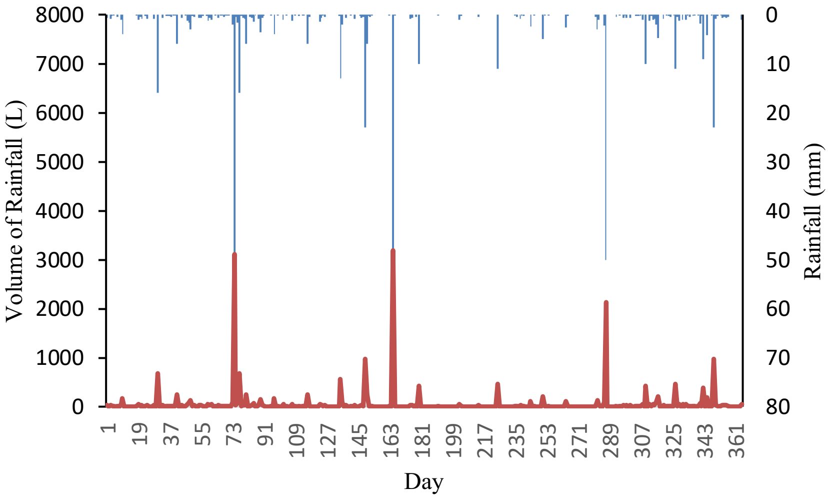

Figure 1. Graph of daily rainfall and volume of rainfall

3.4 Simulation of Rainwater Harvesting System

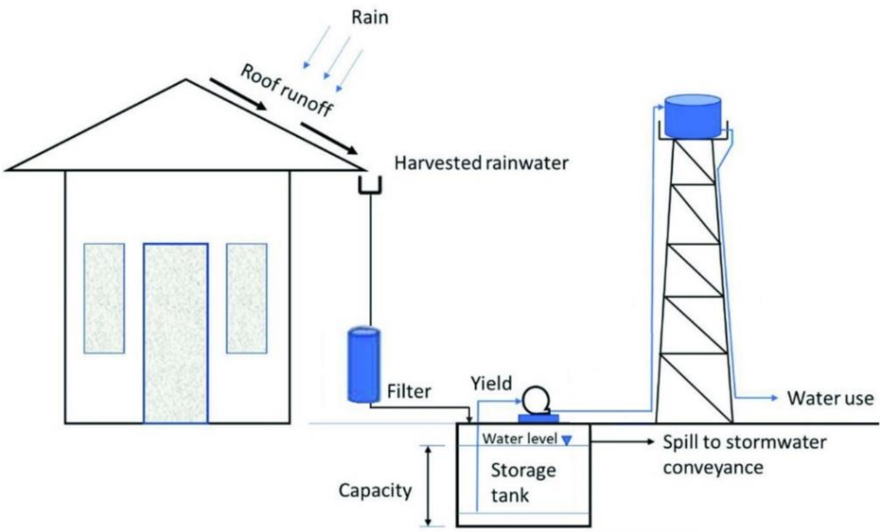

Figure 2. Rainwater Harvesting System Scheme

The simulation for the rainwater harvesting system's design and construction was conducted by calculating household water needs, simulating a water balance, and calculating the expenses of the local water utility (PDAM) and the cost savings from using the rainwater harvesting system. Household water needs were determined by multiplying the daily water requirement per person by the average number of family members in Indonesia. According to SNI 03-7065-2005 on Plumbing System Planning

Procedures, water usage for residential homes is 120 liters per person per day. The average family size in Indonesia was 4 people (Statistics Indonesia 2019). Therefore, household water needs were 175,200 liters per year. The unit price of water per cubic meter (m^3) for homes classified under tariff category Domiciliary Occupational Health and Safety (upper-middle-class households) based on the Regulation of the Ministry of Home Affairs Number 71 of 2016 was Rp8,200/m^3. Hence, the annual expenses to meet household water needs amounted to Rp1,416,900.

Based on the calculations, with a rainwater harvesting system from a 53.12 m^2 roof area, the volume of rainwater used to meet daily household water needs was 20,234.18 liters per year. The use of the rainwater harvesting system could save water expenses of Palembang Local Water Company (Regional Water Supply Company) by IDR 165,920.2 per year.

3.5 Conclusion

The average volume of harvested rainwater was 132.59 liters per day and could meet the daily water needs of one person from the average family size in Indonesia. The use of the rainwater harvesting system saved water expenses of Palembang Local Water Company (Regional Water Supply Company) by IDR 165,920.2 per year.

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