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Low Impact Development-Based Drainage Design in Residential Areas: A Case Study of Mastrip Housing

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Abstrak

Drainase konvensional menghadapi tantangan yang diperparah oleh peningkatan limpasan permukaan. Rain barrel adalah salah satu teknik *Low Impact Development* (LID) yang menyediakan penampung sementara yang berpotensi mengurangi limpasan. Oleh karena itu, penelitian ini menyelidiki penerapan rain barrel untuk meningkatkan ketahanan terhadap banjir di Mastrip Housing. Menggunakan Storm Water Management Model (SWMM), limpasan hujan dimodelkan dalam kondisi sebelum dan sesudah implementasi di 71 subcatchment untuk menilai dampak infrastruktur LID. Hasilnya mengungkapkan bahwa rain barrel dapat mengurangi puncak limpasan sebesar 11% hingga 51%, dengan rata-rata pengurangan sebesar 12%. Efektivitasnya bervariasi, dipengaruhi oleh kepadatan rain barrel, cakupan area, dan penggunaan lahan. Ada tren yan menunjukkan subcatchment dengan area kecil dan unit rain barrel lebih banyak menunjukkan pengurangan peak runoff yang lebih besar, menekankan pentingnya pertimbangan rasio. Meskipun demikian, penelitian ini menemukan bahwa penggunaan rain barrel tidak selalu berhasil dalam semua situasi. Sementara mereka mungkin efektif dalam meminimalkan limpasan di beberapa lokasi, efektivitasnya bervariasi di tempat lain bahkan di area perumahan yang sama. Oleh karena itu, metode infiltrasi LID dapat dipertimbangkan untuk meningkatkan efektivitas pengurangan. Penelitian ini memberikan wawasan bagi pengembang properti menuju perumahan ramah lingkungan dan pembangunan berkelanjutan dengan penerapan rain barrel dan LID.

Kata kunci: *Low-Impact Development (LID), Strategi, Stormwater Management Model, Rain Barrel, Peak Runoff*

Abstract

The conventional drainage face challenges exacerbated by increased surface runoff. Rain barrels are one of the Low Impact Development (LID) techniques that provide temporary storage which potentially can reduce runoff. Therefore, this study investigates the application of rain barrels to enhance flood resilience in Mastrip Housing. Using the Storm Water Management Model (SWMM), rainfall runoff was modeled under pre- and post-implementation conditions in 71 sub-catchments to assess LID infrastructure impact. Results reveal rain barrels can reduce peak runoff by 11% to 51%, averaging a 12% reduction. The effectiveness varies, influenced by rain barrel density, area coverage, and land use. There is trend revealed, exhibiting sub-catchments with small area and more rain barrel unit showing bigger peak runoff reductions, emphasizing the necessity of ratio consideration. Nonetheless, this study finds that the usage of rain barrels is not equally successful in all situations. While they may effectively minimize runoff in some locations, their efficacy varies elsewhere even in the same housing area. Therefore, infiltration LID methods can be considered to improve the effectiveness of reduction. This study provides insights for property developers towards environmentally friendly housing and sustainable development with rain barrel and LID implementation.

Keywords: *Low-Impact Development (LID), Strategy, Stormwater Management, Rain Barrel, Peak Runoff*

1. Introduction

Urbanization is an event that has caused serious disruption and damage to the natural hydrological cycle, leading to a series of problems such as urban flooding, water pollution, and destruction of watershed ecosystems (Zhang et al., 2023). The impact of increasing urbanization causes major changes in the living arrangements of people, which has a profound effect on daily life, the environment, and the development process (Kuok et al., 2024). In urbanization, naturally water-absorbing surfaces are replaced with impermeable coverings, such as concrete and asphalt, leading to reduced soil infiltration capacity, resulting in increased surface runoff during rainfall that overwhelms urban infrastructure and causes flooding (Ghimire et al., 2023).

Jember District, Indonesia is one of the locations that still uses conventional drainage systems in addressing water and water management issues in the region. These drainage systems have become an important part of the district's urban and rural infrastructure, helping to drain stormwater and minimize the risk of flooding and other negative impacts. Mastrip Housing is one of the estates on Mastrip Road, Jember Regency. This estate often experiences waterlogging due to several factors, such as an inadequate drainage system that makes it difficult to drain rainwater, especially during high rainfall, the location of the estate itself that is in a basin causes water to gather inside, among several other factors. Channel blockages and lack of maintenance also contribute to the problem. In addition, the existing drainage still uses conventional drainage, which has the principle that all rainwater must be immediately discharged into the nearest water bodies (Arifin et al., 2022).

Mastrip Housing is a residential area located in Jember Regency, Indonesia, which frequently experiences flooding due to inadequate drainage systems and its position in a low-lying basin. The area has a conventional drainage infrastructure that fails to manage stormwater efficiently, especially during heavy rainfall. This study focuses on improving the flood resilience of Mastrip Housing by implementing LID techniques such as rain barrels, which aim to reduce peak runoff and enhance water retention on-site.

So far, excess water such as flooding is often considered as a problem related to the city's infrastructure such as pipe systems to drain rainwater to water treatment plants or to surface waters (Hidayah et al., 2024). Contrary to this concept, the current goal is to manage rainwater on-site (storing, infiltrating, and evaporating) to approach the natural water balance (Pochodyła et al., 2021). To solve this problem, solutions are needed to ensure resilient water management in urban environments. One of the widely used rainfall-runoff models is the Storm Water Management Model (SWMM) developed by the US Environmental Protection Agency (EPA). It includes a Low Impact Development (LID) module that allows simulation of various other stormwater management measures such as permeable pavement and rainwater harvesting (Rossman & Simon, 2022).

This study examines the application of Low Impact Development (LID) concepts to enhance flood resilience and improve water management in urban areas. Specifically, it focuses on the implementation of LID infrastructure in Mastrip Housing, Jember Regency, Indonesia, and its impact on reducing surface runoff and flood risks. Through the use of the Storm Water Management Model (SWMM), the research simulates rainfall-runoff processes and evaluates the effectiveness of various LID techniques, such as permeable pavements and rainwater harvesting, in managing stormwater during a 2-year rainfall event. The study's objectives include assessing the current performance of the conventional drainage system in Mastrip Housing under high rainfall conditions, evaluating the potential of LID strategies to reduce runoff and flood risk, and comparing pre- and post-implementation flood scenarios to measure the effectiveness of LID infrastructure in improving water management and urban resilience. By addressing these objectives, the research aims to provide valuable insights into how LID infrastructure can contribute to sustainable urban water management, particularly in areas facing similar challenges.

2. Methods

This research is divided into 3 phases, namely data collection, evaluation of drainage performance in actual conditions, and application of the LID concept at the research site. The process begins with the selection and design of LID parameters, which are then modeled using the EPA-SWMM system. LID controls are employed to develop two scenarios: Scenario (1) represents conditions before LID implementation, while Scenario (2) focuses on the use of rain barrels as a specific LID measure.

On the other side, the existing drainage map, land use data, soil map, return period, digital elevation model, and CN (Curve Number) infiltration number are integrated into a GIS database. The GIS data is then used to initialize the EPA-SWMM model, leading to results analysis. Finally, a comparison of the flooding node before and after the implementation of LID is conducted, providing insight into the effectiveness of LID measures in flood mitigation and water management.

2.1 Rainfall Frequency Distribution Analysis

Frequency distribution analysis is an analysis to estimate whether the water flow discharge will exceed or equal a certain return time, for example for 10 years, 20 years, and so on in the future (Limantara, 2018). The frequency analysis equation for each distribution:

Normal Disrtribution:

$$f(z) = \frac{1}{\sqrt{2\pi}} e^{\frac{-z^2}{2}} \quad (1)$$

$$\varphi(z) = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{z} e^{\frac{-t^2}{2}}\, dt \quad (2)$$

Gumbel Disrtribution:

$$f(x;\mu,\beta) = \frac{1}{\beta} e^{-\left(\frac{x-\mu}{\beta}+e^{-\frac{x-\mu}{\beta}}\right)} \quad (3)$$

$$f(x;\mu,\beta) = e^{-e^{-\frac{x-\mu}{\beta}}} \quad (4)$$

Log Normal Disrtribution:

$$f(t) = \frac{1}{\sqrt{2\pi\sigma t}} \exp\left[-\frac{1}{2}\left(\frac{\ln t-\mu}{\sigma}\right)^2\right] \quad (5)$$

$$f(t) = \varphi\left[\frac{\ln t-\mu}{\sigma}\right] \quad (6)$$

Log Pearson Type III:

$$f(x;\alpha,\beta,\gamma)=\frac{1}{x\beta\Gamma(\alpha)}\left(\frac{ln(x)-\gamma}{\beta}\right)^{\alpha-1}exp\left(-\frac{ln(x)-\gamma}{\beta}\right) \tag{7}$$

$$(\mathrm{x};\alpha,\beta,\gamma)=\frac{\Gamma_{\frac{\ln(x)-\gamma}{\beta}}(\alpha)}{\Gamma(\alpha)} \tag{8}$$

2.2 Goodness of Fit Test

Goodness of Fit Test is a stage to determine whether the distribution of data opportunities can be accepted or rejected. This fit test can be done through several methods, one of which is the Kolmogorov-Smirnov test (Ruhiat, 2022). This test is used to determine the percentage of skewness and maximum data deviation is acceptable or not. The distribution requirement accepted by the Kolmogorov-Smirnov test is when D < DCritical (Limantara, 2018). If the deviation value of the calculated data (D) exceeds the maximum deviation of the data, then the statistical properties are unacceptable (ΔCritical) (Aslam, 2020).

$$D=max\left|F_{n_1}(x)-F_{n_2}(x)\right| \tag{9}$$

2.3 Rainfall Intensity Analysis

Rainfall intensity analysis measures the height or volume of rainwater in a period of time. Short rain duration has a high intensity, and using a large return period will produce a higher rain intensity (Yulius, 2018). The Mononobe method is used for daily rainfall data which can be seen in equation 2.11.

$$I=\frac{R_{24}}{24}\left(\frac{24}{t}\right)^{\frac{2}{3}} \tag{10}$$

2.4 Surface Flow Coefficient

Surface flow coefficient (C) is the ratio of peak surface flow to rainfall intensity (Kamiana, 2011). To determine the value of C in an area with various land uses, one can use the average C of each land use by considering the area represented. There are several factors that can affect the conveyance coefficient. One of them is based on land use and surface type.

$$C=\frac{\sum_{i=0}^{n}C_i.A_i.}{\sum_{i=0}^{n}A_i} \tag{11}$$

2.5 Study Area

The study site is in Mastrip Housing, Jember Regency. The study site is located at coordinates 113°43'22" E 8°9'57" S. The study site has an area of 11.14 ha which has various types of land cover such as roads, buildings, and green land overgrown by several perennials. Two nearby rain gauge stations provide rainfall data, namely the Jember rain gauge and the Sembah rain gauge. The Jember rain gauge station is about 3.8 km from the study site, while the Sembah rain gauge station is about 3.5 km from the study site. This location is close to the Bedadung river, so surface runoff passes through five designated outlets into its sub-river. These outlets have an important role in regulating the flow of abundant rainwater, especially during periods of high rainfall. In addition, the presence of the Bedadung river as a significant environmental element can influence the hydrological dynamics and water management in this study area.

Figure 1 Study Area

2.6 Rainfall Data

2.6.1 Observed Rainfall Data

The observed rainfall data is based on the monitoring of the Jember and Sembah rain gauges provided by Dinas Pekerjaan Umum, Bina Marga, dan Sumber Daya Air, Jember Regency (PUBMSDA). In addition, rainfall data on selected dates were taken for model calibration. The December 27, 2023, rainfall was a typical rainfall event in Jember that started at 15:06 and ended around 18:30. The total rainfall was about 87 mm in about 3.5 hours.

2.6.2 Rainfall Analysis

In general, each region has a different rain distribution model. Various rain distributions in a region include Normal (Kurniawan, 2019), Gumbel (González-álvarez et al., 2019), Lognormal (Norrulashikin et al., 2021), and Log Pearson Type III (Desvina et al., 2019) and this is adjusted to the climatic characteristics of the research area. Stochastic models that use cumulative distribution functions (CDFs) allow the simulation of hydrological data based on their frequency of occurrence (Progênio & Blanco, 2020). To select the CDF that best fits the daily rainfall data, the Kolmogorov-Smirnov (KS) test was used. This test refers to the absolute difference between the observed rainfall data and the CDF. The highest value of this absolute difference is identified and compared to the critical value at 5% significance level ($\alpha = 0.05$). The null hypothesis (H_0) is that both data set values come from the same continuous distribution. The alternative hypothesis (H_1) is that these two data sets come from different continuous distributions.

2.7 Hidrological Model Selection

There are many types of methods to evaluate the impact of LID concepts. Relevant models include the Long-Term Hydrologic Impact Assessment-Low Impact Development model (L-THIA-LID) (Cai et al., 2023), improved SCS-CN model (Shi & Wang, 2020), System for Urban Storm-water Treatment and Analysis Integration (SUSTAIN) model (Nazari et al., 2023), and SWMM (Rossman & Simon, 2022). SWMM being the most used to simulating surface runoff and LID because its simplicity and accurate result (Lee et al., 2020), therefore this study using SWMM to model LID.

SWMM is a simulation model based on physical principles, which allows simulating the amount of rainfall runoff based on processes such as surface runoff, infiltration, surface ponding, and flow routing (Luan et al., 2017). In LID simulation, SWMM is one of the early hydrological models equipped with LID modules (Rossman & Simon, 2022). SWMM provides a wide range of LID concepts for rainfall runoff control. Hydrological processes such as regional surface runoff and peak discharge can be simulated by applying the LID module in combination with the hydraulics module. Therefore, the runoff reduction effect of LID can be evaluated through these factors.

2.8 LID Scenario Design

In the EPA-SWMM software, there are various LID concepts available. Among these, the rain barrel was chosen for simulation based on the technical characteristics of the research area (Putri et al., 2023a). Rain barrels were selected for this study as a LID concept because Mastrip Housing is a densely populated area, limiting the applicability of several other LID techniques. Rain barrels are particularly suitable as they do not require significant space for installation. The number of rain barrels utilized was determined based on the type of land cover and the number of households within each sub-catchment of Mastrip Housing. Additionally, an existing scenario without LID was designed to serve as a comparative baseline for drainage conditions.

3 Result and Discussion

3.1 Rainfall Analysis

Rainfall data used for the plan rainfall analysis was obtained from Jember and Sembah Rain Stations from 2003 to 2022. The cumulative distribution function (CDF) plot of the rainfall data is shown in Figure 3. The KS test results provide KS (D) statistical values on each of the normal, gumbel, lognormal, and log Pearson type III distributions of 0.112; 0.098; 0.094; 0.098 and a p-value of 0.294 which indicates that the null hypothesis (H0) on all distributions is accepted. The KS test performed using this dataset at the 5% significance level yields the result that the null hypothesis is not rejected, indicating that the samples are drawn from the same continuous distribution. Considering the lowest value of the KS statistic, which is 0.094, we can refer to the selection of the lognormal distribution as the most suitable distribution for the observed rainfall data.

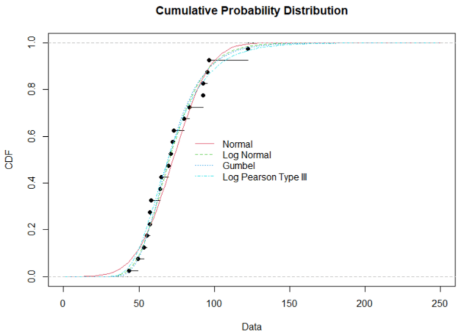

Figure 2 Cumulative Probability Distribution

After obtaining a reliable rainfall distribution, rainfall intensity analysis is carried out using the Mononobe method, which can be applied when only daily rainfall data is available. This research assumes that rain occurs for 4 hours (Limantara, 2018). Meanwhile, according to PerMen PU No. 12 of 2014, for an area of 10 - 100 ha, a return period of 2-5 years is used, because the research area has an area of about 11.15 ha, then in this study a return period of 2 years is used.

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The results of the calculation of rain intensity analysis can be seen in Table 1. It shows that the longer the rain duration, the smaller the rain intensity.

Table 1 Precipitation Intensity

Duration (minute)	Intensity (mm/h)
5	127,672
10	80,428
15	61,378
20	50,667
40	31,918
60	24,358
90	18,589
120	15,345
150	13,224
180	11,710
210	10,566
240	9,666

Analysis of rain intensity using the Mononobe method will produce an intensity-duration-frequency (IDF) curve (Priambodo et al., 2019). The IDF curve is a representation that summarizes the likelihood of rain occurring (Khadka et al., 2020). Analyzing rain intensity using the log normal method produces an IDF curve as shown in Figure 4, that provides important information regarding the frequency and duration of rain.

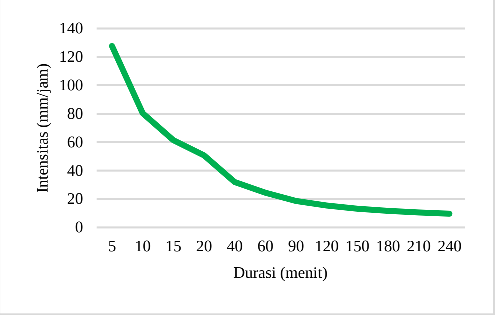

Figure 3 IDF Curve

3.2 Actual Drainage Performance

Simulation of the actual conditions of Mastrip Housing drainage is intended to see the drainage performance and runoff points that occur. The simulation results show that the existing drainage system can handle most of the water flow generated by rainfall. However, there are some runoff points that occur at some junctions, as shown in Figure 5.

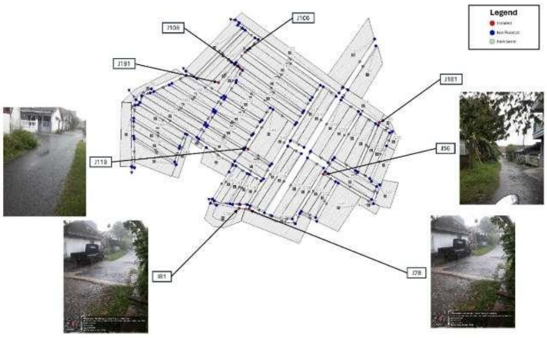

Figure 4 Actual Drainage Simulation

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Based on the simulation of actual conditions, there are Flooding Nodes (overflow points) located in eight locations. The simulation results match the field conditions which both show an overflowing condition. The total value of flood volume at the runoff point is described in Table 2.

Table 2 Locations of Drainage Overflow Points

Node	Hours Flooded	Maximum Rate (m3/s)	Total Flood Volume (m3)
$J_{56}S_{33}$	0,21	0,099	34
$J_{78}S_{38}$	0,05	0,011	1
$J_{81}S_{39}$	0,22	0,022	13
$J_{106}S_{13}$	0,11	0,022	5
$J_{108}S_{10}$	0,12	0,018	5
$J_{116}S_{48}$	0,13	0,017	6
$J_{181}S_{5}$	0,07	0,005	1
$J_{191}S_{9}$	0,08	0,006	1

Figure 5 and Table 2 illustrate the results of the actual drainage simulation, identifying eight flooding nodes (overflow points) within Mastrip Housing. These nodes are characterized by their hours flooded, maximum runoff rates, and total flood volumes. The simulation results closely reflect field conditions, confirming the model's reliability in predicting areas prone to overflow during heavy rainfall events.

Junctions such as J78 in sub-catchment S38, J181 in sub-catchment S5, and J191 in sub-catchment S9 exhibit relatively low maximum flow rates of 0.011, 0.005, and 0.006 m³/s, with corresponding flood volumes of 1 m³, indicating localized and less severe flooding. These areas face smaller-scale flood risks, likely due to their localized water accumulation, and the drainage system in these points is still somewhat capable of handling runoff, although improvements are still necessary.

In contrast, nodes such as J81 in sub-catchment S39 and J56 in sub-catchment S33 show much greater maximum flow rates of 0.022 and 0.099 m³/s, along with higher flood volumes of 13 m³ and 34 m³, indicating more widespread and severe flooding. The elevated flood volumes at these nodes suggest significant system inefficiency, as these locations serve as accumulation points for runoff from multiple preceding junctions with steep slopes. The steep slopes create greater gravitational forces, accelerating water flow into these nodes, leading to a rapid accumulation of stormwater (Legese & Gumi, 2020). This higher volume of floodwater is exacerbated by the relatively small channel capacity in these areas. For instance, Junction J116 in sub-catchment S48 has a channel with a depth of only 32 cm and a width of 20 cm, significantly smaller than other channels, some of which have dimensions of 100 cm by 100 cm. This insufficient channel size limits the drainage system’s ability to handle stormwater, causing flooding (Siregar et al., 2020).

Proper hydraulic infrastructure design is critical in ensuring that drainage channels can accommodate anticipated water volumes, especially in areas with high runoff rates. Before constructing drainage networks, it is essential to carefully plan and implement an adequate drainage capacity that matches the area's topography and water flow patterns (Bakhshipour et al., 2021).

To address these issues, this study proposes the implementation of Low Impact Development (LID) techniques, such as rain barrels and permeable pavements, aimed at reducing peak runoff and increasing water retention in the most flood-prone nodes. These interventions are expected to mitigate surface runoff, particularly in critical points like J5S33, where the existing system is overwhelmed, and flooding is most severe. By enhancing water management infrastructure, these strategies will improve urban flood resilience and reduce the risk of recurrent flooding in Mastrip Housing.

3.3 Model Calibration

The field water level data used for calibration is data taken on December 27, 2023, at 16:21 with a rain duration of 3.5 hours which can be seen in Figure 6. The calibration results of the EPA-SWMM model are then evaluated through analysis of the percentage error in Table 3.

Figure 5 Model Calibration

Table 3 Calibration Data

Conduit	EPA-SWMM Simulation Height (m)	Field Measurement Height (m)	Percentage Error (%)
C_2S_{24}	0,19	0,2	5
C_2S_{29}	0,26	0,25	4

The simulation results obtained by EPA-SWMM software at conduit C_2S_{24} were 0.19 m high and the actual height was 0.2 m, resulting in a percentage error of 5%. Other conduit, C_2S_{29}, the simulation results obtained a water level of 0.26 m and in actual conditions in the field there was a difference in water level of 0.01 m, so the resulting percentage error was 4%. These results can illustrate that rainfall data predicted with EPA-SWMM software is said to be good because the resulting error value can be less than 10% (Rossman, 2022).

3.4 Rain Barrel Simulation

This research uses the LID Water Storage concept. One of the water storage technologies in LID is rain barrel (Oberascher et al., 2021). The specifications of the rain barrel used in this study can be seen in Table 4. In addition, rain barrels will be placed in each house in the research location to reduce the burden of the drainage system, by slowing down the flow of water into the drainage system which is sometimes unable to handle rapid spikes in water volume (Qin, 2020). However, there are also sub-catchments that are not given rain barrel installations because the area is a grassy field (S_{31}) and sandy vacant land (S_{70}) with no house.

Table 4 Rain Barrel Parameters

Layer	Parameter	Unit	Value	Source
Storage	Barrel Height	mm	1290	Local Market
Drain	Flow Coefficient	-	11,972	$\frac{2\sqrt{h}}{t}$ (Rossman & Simon, 2022)
	Flow Exponent	-	0,5	(Zhang et al., 2023)
	Offset Height	mm	100	Local Market
	Drain Delay	hours	6	(Zhang et al., 2023)

This parameter values and the number of rain barrels were then entered into the EPA-SWMM software to simulate the impact of rain barrel implementation on the drainage system at the study site. The results of this simulation can be seen in Figure 7.

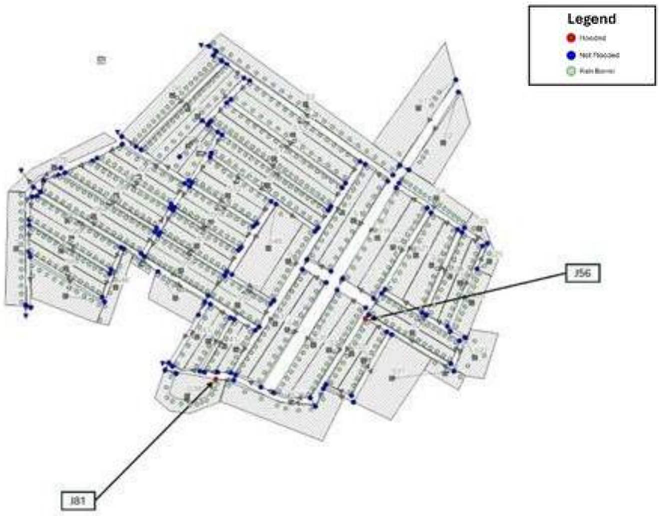

Figure 6 Rain Barrel Simulation

There is a decrease in flood points at the research location which can be seen in Table 5. There are only two overflow points left with the largest water volume located at Junction J_{81} and J_{56}. This location still has flooding even though a rain barrel has been applied. Even so, the rain barrel utilization was able to significantly reduce the total flood volume by at least half and even more, from 13 m^3 and 34 m^3 into 6 m^3 and 3 m^3 at junction J81 and J56. This indicates that the use of rain barrels can ease the workload of existing drainage channels and potentially reduce flood (Li et al., 2021).

Table 5 Locations of Drainage Overflow Points

Node	Hours Flooded	Maximum Rate (m3/s)	Total Flood Volume (m3)
$J_{56}S_{33}$	0,07	0,025	3
$J_{81}S_{39}$	0,14	0,015	6

3.5 Runoff Reduction Using Rain Barrel

After simulating drainage under actual conditions and using the LID concept, the performance of the simulation is compared as shown in Figure 8. By using rain barrels, sub-catchments experienced a reduction in peak runoff of up to 51%, such as in sub-catchment S_{45}. The use of rain barrels in other sub-catchments such as S_5, S_8, S_9, S_{25}, S_{28}, S_{30} and S_{33}, resulted in a 31-37% reduction in peak runoff. The use of rain barrels in sub-catchments S_2, S_{14}, S_{15}, S_{32}, S_{40}, S_{44}, S_{46}, and S_{55} reduced peak runoff by 20 - 29%. Rain barrels placed in these areas with reduction rate above 20% are considered good in reducing inundation, which based of research by Arjenaki et al., (2021), the results of applying rain barrels in 14 selected subcatchments showed that the volume and discharge of runoff in these sub-catchments are reduced by 25%.

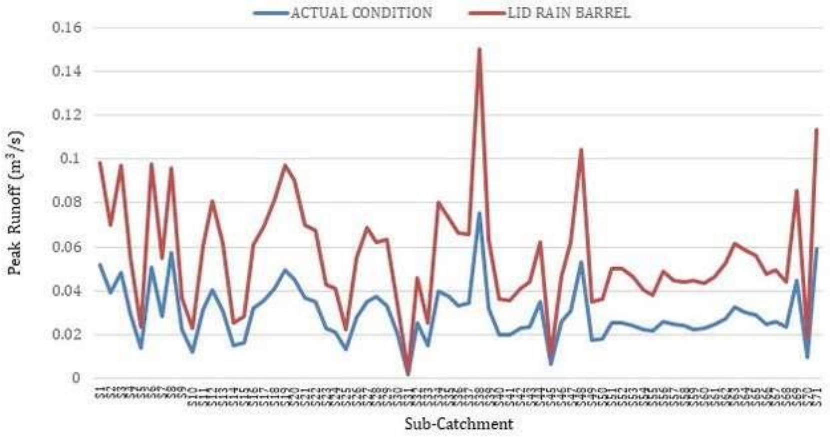

Figure 7 Runoff Response Comparison

On the other hand, rain barrels in sub-catchments S_1, S_4, S_{10}, S_{23}, S_{29}, S_{37}, S_{41}, S_{43}, S_{54}, S_{57}, S_{58}, S_{68}, S_{60}, S_{61}, and S_{63} were only able to reduce 11-19% of peak runoff. While the other 39 sub-catchments experienced a reduction of 0 - 10%. In these areas, the use of rain barrels is considered ineffective to reduce runoff. A study conducted by Aves (2022), showed similar low results. The research was conducted in Surigao City, Philippines and used rain barrels as LID to be applied there. The study revealed that the SWMM simulation resulted in a percentage reduction in peak runoff discharge of 7.98%. Nonetheless, the average peak runoff reduction in this study is 12%. Thus, the utilization of rain barrels in this area is considered ineffective, especially during strong storms or continuous heavy rains that can result in major flooding.

3.6 The Relationship Between Rain Barrel Numbers and Area on Reducing Peak Runoff

The fluctuations in reduction value are influenced by the number of rain barrels installed and the area covered as shown in Figure 9. In sub-catchments with smaller areas but multiple rain barrels usage, there is a notable increase in peak runoff reduction. This trend is observed in various sub-catchments, including S_8, S_9, S_{10}, S_{14}, S_{15}, S_{25}, S_{28}, S_{30}, S_{32}, S_{33}, S_{40}, S_{41}, S_{42}, S_{45}, S_{57}, S_{60}, S_{61}, and S_{68}. For instance, sub-catchment S45 demonstrates the highest peak runoff reduction percentage, reaching 51%, due to it having 4 rain barrels covering just 0.022 hectares or 220 m^2. In other words, the ratio of the number of rain barrels to the area is very large at 180 units/ha. Conversely, sub-catchments with larger areas but fewer rain barrels usage, like S_1, S31, S38, and S48. With an area of 0.42 ha or 420 m^2 using 4 rain barrel where the ratio of the number of rain barrel units and the area of 9 units/ha, is only able to reduce 11% of the existing peak runoff as sub-catchment S_1. These results are corroborated by research from Stec (2018), using rain barrels in Przemysl, Poland. Researchers used 3 scenarios in the installation of rain barrels, namely, scenario 1 covering 50% of the study area, scenario 2 using as much as 75%, and scenario 3 using rain barrels as much as 100% of the study area. Sequentially, scenarios 1, 2, and 3 show that the wider the coverage of rain barrels, the higher the decrease in peak runoff discharge produced, namely 9.7%, 10.8%, and 14.1%.

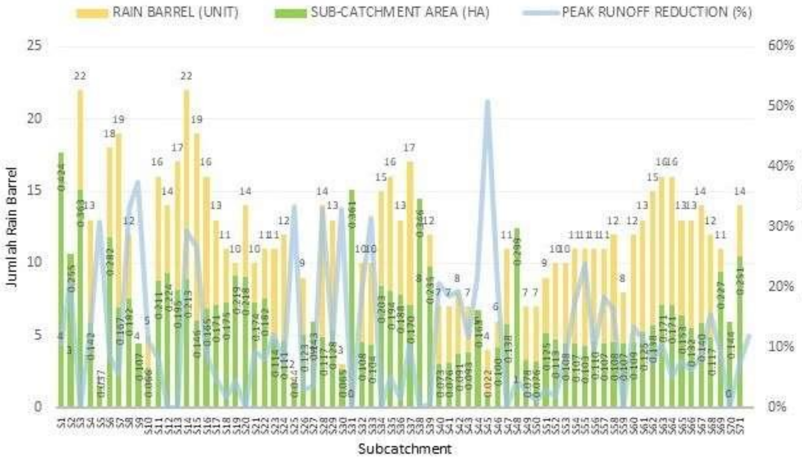

Figure 8 The Relationship Between the Number of Rain Barrels and Sub-Catchment Area on Peak Runoff Reduction

However, in some areas that have a large ratio of the number of rain barrels and areas such as in sub-catchments S_3, S_{12}, S_{13}, S_{20}, S_{34}, S_{47} and S_{59} which are in the range of 61 units/ha to 80 units/ha show no peak runoff reduction value at all or 0%. This might be because the land use in each sub-catchment affects the ability of the area to infiltrate water, potentially reducing runoff (Jemberie & Melesse, 2021). In addition, these sub-catchments receive runoff from the previous areas, so the load on these sub-catchments is greater than the others. For instance, despite S_1 having fewer rain barrels than S_3, its land cover primarily comprises grassy vacant land, which is enough to absorb water. The rainwater that is not collected in rain barrels and not absorbed by the soil in S_1 will surpass S_3, become a burden for S_3 despite the large number of rain barrels, so the barrels cannot work effectively. It is indicating that the uses of rain barrels alone are not enough in this area, hence, it would be better to combine rain barrels with other LID practices, especially the LID infiltration method ones, like bioretention or permeable pavement to reduce higher amount of peak runoff (Putri et al., 2023).

4 Conclusion and Suggestion

4.1 Conclusion

Urbanization poses significant challenges to natural hydrological cycles, leading to adverse effects such as urban flooding, water pollution, and ecological degradation. In Jember District, Indonesia, the adverse impacts of urbanization are evident, especially in areas like Mastrip Housing, where conventional drainage systems struggle to manage increased surface runoff and frequent waterlogging incidents. The use of Low Impact Development (LID) strategies, such as rain barrels, has proven effective in reducing peak runoff in several sub-catchments.

This study demonstrates that the implementation of rain barrels can reduce runoff in sub-catchments by 11% to 51%, with an average reduction of 12%.

However, the effectiveness varies across areas due to factors such as the number of rain barrels installed, the size of the catchment, and land use. In catchments with larger rain barrel coverage, greater reductions in peak runoff were observed. Conversely, areas with fewer rain barrels or lower installation density showed minimal to no reduction in runoff, indicating the need for complementary LID practices.

These findings emphasize the importance of integrating rain barrels with other water management strategies to enhance their effectiveness in reducing urban flooding. Developers and local authorities can use this information to design more resilient drainage systems in urban areas, ensuring environmentally sustainable development.

4.2 Suggestion

This research has used rain barrels as a LID method to reduce surface runoff. To complement the existing results, the use of other LID methods, especially infiltration LID such as bioretention and permeable pavements, can be considered. Comparative studies between the various LID methods can provide a more comprehensive picture of the most effective methods in residential neighbourhoods.

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