Analysis of Rainwater and Runoff Water Quality on Vegetated and Unvegetated Green Roof

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Abstract. Green roof is a green technology innovation in the form of a roof planted with vegetation on a substrate that is an effective solution to replace the role of green open space (GOS) lost due to construction and development. As the main component of green roof, vegetation can significantly affect the quantity and quality of runoff water. This research aims to analyze the quality of rainwater and green roof runoff water on green roofs planted with Portulaca grandiflora (PG) and unvegetated green roof (UV) as a control. Runoff samples were analysed to determine the value of water quality parameters used, especially temperature, TDS, pH, BOD, COD, DO nitrite, ammonia. Water quality status is determine by applying the STORET (Storage and Retrieval) Method. Based on the quality standards of "Peraturan Pemerintah Republik Indonesia No 22 Tahun 2021", the STORET value in rainwater is categorized as moderately contaminated with a value of -20. While the STORET value in green roof runoff water planted with Portulaca grandiflora and unvegetated green roof, both are categorized as lightly contaminated with a value of -8 and -10 respectively. While based on the quality standards of "Peraturan Menteri kesehatan No 22 tahun 2023", the STORET value in rainwater is categorized as lightly contaminated with a value of -8. While the STORET value in green roof runoff water planted with Portulaca grandiflora and green roofs that are not planted, both are categorized as meet the quality standards.
Keyword : green roof, water quality, runoff, vegetated, unvegetated, Portulaca grandiflora

1 Introduction

The world has experienced rapid urbanization over the past few decades. This social phenomenon can be seen in the increasing development to accommodate the population shift from rural to urban [1]. Large cities in Indonesia experience economic growth of 3-6% and a population of 1.1-3.2% [2]. High economic growth makes cities or countries tend to grow, increasing their size and changing their structure [3], increasing the need for land for the construction of economic centers and settlements, and reducing green open space (GOS) as

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a result of replacing land with buildings. Over a 25-year period, the amount of green space in Kuala Lumpur, Manila, and Jakarta plummeted from 45% to 20% due to increasing urbanization [4]. The reduction of vegetation that absorbs rainwater results in increased surface water runoff, puddles, and floods that threaten infrastructure and the welfare of the population. Green roof is a potential solution for increasing the quantity of GOS.

Green roofs effectively address the concerns of urban development and a changing climate, one consequence of structures taking up 50% or more of the city's surface area is the decrease of green open space (GOS) [5]. Green roof is a green technology innovation that recovers the lost green open space (GOS) function by planting the roof with various types of vegetation on a growing medium (substrate) [6]. According to [3], green roofs can function as rainwater catchment areas, increase green open space, and filter rainwater to enhance the overall quality of water that seeps to the surface through absorption and retention by the substrate and plant root system. Carefully selected vegetation for green roofs contributes to absorbing surplus water and improving water quality via natural filtration. [7]. To manage dwindling water resources, green roofs are essential for reducing the volume of stormwater runoff and restoring water quality in urban areas.

To improve runoff water quality and reduce stormwater runoff, choosing the right type of vegetation is crucial for green roof efficiency. Optimal vegetation selection can maximize the lifespan of green roofs [6]. Through increased substrate absorption, green roofs are intended to reduce contaminants and enhance the quality of runoff water. [8] and plant nutrient uptake [9]. In addition, vegetation increases evapotranspiration, reducing stormwater runoff discharge through the evaporation and absorption of water into the soil medium. New green roof systems are prone to releasing runoff water with nutrients and particles, but this effect diminishes over time due to increased plant uptake.

Plants with different characteristics have different abilities to absorb and filter rainwater, so it is important to understand the most effective types of plants to use on green roofs. [6] states that optimal vegetation for green roofs has characteristics such as tolerating drought conditions, being readily available, having short and tender roots, requiring little maintenance, fast growth, and high ground cover. It is extremely difficult to find plants with all of the desirable properties. Around the world, sedum varieties are the most preferred choice for extensive green roofs. [10], as they can perform well in a variety of different climatic conditions. However, sedum plants are not widely available, and more research is needed to identify appropriate local plants for improved green roof performance.

There are several local plants in Indonesia that have potential characteristics to be planted on green roof systems. One of them is Portulaca grandiflora. This vegetation has potential characteristics to be planted on a green roof system, hence the need for research that aims to investigate these characteristics. One of the characteristics of Portulaca grandiflora is its effectiveness in high water and nutrient absorption [11]. The aim of this research is to evaluating the quality of runoff water from green roof systems planted with Portulaca grandiflora to an unvegetated green roof.

2 Methodology

2.1 Research Location

This research is carried out on the campus of IPB University in Dramaga District, Bogor Regency, Indonesia. According to Köppen's climate classification, Indonesia belongs to an area with a tropical rainforest climate, characterized by relatively uniform air temperatures and high rainfall spread throughout the year [12]. The Bogor region is called the Rain City because of the high amount of rainfall and many rainy days in one year, with a total annual rainfall of 4000-4500 mm. The average rainfall in the Bogor region has one peak period that occurs in February with 500 mm of rainfall, while the lowest occurs in August with 24 mm of rainfall [13]. There is a main road near the research location; in addition, there are compost production activities and plantations around the research location. The main land uses around the study area are educational facilities, housing, plantations, and farms. The study facility is situated on the concrete deck of IPB University's Advanced Research Laboratory Building.

2.2 Tools and Materials

The equipment for this research includes 2 green roof models, 2 iron frames supporting the green roof model, 2 HDPE tanks of 120 liters, 2 tipping bucket type rain gauges, 2 water gauges, and ½ inch PVC pipes and their connections. The research materials used were soil, zeolite, geomembrane, drainage carpet, manure, and moss rose (Portulaca grandiflora). The programs used are AutoCAD 2021, Microsoft Word 2017, and Microsoft Excel 2017.

Both primary and secondary data were needed for this research. Primary data used are derived from assessing the quality of rainwater and green roof runoff water, as well as measuring the volume of green roof runoff water using a water meter. Secondary data required are temperature in the air and everyday rainfall information provided from the Cikabayan rain station held by the Department of Geophysics and Meteorology FMIPA IPB. Overall, the tools used in testing rainwater samples and green roof runoff water are sample bottles, measuring flasks, measuring cups, erlenmeyers, analytical pipettes, volumetric pipettes, bulbs, analytical balances, ovens, desiccators, refrigerators, spectrophotometers, turbidimeters, TDS meters, pH meters and reagents for measuring the parameters used.

2.3 Research procedure

2.3.1 Green roof models

The green roof model box is made of 8 mm multiplex wood and has a size of 1 × 1 × 0.3 m. The green roof model was placed on a 100 cm high stand frame made of angle iron so that the water runoff generated could be collected in the HDPE tank as shown in Fig. 1. The green roof model was designed with a 5% slope so that runoff water would overflow on one side at the lowest part of the box. A tipping bucket type rain gauge was attached just below the green roof box to determine the runoff volume and when the water overflowed. The water meter was connected to the model using a 60 cm length of ½ inch HDPE pipe.

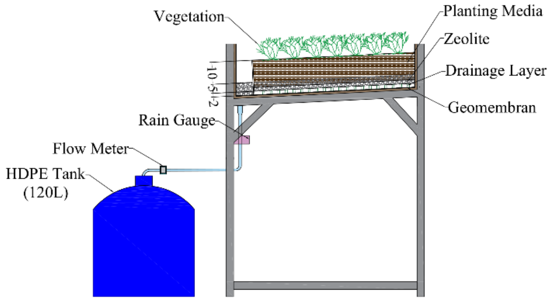


Fig. 1. Design of green roof model.

The study used 2 models planted with Portulaca grandiflora (PG) and unvegetated as a control (UV). All green roof models were filled with a mixture of soil and manure with an additional dose of manure as much as 3 kg. The green roof layers were arranged from the bottom, namely the drainage layer (6 mm PVC rubber carpet), zeolite stone no 3 with a thickness of 5 cm, growing media with a thickness of 10 cm and vegetation. These layers are bounded inside a wall covered with a geomembrane that functions as a waterproof membrane as if it were a conventional roof. The green roof model has a 10 × 100 cm space containing 5 cm thick zeolite stones as a drainage channel to the water storage tank. The model design is shown in Fig. 2.

(a) (b)

Fig. 2. Green roof planted with Portulaca grandiflora (a) and unvegetated green roof (b).

2.3.2 Data collection

This research uses primary data obtained from measuring the volume of green roof runoff water and testing the quality parameters of rainwater and green roof runoff water samples during rainfall. Secondary data is needed to support data processing and analysis. Secondary data in the form of rainfall data was obtained from the Cikabayan weather station owned by the Department of Geophysics and Meteorology, FMIPA IPB. Primary data collection was carried out during rainfall and continued until the rain stopped. Runoff water from the green roof will flow through the drainage layer, enter the rain gauge, and then pass through the water meter as a runoff volume measuring device.

The water collected in the tank will be used as a sample of green roof runoff water and tested for water quality assessment indicators. The physical parameters to be tested are temperature and TDS, while the chemical parameters are potential hydrogen (pH), oxygen dissolved in water (DO), biochemical demand for oxygen (BOD), chemical demand for oxygen (COD), ammonia, and nitrite.. Water quality measurements will be carried out following the instructions set out in the Indonesian National Standard (SNI). Water quality testing was conducted five times on 23 April, 24 April, 30 April, 1 May, and 2 May.

2.3.3 Data analysis

Data of runoff water quality analysis were compared to "Peraturan Pemerintah Republik Indonesia No. 22 Tahun 2021" concerning on enforcement of environmental protection and management, with a water quality designation of class 3. In addition, quality standards based on "Peraturan Menteri Kesehatan No.2 Tahun 2023" on the implementation regulation "Peraturan Pemerintah No.66 Tahun 2014" on Environmental Health with the designation of water for hygiene and sanitation needs are used. After that, status of runoff water quality was determined with the STORET (Storage and Retrieval) method based on "Keputusan Menteri Lingkungan Hidup No. 115 Tahun 2003", as shown in Table 1.

Table 1. Classification of water quality status according to US-EPA

Class	Score	Category	Water Quality Status
A	0	Very Well	Meet the quality standards
B	-1 to -10	.Good	Lightly contaminated
C	-11 to -30	Medium	Moderately contaminated
D	≥ -30	Bad	Heavy contaminated

The measured data for every water parameter is benchmarked against the quality standard value associated with the water designation. If the outcomes of the measurement are below the water quality standard, a score of 0 is assigned. If the measurement results are outside of the water quality standard value (measurement results > quality standard), a score is assigned using Table 1. The negative number of all metrics is accumulated, and the status of runoff water quality is decided by the number of scores received through the value system. The assessment of the water quality status of the STORET method is listed in Table 2.

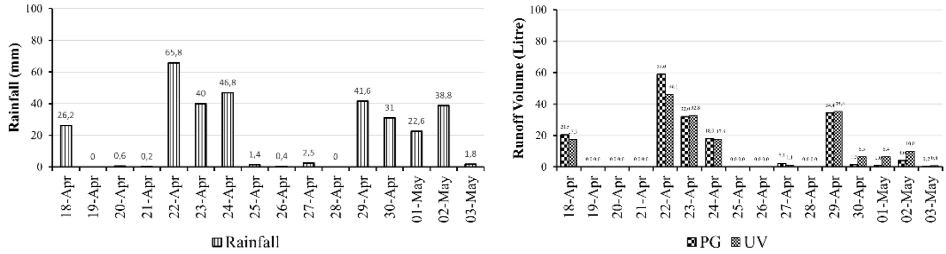
Table 2. STORET method water quality status assessment

Number of samples	**Score**	**Parameter**		
		Physics	**Chemistry**	**Biology**
< 10	Max	-1	-2	-3
	Min	-1	-2	-3
	Avg	-3	-6	-9
≥ 10	Max	-2	-4	-6
	Min	-2	-4	-6
	Avg	-6	-12	-18

3 Results

3.1 Daily rainfall and green roof runoff water

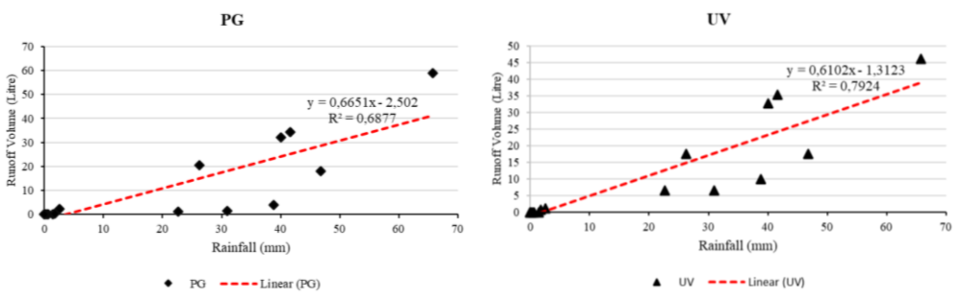
Based on Fig. 3(a), the highest rainfall occurred on April 22 which amounted to 65.8 mm with the volume of runoff in PG and UV respectively of 59 liter and 46.1 liter as presented in Figure 3. Based on Fig. 3(b), there were unexpected results on 18 April, April 22, April 23, April 24 that the unvegetated substrate released the least runoff compared to the vegetated substrate. For example, on April 22, the unvegetated green roof was able to retain 29.95% of the rainwater with a daily rainfall of 65.8 mm. This phenomenon can be caused by the condition of the unvegetated substrate, which is directly exposed to the surrounding conditions, such as wind and sunlight, so that the stored water dries up quickly, while vegetation provides protection to the substrate which allows less evaporation [14].



(a) (b)

Fig. 3. Rainfall volume (a) and green roof runoff (b) during the research.

Portulaca grandiflora were able to help reduce rainwater runoff. The potential of plants to decrease runoff volume depends on the level of plant cover and the ability of plants to absorb water. PG (Portulaca grandiflora) tends to effectively reduce runoff volume for low rainfall events (0.5-20 mm/day) to heavy rainfall (20-50 mm/day). For example, on May 2, the green roof system planted with Portulaca grandiflora was able to retain 88.9% of rainwater with a daily rainfall of 1.8 mm. In addition, on April 24, the green roof system planted with Portulaca grandiflora was able to retain 61.5% of rainfall with a daily rainfall of 46.8 mm. Portulaca grandiflora have a wide rooting area so that it can reduce runoff effectively. These results confirm the results of [9] which indicate the importance of vegetation in increasing the capacity of soil to store water.



(a) (b)

Fig. 4. Correlation between rainwater and green roof runoff water.

The information gathered indicated that the volume of runoff and rainwater had a linear relationship over time. The trend line equation formed is $y = 0.66x - 2.50$ for the vegetated green roof and $y = 0.61x - 1.31$ for the unvegetated green roof, where y represents runoff volume and x represents rainwater volume. The slope values of 0.66 and 0.61 indicate that about 66% and 61% of the falling rainwater volume will become runoff volume. The rest may be absorbed by the green roof substrate, absorbed by plant roots or evaporated.

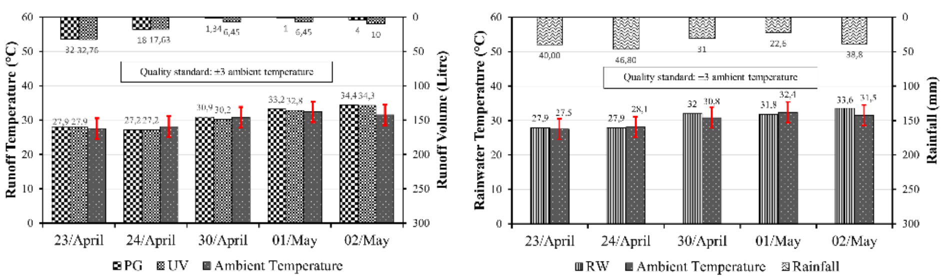
The coefficient of determination $(R)^2$ of 0.69 in the correlation of rainfall with runoff from the green roof planted with Portulaca grandiflora indicates that the 69% of the variation in runoff volume may be described by variations in rainwater volume. This indicates a fairly strong correlation between the two variables, although there is still 31% of the variation caused by other factors not explained by this linear model. Possible other factors could include variations in the condition of the green roof, rainfall intensity, and the physical characteristics of the substrate and vegetation used.

From this analysis, it was found that the green roof functioned quite well in capturing rainwater, with approximately 66% (planted green roof) and 61% (unplanted green roof) of the rainwater falling as runoff. This suggests that these planted green roof systems are effective in managing runoff water, although there is still room for further improvement. Further research may be needed to understand other factors that affect runoff volume, including a more in-depth analysis of the type of vegetation and substrate used.

3.2 Quality of rainwater and green roof runoff water

3.2.1 Temperature

Based on runoff water temperature data from green roofs planted with Portulaca grandiflora (PG) and unvegetated (UV), the PG runoff water temperature ranges from 27.2°C to 34.4°C, with an average of 30.72°C. Meanwhile, the UV model showed a temperature range of 27.2°C to 34.3°C with an average of 30.48°C. Rainwater temperature (RW) ranged from 27.9°C to 33.6°C with an average of 30.64°C, while ambient air temperature ranged from 27.5°C to 32.4°C with an average of 30.06°C. The temperature of rain and green roof runoff water in each sample shows a value that meets the quality standard range of ± 3 of the ambient air temperature at the time of sampling (Fig. 5).



(a) (b)

Fig. 5. Temperature values of rainwater (a) and green roof runoff (b).

3.2.2 Total Dissolved Solids (TDS)

Fig. 6. shows the concentration of Total Dissolved Solids (TDS) in runoff water from green roofs planted with Portulaca grandiflora (PG) and unvegetated green roofs (UV), as well as in rainwater (RW). The TDS concentration in green roof runoff with PG vegetation ranged from 42 to 71 mg/L, with an average of 52 mg/L. Meanwhile, TDS in runoff from green roofs unvegetated (UV) ranged from 46 to 72 mg/L, with an average of 60 mg/L. In comparison, TDS in rainwater ranged from 7 to 16 mg/L, with an average of 11 mg/L. The TDS value of green roof runoff water increased compared to rainwater. This shows that green roofs can be a source of TDS pollutants in green roof runoff water. Based on Fig. 6, it can be seen that the TDS concentration in runoff water from green roofs with Portulaca grandiflora vegetation (PG) is generally lower than runoff from green roofs unvegetated (UV). Both green roof models showed much higher TDS values compared to rainwater TDS. The average TDS in the PG and UV models showed significant differences, with UV having higher TDS values.

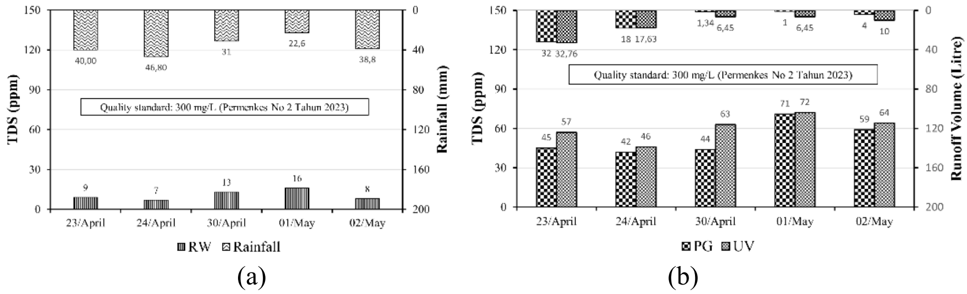


Fig. 6. TDS values of rainwater (a) and green roof runoff water (b).

3.2.3 Potential Hydrogen (pH)

Fig. 7. show the pH value of runoff water from green roofs planted with Portulaca grandiflora (PG) and unvegetated (UV), as well as the pH of rainwater (RW). The pH value of green roof runoff with PG vegetation ranged from 6.6 to 8.0, with an average of 7.16. Meanwhile, the pH value of runoff from green roofs unvegetated (UV) ranged from 6.6 to 7.7, with an average of 7.17. In comparison, the pH value of rainwater ranged from 4.5 to 6.8, with an average of 5.74. The pH value of runoff water from green roofs, both with Portulaca grandiflora (PG) vegetation and unvegetated (UV), tends to be higher than the pH of rainwater.

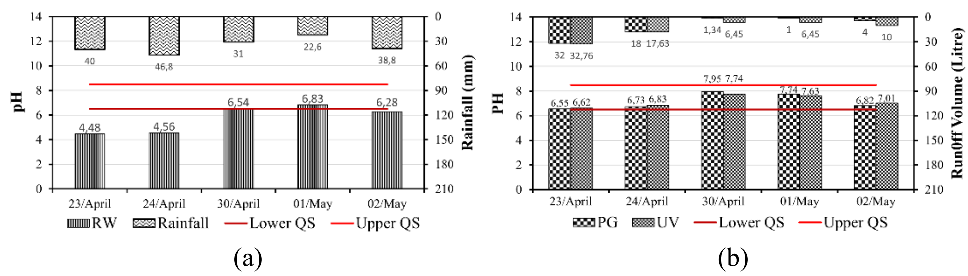
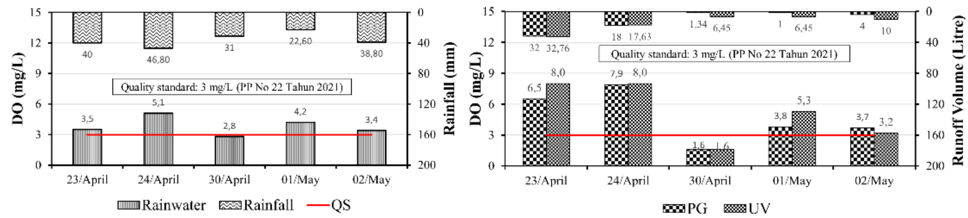


Fig. 7. pH value of rainwater (a) and green roof runoff water.

3.2.4 Dissolved Oxygen (DO)

Fig. 8. shows DO (dissolved oxygen) values in runoff water from green roofs planted with Portulaca grandiflora (PG) and unvegetated green roofs (UV), as well as DO in rainwater (RW). DO values in green roof runoff with PG vegetation ranged from 1.6 to 7.9 mg/L, with an average of 4.7 mg/L. Meanwhile, DO values in runoff from green roofs unvegetated (UV) ranged from 1.6 to 8.0 mg/L, with an average of 5.22 mg/L. In comparison, DO values in rainwater ranged from 2.8 to 5.1 mg/L, with an average of 3.8 mg/L. From these data, it can be seen that DO values in runoff water from green roofs planted with Portulaca grandiflora (PG) are generally lower than those from green roofs unvegetated (UV). However, both green roof models showed higher DO values compared to the DO values of rainwater.

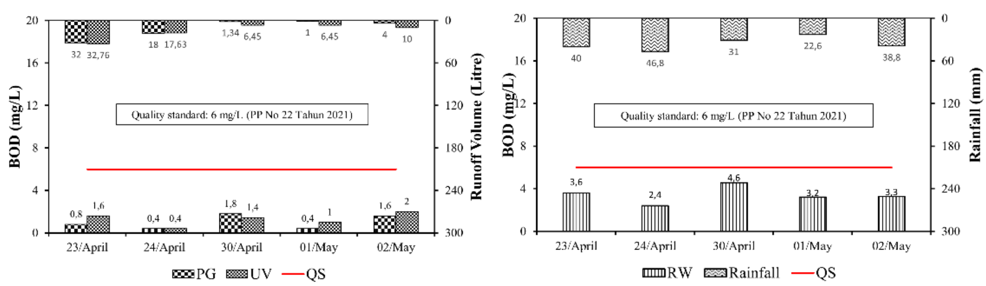


(a) (b)

Fig. 8. DO value of rainwater (a) and green roof runoff water (b).

3.2.5 Biochemical Oxygen Demand (BOD)

Fig. 9. show the value of BOD (biochemical oxygen demand) in runoff water from green roofs planted with Portulaca grandiflora (PG) and unvegetated green roofs (UV), as well as BOD in rainwater. BOD values in green roof runoff with PG vegetation ranged from 0.40 to 1.80 mg/L, with an average of 1.0 mg/L. While the BOD value in runoff from green roofs without vegetation (UV) ranged from 0.40 to 2.00 mg/L with an average of 1.3 mg/L,. In comparison, BOD values in rainwater ranged from 2.40 to 4.60 mg/L, with an average of 3.4 mg/L. From these data, it can be seen that BOD values in runoff water from green roofs planted with Portulaca grandiflora (PG) are generally lower than those from unvegetated green roofs (UV). Both green roof models showed significantly lower BOD values compared to the BOD values in rainwater.

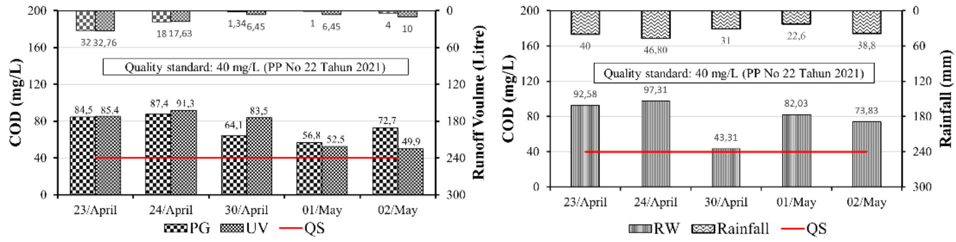


(a) (b)

Fig. 9. BOD content of rainwater (a) and green roof runoff water (b)

3.2.6 Chemical Oxygen Demand (COD)

Fig. 10. show COD (Chemical Oxygen Demand) values in runoff water from green roofs planted with Portulaca grandiflora (PG) and unvegetated green roofs (UV), as well as COD values in rainwater. COD values in green roof runoff with PG vegetation ranged from 56.81 to 87.42 mg/L, with an average of 73.11 mg/L. While the COD value in runoff from green roofs without vegetation (UV) ranged from 49.90 to 91.31 mg/L with an average of 72.53 mg/L,. In comparison, COD values in rainwater ranged from 43.31 to 97.31 mg/L, with an average of 77.81 mg/L. From these data, it can be seen that COD values in runoff water from green roofs planted with Portulaca grandiflora (PG) are generally in a similar range to runoff from unvegetated green roofs (UV), but the average COD value in PG is slightly higher. Both green roof models showed variable COD values, with higher or lower values compared to the COD values in rainwater.

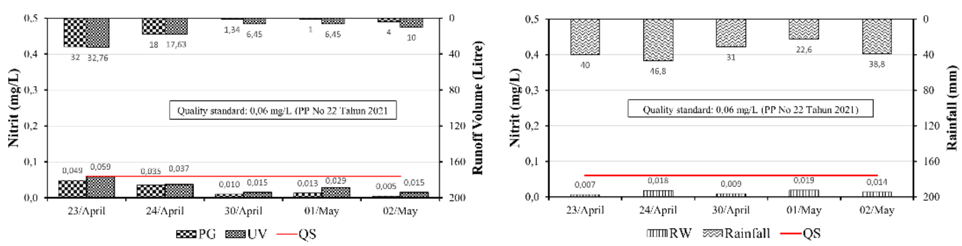


(a) (b)

Fig. 10. COD content of rainwater (a) and green roof runoff water (b).

3.2.7 Nitrite

Fig. 11. show nitrite (NO2) concentrations in runoff water from green roofs planted with Portulaca grandiflora (PG) and unvegetated (UV), as well as nitrite concentrations in rainwater. Nitrite concentrations in green roof runoff with PG vegetation ranged from 0.005 to 0.049 mg/L, with an average of 0.022 mg/L. While nitrite concentrations in runoff from unvegetated green roofs (UV) ranged from 0.015 to 0.059 mg/L with an average of 0.031 mg/L. In comparison, nitrite concentrations in rainwater ranged from 0.007 to 0.019 mg/L, with an average of 0.013 mg/L. From these data, it can be seen that nitrite concentrations in runoff water from green roofs planted with Portulaca grandiflora (PG) are generally lower than runoff from unvegetated green roofs (UV). Both green roof models showed variations in nitrite concentrations, with values tending to be lower on green roofs with PG vegetation.

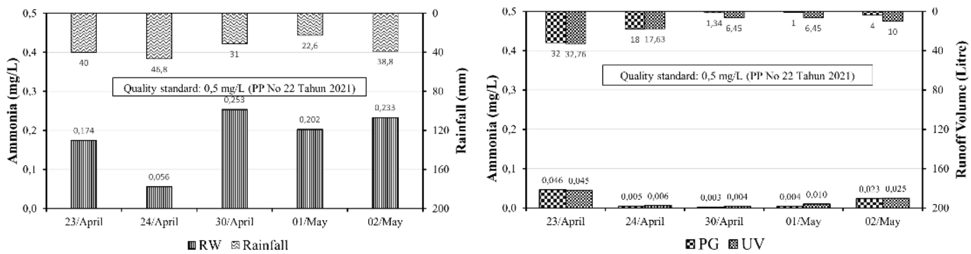


(a) (b)

Fig. 11. Nitrite content of rainwater (a) and green roof runoff water (b).

3.2.8 Ammonia

Based on Fig. 12, some important patterns can be seen. On the green roof with Portulaca grandiflora vegetation, the ammonia concentration showed considerable variation, with a peak concentration on April 23, of 0.046 mg/L and the lowest value on April 30, of 0.003 mg/L. For the unvegetated green roofs, the ammonia concentration was slightly higher than that of the green roof with vegetation, with a peak concentration on the same date of April 23, of 0.045 mg/L and the lowest value on April 30, of 0.004 mg/L. The average ammonia concentration was 0.018 mg/L. The concentration of ammonia in rainwater shows a much higher value than the runoff water from the green roof, with a peak concentration on April 30, 2024, of 0.253 mg/L and the lowest value on April 24, 2024, of 0.056 mg/L. The average ammonia concentration in rainwater was 0.184 mg/L.



(a) (b)

Fig. 12. Ammonia content of rainwater (a) and green roof runoff water (b).

4 Discussion

4.1 Quality of rainwater and green roof runoff water

4.1.1 Temperature

Fig. 5**.** shows that the temperature of rainfall and green roof runoff during five rain events meets quality standards in [15] and with a deviation of ± 3°C from ambient air temperature (Fig. 4(b)). The measured temperature of green roof runoff water ranges from 27.2°C to 34.4°C. The average green roof runoff water temperature for PG dan UV is 30.72°C and 30.48°C, respectively. While the average temperature of rainwater is 30.64°C. The temperature between rainwater and green roof runoff does not show a significant difference, so it can be seen that vegetation on the green roof system does not greatly affect the temperature of runoff water The temperature difference between rainwater and green roof runoff is not significant, indicating that vegetation on green roof systems has little effect on the temperature of runoff water.

4.1.2 TDS

Based on Fig. 6, the TDS value of green roof runoff water is much higher than the TDS value of rainwater. The average TDS value of rainwater for five rainfall events amounts to 10 mg/L, so the rainwater collected is considered pure water. Although the green roof runoff water has a higher TDS value than the rainwater TDS value, the TDS value on the green roof system planted with Portulaca grandiflora and the green roof that is not planted meets the TDS quality standard in [15] which is below 300 mg/L. PG planted with Portulaca grandiflora have a lower TDS value than unvegetated green roof with an average TDS value of 52.2 mg/L. This can occur due to the morphology of Portulaca grandiflora which has roots with fine characteristics so that it can absorb nutrients which are the cause of high TDS values [11]. Portulaca grandiflora is able to accumulate organic and inorganic substances, especially metals. A research that was conducted [16] showed that Portulaca grandiflora can reduce the concentration of metals derived from substrates (Pb, Cd, Cu, Al, Cr, Ni, Fr) green roof so that it can improve runoff water quality through the potential of phytextraction.

4.1.3 pH

Rainwater has a low pH value, with an average of 5.7. The pH value of rainfall on April 23 and April 24 did not meet the quality standards based on [17], with a pH range of 6.5–8.5.

The pH measurement results of green roof runoff water for vegetated and unvegetated green roofs in Fig. 7(b) show values that are relatively higher than rainwater and have met the quality standards. The average pH value for runoff water from green roof systems (PG and UV) is 7.16 and 7.17, respectively. The results showed that vegetated and unvegetated green roofs significantly changed the pH of rainwater. The factor that causes the difference in pH between rainwater and green roofs is that rainwater passing through the green roof comes into contact with the media (soil) on the green roof. Plant roots produce various exudates that can affect the pH of the surrounding soil and water, thereby affecting nutrient mobility [18]. In addition, the occurrence of the nitrification process can reduce the pH value of the soil so that it affects the pH value of the green roof runoff water [19]. Plants can increase pH when hydrogen ions are absorbed by them to maintain ionic balance.

4.1.4 DO

The outcome of DO measurements on rainwater samples show that the DO value of rainwater still meets the quality standards based on [17], which is not less than 3 mg/L. Both the green roof planted with Portulaca grandiflora and the unvegetated green roof showed an increase in DO in the green roof runoff water as shown in Fig. 8 (b). The average DO value of green roof runoff water planted with Portulaca grandiflora is 4.7 mg/L while the average DO value for unvegetated green roofs is 5.2 mg/L. There was a decrease in the DO of green roof runoff water on April 30, this can be caused by the high organic substances that act as pollutants in green roof runoff water. On April 30, the small volume of green roof runoff made the water more concentrated and contained more organic matter. This aligns with research conducted by [20] which found that DO values are affected by pollutants and sedimentation which causes oxygen dispersion to decrease due to sediment at the bottom of the water.

4.1.5 BOD

The BOD number doesn't reflect the actual quantity of organic substances, but rather measures the proportionate amount of oxygen required to oxidize the waste material. [21]. The results of BOD measurements on rainwater samples show that the BOD value of rainwater has met the quality standards based on [17], which is 6 mg/L. The BOD value of green roof runoff water also meets the quality standard as shown in Fig. 8 (b). Nilai BOD pada air hujan relative rendah yaitu diantara 2,4-4.6 mg/L. Research conducted by [22] also reported relatively low BOD values in rainwater, between 2.58-5.07 mg/L. Rainwater BOD values in this range can occur due to contamination with impurities such as bird droppings, leaves, and also contaminants around the wind-blown water catchment. The most common impurities analyzed in harvested rainwater are microbes, organic compounds (carbon and nitrogen), dust, heavy (Ni, Cu, Mn, Pb, Fe, Zn), fine particles and ions (nitrate, sulfate, Mg, Ca, Na, and K). Several research papers have also reported that collected rainwater is often contaminated with fecal coliform from animals. [23][24].

The average BOD value on the green roof system planted with Portulaca grandiflora and the unvegetated green roof is 1 mg/L and 1.29 mg/L, respectively. Both the BOD value on the vegetated green roof and unvegetated green roof has decreased compared to the BOD value of rainwater which has a average value of 3.41 mg/L. These plants can degrade the organic matter contained in rainwater into less harmful forms through biochemical processes, such as nitrification and denitrification. Biochemical processes such as plant-assisted nitrification and denitrification have a complex influence on BOD (Biochemical Oxygen Demand) values in runoff water from green roofs. Plant roots provide surfaces and environments that support nitrifying and denitrifying bacteria. The outcome of the analysis obtained are in line with the results of study carried out by [25] which examined the hydrological performance and runoff water quality of different green roof configurations in Bogota, Colombia. The results of this study showed that vegetation and substrate type had a significant influence on stormwater retention efficiency and runoff water quality, including parameters such as BOD.

4.1.6 COD

One of the chemical parameters that is an indicator of water quality to determine the content of pollutants is Chemical Oxygen Demand (COD). The COD value describes the quantity of oxygen that are necessary to chemically oxidize both biodegradable and non-biodegradable organic materials into CO2 and H2O [26]. Based on Fig. 10, the COD content in rainwater and green roof runoff water is above the quality standard in the [17], which is 40 mg/L. The average COD concentration in rainfall was 77.81 mg/L, then the COD content of runoff water from green roofs planted with Portulaca grandiflora and unvegetated green roofs was 73.11 mg/L and 72.53 mg/L consequently.

Based on Fig. 10, COD concentration in green roof runoff water is smaller than the COD concentration in rainwater. Observing the trend over time, COD from vegetated green roof and unvegetated green roof showed a high peak in the second sample (87.4 mg/L – 91.3 mg/L) and decreased in the next three samples from each rainfall event. This was due to the buildup of organic matter in the green roof layer that was washed away at the beginning of the outflow. The COD content in the runoff water of the planted green roof is lower than the unvegetated green roof. This can occur because the plants on the green roof carry out evapotranspiration, which is the process of absorbing water and decomposing organic substances by plants [27]. This process can reduce the COD content in runoff water because the organic substances contained in rainwater are broken down by plants, so that the COD content decreases.

4.1.7 Nitrite

Based on Fig. 11, the test results on rainwater show that the nitrite content still meets the quality standards based on [17], which is 0.06 mg/L. The nitrite content in green roof runoff water in PG and UV does not show an insignificant difference and still meets quality standards. The average nitrite concentration on the planted green roof was 0.022 mg/L, while on the unvegetated green roof it was 0.031 mg/L. There was an increase in nitrite content in green roof runoff water for both vegetated and unvegetated green roofs. The average increase in nitrite in PG runoff water was 243.61 mg/L in three rain events out of five rain events. While the increase in nitrite in UV runoff water amounted to 202.73 mg/L for five rainfall events. The increase in nitrite on vegetated green roofs is quite high due to the influence of roots that mediate contact between plants and soil microbes. [28]. This allows ammonia from manure to be oxidized to nitrite through the process of nitrification, mediated through a one-step reaction by the bacterial groups Nitrosomas and Nitrobacter. [29].

4.1.8 Ammonia

Based on Fig. 12, the test results on rainwater show that the ammonia content still meets the quality standards based on [17], which is 0.5 mg/L. The highest ammonia content in rainwater occurred on April 30, which amounted to 0.253 mg/L. High ammonia concentrations in rainwater are caused by a combination of ammonia emission sources (such as agricultural, industrial, and natural), atmospheric transport and transformation processes, meteorological conditions, and chemical reactions. Research shows that areas with intensive agricultural activities, such as areas with high nitrogen fertilizer use, tend to have rainwater with higher ammonia concentrations. For example, a study by [30] in rural and urban areas in several countries showed that fertilizer use and emissions from farm activities are major contributors to the increase of ammonia in the atmosphere and deposition in rainwater. The average ammonia content in green roof. runoff water that is vegetated and unvegetated green roof is 0.016 and 0.018, respectively. Unvegetated green roof runoff water contains higher ammonia concentrations than vegetated green roof runoff water. This may be caused by the shorter reaction time for nitrification which converts ammonia to nitrite..and nitrate [9].

4.2 Determination of the quality status of rainwater and green roof runoff water

The assessment of water quality status is based on the quality standards set in [15] and has been given a score according to the value weighting. Based on Table 3, rainwater gets a water quality status that is moderately contaminated at -20 because the maximum, minimum and average concentrations of COD do not meet the quality standards so that they are respectively given a score of -2, -2 and -6. Also, the minimum DO value of rainwater does not meet the quality standards so it gets a value of -2. Rainwater has an acidic pH value and still does not meet quality standards, the minimum and average pH values do not meet quality standards so they get a score of -2 and -6 respectively.

Table 3. Assessment of the quality status of runoff water from green roof systems PG, UV and rainwater based on the quality standards of "Peraturan Pemerintah Republik Indonesia No 22 Tahun 2021"

Water Sampel	Water Quality Status
Rainwater	Moderately contaminated
Vegetated Green Roof (PG)	Lightly contaminated
Unvegetated Green Roof (UV)	Lightly contaminated

Runoff water in PG has a water quality status is lightly Contaminated at -8, while UV has a water quality status that is lightly Contaminated at -10. The maximum, minimum, and average concentrations of COD in PG do not meet the quality standards so they are scored -2, -2, and -6, respectively. In UV, the maximum value of nitrite does not meet the quality standard so it is given a value of -2 and the maximum, minimum, and average concentrations of COD in PG do not meet the standard so they are given a value of -2, -2, and -6 respectively.

Based on Table 4, water quality status is determined using quality standards set in [16] and has been given a score according to the value weighting. Rainwater gets a water quality status that is lightly Contaminated with a score of -8 because the minimum and average nitrite concentrations do not meet the quality standards so that they are given a score of -2 and -6 respectively. Meanwhile, for green roof runoff water, both vegetated and unvegetated green roof, both have met the quality standards according to "Peraturan Menteri Kesehatan No 2 Tahun 2023".

Table 4. Assessment of the quality status of runoff water from green roof systems PG, UV and rainwater based on the quality standards of "Peraturan Menteri Kesehatan No.2 Tahun 2023"

Water Sampel	Water Quality Status
Rainwater	Lightly contaminated
Vegetated Green Roof (PG)	Meet the quality standards
Unvegetated Green Roof (UV)	Meet the quality standards

5 Conclusion

The vegetation on the green.roof system affects the.quality.of green roof runoff water. Based on the quality standards of [15], the STORET value in rainwater is categorized as moderately contaminated with a value of -20. While the STORET value in green roof runoff water planted with Portulaca grandiflora and unvegetated green roof, both are categorized as lightly contaminated with a value of -8 and -10 respectively. COD, DO, and pH in rainwater do not meet standards of quality. The parameter values that fail to meet the quality standards on the vegetated green roof are simply COD, whereas the parameters on the unvegetated green roof are both COD and nitrite. While based on the quality standards of [16], the STORET value in rainwater is categorized as lightly contaminated with a value of -8. While the STORET value in green roof runoff water planted with Portulaca grandiflora and unvegetated green roof, both are categorized as meeting quality standards. Nitrite is an indicator that does not comply with rainwater quality criteria. The parameter that fail to meet the quality standards on the planted green roof are simply COD, whereas the parameter that do not meet the quality standards on unvegetated green roofs are both COD and nitrite.

Although both vegetated and unvegetated green roofs' runoff water quality is classified as lightly contaminated by the STORET method, vegetated green roofs have an advantage in terms of quantity and quality. Because of its higher water retention capacity, a planted green roof can minimize runoff volume more efficiently, which reduces flood risk and increases water infiltration. In addition, runoff water quality from planted green roofs tends to be better in the long run because plants play a role in the bioremediation process, breaking down pollutants through biological mechanisms. Plants also help stabilize the substrate and prevent erosion, thereby reducing sedimentation in runoff water. These results show that while the current water quality is similar, vegetated green roofs offer additional advantages in runoff water quantity and quality management and provide wider ecological benefits. Thus, vegetated green roofs are more advantageous in terms of sustainability and effectiveness of urban environmental management.

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