The effect of roof surface area on the quality and quantity of rainwater runoff in the rainwater harvesting system

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Abstract. Rainwater harvesting system is one of the alternative sources of clean water supply to be used during the dry season. The purpose of this research was to analyze the effect of roof area on the quality and quantity of rainwater runoff and determine the potential of rainwater runoff based on quality standards. The observation was conducted 2 different times and collected 23 samples of rainwater runoff from 11 different roof areas. Daily rainfall intensity data during the observation period were analyzed to estimate the quantity of rainwater runoff discharges from the rooftop catchment area. The results showed that parameters that meet the clean water quality standard are turbidity, iron, manganese, nitrate, and nitrite in both observation time. While the color, pH, TDS, and E. coli exceeds the clean water quality standard. The highest rainwater runoff volume was 20.59 m³ for the first week and the second week was 14.06 m³. In conclusion, the rooftop catchment area significantly affects the quantity and quality of rainwater runoff, and potentially be used as a clean water supply through a simple water treatment unit.

1. Introduction
Water is one of the necessities for humans to survive. Owing to that fact, every activity carried out in human daily life usually requires water, for instance, cooking, washing, and other important activities. Nowadays, the growing need for clean water in big metropolitan cities has been a quite serious problem that needed to be solved. There are several factors that cause this problem, for example, the changes in lifestyle and the growth of building infrastructure that causes more impervious cover that prevent water absorption and affects the water cycle. Thus, water that falls to earth through rain cannot be accommodated optimally on land and causes several inundations in some areas. To solve this problem, an alternative solution is needed, for example, optimizing the use of high-intensity rain in Indonesia using a Rainwater Harvesting system (PAH) [1]. Based on its scope, the rainwater harvesting technique is divided into two methods, namely by using a building roof or using a reservoir. In utilizing rainwater or daily activities, firstly, pay attention to the quality of rainwater collected by following the associated standards in line with the aims of the activity. The quality of rainwater runoff that has been collected is determined by the roof condition (age, cleanliness, slope, and material), and environmental conditions of the area (local climate, atmospheric pollution level, and other aspects) [2].

Other than quality aspects, the harvested rainwater quantity must also be considered to determine the harvested rainwater availability with the required volume. The factors that affect the water quantity are the size of the reservoir, the slope of the used media, rainfall intensity, the catchment area, and the rainfall duration. In previous researches, only a few have analyzed the effects of roof surface area on
both the quality and quantity of the rainwater runoff, such as assessment of water quality of first flush roof runoff and harvested rainwater, by Georgios D. (2012), and roof selection for rainwater harvesting: quantity and quality assessment in Spain, by Ramon Farreny (2011) [1,2]. Therefore, this research aims to analyze the effect of variations in roof surface area on the quality and quantity of rainwater runoff and to compare the results of the study with environmental health quality standards and water health requirements for sanitation hygiene needs.

2. Methodology

2.1. Data collection techniques
Daily rainfall data from Engineering Faculty of Indonesia University’s Rainfall Station is used to estimate the rainwater runoff volume that can be harvested, based on the roof surface area variance. Rainwater runoff quality is obtained by collecting samples of rainwater runoff from various roof areas (table 1) and laboratory testing. The water quality parameters tested include turbidity, color, TDS, pH, iron, nitrate, nitrite, manganese, and E. coli, referring to the Minister of Health Regulation No. 31 of 2017 for ‘hygiene’ sanitation needs. The surface area of the roof is obtained based on a survey of residents' houses in residential locations in Beji District, Depok, exclusively those that use tile roofs and have gutters. The surface area of the roof is measured with the help of the google earth application, and with the assumption that the roof is a flat plane.

Table 1. Roof surface area at sampling location.

| Num | Sampling Location | Roof Surface Area (m²) |
|-----|-------------------|------------------------|
| 1   | Enha Rent-house   | 18                     |
| 2   | Mushala           | 20                     |
| 3   | Emy 2 Rent-house  | 24                     |
| 4   | Car port garage   | 38.5                   |
| 5   | Mosque            | 40                     |
| 6   | House             | 70                     |
| 7   | Kenanga Resto     | 76                     |
| 8   | Padang Resto      | 82                     |
| 9   | Emy 1 Rent-house  | 83                     |
| 10  | D’mang Resto      | 90                     |
| 11  | Bahari Resto      | 150                    |

2.2. Sampling method
Samples of water are collected from rainwater runoff that falls on the roof and flows through the gutter. Thus, the sample is being collected in a bottle and brought to the laboratory for water quality testing based on physical, chemical, and biological parameters. Observation and sampling were carried out during the highest rainfall intensity period, namely in February and March 2020, with the total samples are 23 sample (table 2).

Table 2. The number of rainwater runoff samples.

|                  | Indirect sampling | Direct sampling | Total Sample |
|------------------|-------------------|-----------------|--------------|
| W1 (28 February) | 11                | W2 (12 March)   | W1 (28 February) | 1 | 23 |

2.3. Measuring method
The quality of rainwater runoff is calculated using the following formula approach:
Details:

\[ V_r = d \times C \times A \]  

(Vr: Rainwater runoff volume (m³)

\( d \): Rainfall depth (mm) = Daily rainfall depth \( \frac{\text{mm}}{\text{day}} \) x sampling duration (hour)

(C: Roof runoff coefficient (= 0.75)

(A: Roof area (m²)

2.4. Data Analysis

Statistical analysis using ANOVA (Analysis of Variance) was carried out to determine the effects of roof area variance on the quality of rainwater runoff in each tested parameter. In addition, descriptive analysis was also done to describes the relationship of each observed variable.

3. Results and discussion

3.1. Rainwater runoff quantity

Rainwater runoff volume collected from the variation in the surface area of the roof from 18 to 150 m² in the 2th week sampling period is shown in the following graph:

![Figure 1. Rainwater runoff volume.](image)

Based on the graph above, it can be seen that the surface area of the roof is directly proportional to the volume of rainwater runoff. Potentially, harvesting rainwater through a wider roof will result in a greater volume of water. However, the volume of captured rainwater runoff is subject to change due to the effects of rainfall intensity, the size of the reservoir, and the slope of the roof.

3.2. Rainwater runoff quality

In terms of physical parameters, figure 1 shows that there are several areas of the roof that have color concentrations that do not meet quality standards, or more than 50 NTU, such as Mushala, House and Carport garage [3]. This can be due to dirty gutters, pollutants in the atmosphere, and poor roof surface conditions. In the case of turbidity and TDS parameters, all roof areas have concentrations that meet quality standards or below than 1000 mg/l.
A high TDS concentration could be due to the presence of high concentrations of magnesium, sulfate, nitrate, iron, calcium, and other ions [4]. Therefore, there is a correlation between TDS concentration, color, and turbidity, which is directly proportional.

The occurrence of the nitrogen cycle in the atmosphere, causing a high content of nitrate and nitrite in harvested rainwater runoff. The burning activities around the sampling location, such as what happened in rainwater runoff from Warung Padang (restaurant) having the highest nitrate concentration compared to other locations, about 8.4 mg/l. This can be caused by a dry period, rainfall intensity, and also other external environmental condition factors around the location, such as fallen leaves that fall into a storage container for sampling. There was an occurrence of fluctuation in nitrite concentration in harvested rainwater runoff [5]. The samples taken on days 0, 10, 20 and 30 were, respectively, 0 mg/l, 0.01 mg/l, 0.02 mg/ and 0.01 mg/l. This can be generated by the sampling location. In that research, the sampling location was surrounded by green fields and forests and was not in condition with a high level of pollution rate. However, since the location is close to fertile fields and forest, there were more chances of fallen leaves to accidentally fall into the storage during sampling. In line with that, the nitrite concentration in this study is higher than the graph of the results of the study above. Furthermore, the
The concentration of nitrite and nitrate can also be affected by the pH value. Changes in pH value can be caused by high alkalinity rates, limited nitrate, and sulfate rate in rainwater at the time of checking [6]. Based on the graph above, it is known that the pH value is directly proportional to nitrite and inversely proportional to the nitrate concentration.

![Iron and Manganese graph](image)

**Figure 4.** Quality of rainwater runoff: iron and manganese concentration.

Based on the graph above, in the second week, Enha rent house has extreme iron concentration (0.75 mg/l). This can be caused by byd corrosion and porosity in the media used. Fe concentration ranged from 6 to 40 µg/l due to the influence of dry sedimentation in rainwater quality and also due to the industrial activity in the area during the sampling period [7].

The next step is *E. coli* concentration checking in the biological parameter. There was a significant result difference between the first week and the second-week test results. This is generated by the occurrence of dirt accumulation that came from animals, plants, and other pollutants in the atmosphere that adheres to the roof surface. Apart from that, during the sampling period for the first and second weeks, the frequency of rain was quite high from day to day, so that at the time of sampling in the second week, the *E. coli* concentration was lower than in the first week. The following is a graph of the results of checking the *E. coli* concentration:

![E.Coli graph](image)

**Figure 5.** *E. coli* concentration.
3.3. Significance test
In determining whether the surface area of the roof affects a certain parameter, an ANOVA analysis is necessary. Based on the results of ANOVA analysis on physical, chemical, and biological parameters, there are 2 parameters that affect the surface area of the roof, namely color and TDS, namely based on the results of the value of $F > F_{crit}$.

4. Conclusion
The variation in roof surface area does not fully affect the quality of rainwater runoff (physical, chemical, and biological) but can be influenced by external factors. However in this case, the surface area of the roof affects the quality of rainwater runoff on color and TDS, this is due to the presence of leaves and other solids matter that enters the rainwater runoff storage container and affects the color and TDS of the sample. Based on the calculation of the roof surface area used and the daily rainfall data obtained, it can be concluded that the roof surface area greatly affects the quantity of rainwater runoff harvested. The greater the surface area of the roof used, the greater the volume of rainwater that will be collected. Nonetheless, the quantity of rainwater runoff can also differ from the calculation results due to several external factors, such as the volume of the storage containers and the volume of the first flush that is wasted. The parameters that meet the quality standards of the Ministry of Health Republic of Indonesia No. 32 of 2017 for 'hygiene' sanitation needs at all of the locations and the two sampling times, namely, turbidity, Fe, hardness, manganese, nitrate, and nitrite. Meanwhile, parameters that do not meet quality standards, namely pH, chrome, E. coli, color, and TDS.

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