Implementation of Low Impact Development for Reducing Surface Runoff: A Case Study of Bumi Harapan Residential Area, Cileunyi

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Abstract — This study analyzes surface runoff and evaluates the effectiveness of Low Impact Development (LID) in the Bumi Harapan residential area, Cileunyi District, Bandung Regency. A descriptive quantitative method was applied using hydrological modeling with PCSWMM. Rainfall data from Cibiru and Cileunyi stations were analyzed, and the log normal distribution with a 2-year return period (83.22 mm) was selected. Rainfall intensity was modeled using the SCS Type I method with a 15-minute interval. The drainage model consisted of 26 subcatchments, 108 junctions, 133 conduits, 1 pump, and 2 outfalls. Initial results showed an average runoff of 79.92 mm, ranging from 65.89 mm (S24) to 81.63 mm (S18). After applying LID controls (rain barrels, rain gardens, bioretention, and permeable pavements), runoff volume decreased significantly—up to 64%, with reductions from 61.61 mm (S26) to 4.29 mm (S24). These results highlight LID's potential for sustainable stormwater management.

Keywords: drainage; low impact development; PCSWMM; zero runoff.

I. INTRODUCTION

Rainwater that falls will seep into the ground or flow towards drainage systems and rivers. Most rainwater cannot seep into the ground or becomes surface runoff and then becomes runoff. The category of rainfall that falls in each area will also vary, so the determination of rainfall intensity categories is done through rainfall analysis calculations. High rainfall intensity combined with insufficient drainage network capacity to accommodate the water can lead to flooding or accelerate surface runoff.

Floods are natural disasters that have a very widespread impact. Indonesia is prone to flooding due to its geographical conditions, which include many rivers and high rainfall. Flooding has occurred in the Bumi Harapan Residential Area, which is a densely populated residential area. The causes of the flooding include heavy rainfall, insufficient water absorption areas, poor drainage infrastructure, and topographical factors. The flooding issues in the Bumi Harapan Residential Area require preventive measures involving various stakeholders, from the government to the local community.

In anticipation of these problems, the Zero Runoff concept can be applied. Zero Runoff can reduce surface runoff from maximum rainfall to very little or even close to zero surface runoff discharged from the area. This concept is particularly important in the context of water conservation and water resource management, especially in residential areas. Planning the Zero Runoff concept using PCSWMM based on Low Impact Development (LID) is sufficiently capable of simulating runoff flow. PCSWMM (Personal Computer Storm Water Management Model) accepts input data in the form of rainfall in the area, converts it into surface runoff flow, and traces the flow through the channels.

II. LITERATURE REVIEW

2.1 Zero Runoff

Some rainwater that flows over the ground into rivers, lakes, or the sea is called runoff. This occurs when the ground is saturated and cannot infiltrate water. Rain can also fall on surfaces that cannot infiltrate water or are impermeable, such as concrete, asphalt, ceramics, etc (Bobo et al, 2023). Runoff water management involves coordinated efforts in planning, administration, regulation, and oversight at the regional level, aligned with established policies (Mukarromah et al, 2018). Zero Runoff System (ZROS) is a concept that aims to manage rainwater efficiently, thereby reducing or even eliminating surface runoff that can cause flooding. This concept focuses on water conservation by collecting and infiltrating rainwater into the ground, so that no water flows out of a specific area (Wirasembada et al, 2014). In Indonesia, there are regulations that support the implementation of Zero Runoff. Government Regulation No. 13 of 2017 stipulates that every building must manage water runoff within its own area to prevent an increase in flow to the drainage system. The regulation includes a 'zero delta Q policy,' which requires that each building must not cause an increase in water flow to the drainage system or river system. The increase in rainwater runoff due to conversion to development must be contained so that the additional flow (ΔQ) is zero.

2.2 Low Impact Development (LID)

Low Impact Development (LID) optimization planning has rapidly advanced in recent years, as many early studies have emphasized the benefits of applying optimization approaches (Zhang & Jia, 2023). The LID system is more effective for urban flood mitigation and reducing flood risk in urban areas. Strategically, LID aims to mimic natural hydrological processes by reducing runoff and encouraging infiltration. Thus, the LID system offers a solution for effective rainwater management (Essamlali et al, 2024). In addition, as part of a climate change adaptation strategy, the LID concept can improve urban resilience. This concept is particularly suitable for urban areas with limited land area, as it maximizes the use of surrounding land (Yuono et al, 2024). LID control includes infrastructure such as green roofs, rain gardens, bio-retention, rain barrels, permeable pavements, infiltration trenches and vegetative swales. They seek to control stormwater by minimizing runoff and pollution through processes such as retention, infiltration, filtration, and evapotranspiration (Goncalves et al, 2018)

III. METHOD

This study uses a descriptive quantitative approach because this type of research focuses on describing events and analysing data in the form of numbers or statistics. The descriptive method in this study is categorized as a case study. This method often analyses data related to a particular case. The purpose of this method is to determine the maximum flood discharge, the existing capacity of the drainage network, and to describe solutions for reducing runoff in the Bumi Harapan Cibiru Residential.

3.1 Research Object

The flood location is in the Bumi Harapan Residential, Cibiru Hilir, Cileunyi District, Bandung Regency, West Java 40626.

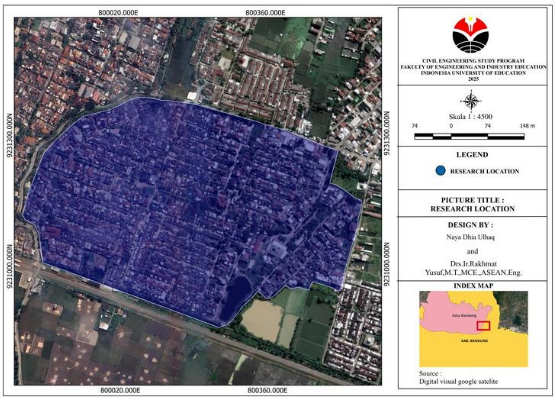

Figure 1. Research location

This housing complex has an area of approximately 288,465 m² with an elevation between 664 m and 666 m above sea level. The research was conducted on the drainage network in the Bumi Harapan Residential Area.

3.2. Data Inventory

The primary data used is data obtained directly in the field in the form of existing drainage data such as channel depth, channel width, channel water depth, and drainage cross-section shape. Meanwhile, the secondary data used is rainfall data and topographic maps (DEMNAS). The data analysis techniques used in this study include hydrological analysis, hydraulic analysis, and PCSWMM software modelling.

IV. RESULTS AND DISCUSSION

4.1 Hydrological Analysis

The rainfall data used in this study was sourced from the nearest rain gauge station obtained through the Water Resources Agency and NASA's official website. To calculate regional rainfall, the arithmetic method was used because it is simple and suitable for the relatively narrow characteristics of the study area

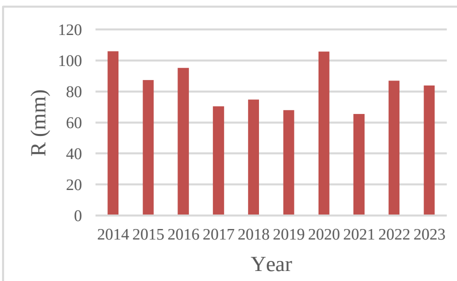

Figure 2. Maximum annual rainfall

Rainfall frequency analysis was performed using four types of distributions, namely Normal distribution, Gumbel distribution, Log-Normal distribution, and Log-Pearson III distribution. Furthermore, distribution goodness-of-fit tests were performed using three methods, namely Chi-Square test, Smirnov-Kolmogorov test, and Least Squares method.

Table 1. Recapitulation of hydrological analysis

Testing		Planned rainfall (mm)			
	Repeat Period	Normal	Log Normal	Gumbel	Log Pearson III
Frequency Analysis	2	84.37	83.22	82.37	83.05
	5	96.78	96.39	100.01	96.35
	10	103.28	104.10	111.68	104.26
	20	108.60	110.87	122.88	110.33
Statistical test		Accepted	Accepted	Rejected	Accepted
Chi Kuadrat		Accepted	Accepted	Accepted	Accepted
Smirnov Kolmogorov		Accepted	Accepted	Rejected	Accepted
Least Square		1.95	1.58	1.30	2.88

The research location is in Cileunyi District, with a population of approximately 192,000 and an area of 29.26 km², making it a medium-sized city based on population density and area classification. The analysed catchment area is less than 10 hectares, so the planning return period is two years. From the results of the rainfall distribution analysis, the selected distribution is the log normal distribution with a 2-year return period of 83.22 mm. In this study, the rainfall intensity in PCSWMM was determined using SCS type 1 with a storm duration of 24 hours and a rain interval of 15 minutes.

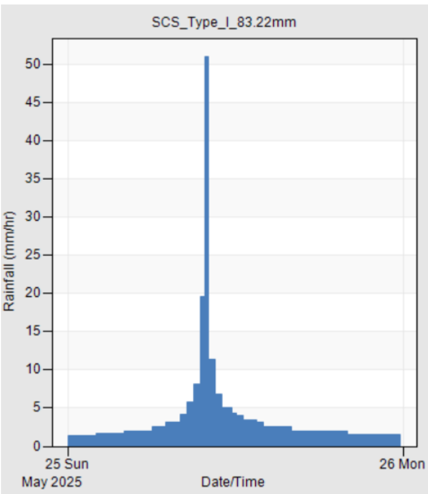

Figure 3. Rainfall intensity graph

4.2 Analysis of Existing Conditions

The PCSWMM model for the Bumi Harapan Residential was created with a scheme of 26 subcatchments, 108 junctions, 133 conduits, 1 pump and 2 outfalls.

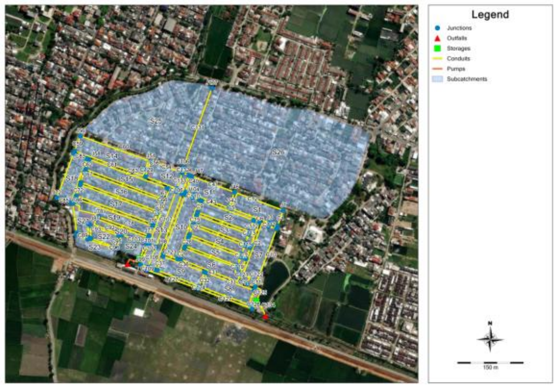

Figure 4. Existing modeling

After the drainage system modelling was completed, a simulation process (running) was carried out to evaluate the drainage system based on actual conditions and data in the field. Through PCSWMM, the simulation results can identify catchment areas (subcatchments) that experience flooding. The following is a description of subcatchments that experience excessive runoff, including:

Table 2. Subcatchment runoff summary existing

Subcatchment	Total Precip	Total Infil	Total Runoff	Runoff Coeff
	mm	mm	mm	
S1	83.22	0.63	81.06	0.974
S2	83.22	0.88	79.9	0.96
S3	83.22	0.03	80.53	0.968
S4	83.22	0	81.36	0.978
S5	83.22	0.13	80.8	0.971
S6	83.22	0.38	80.89	0.972
S7	83.22	1.01	79.54	0.956
S8	83.22	0.5	80.4	0.966
S9	83.22	0.38	80.75	0.97
S10	83.22	0	80.67	0.969
S11	83.22	0.75	80.26	0.964
S12	83.22	1.63	79.85	0.96
S13	83.22	0.75	79.58	0.956
S14	83.22	0.5	80.9	0.972
S15	83.22	0.75	80.28	0.965
S16	83.22	0	80.8	0.971
S17	83.22	0.13	80.8	0.971
S18	83.22	0	81.63	0.981
S19	83.22	1.89	78.87	0.948
S20	83.22	0	81.41	0.978
S21	83.22	1.89	79.41	0.954
S22	83.22	0	81.29	0.977
S23	83.22	2.26	79.08	0.95

Subcatchment	Total Precip	Total Infil	Total Runoff	Runoff Coeff
	mm	mm	mm	
S24	83.22	11.57	65.89	0.792
S25	83.22	0.38	81.04	0.974
S26	83.22	0.38	81.04	0.974

Based on the simulation results, all subcatchments showed fairly high surface runoff values. This condition was caused by the lack of water absorption areas and the dominance of impervious areas in the region. The subcatchment with the highest runoff value was S18, which reached 81.46 mm, while the lowest runoff occurred in S19, with a value of around 78.7 mm. The simulation results can also identify locations that experience flooding. The following is a description of junctions that experience flooding, including:

Table 3. Node flooding summary existing

Node	Hours Flooded	Maximum Rate CMS	Time of Max Occurrence		Total Flood Volume	Maximum Ponded Depth
			days	hr:min	10^6 ltr	Meters
J23	0.35	0.037	0	10:03	0.029	0
J25	0.71	0.065	0	10:00	0.074	0
J29	0.37	0.031	0	10:00	0.025	0
J40	1.25	0.048	0	10:03	0.103	0
J52	0.63	0.185	0	10:01	0.239	0
J53	0.46	0.051	0	10:00	0.051	0

4.3 Low Impact Development Modeling

After modelling the existing conditions, it was found that all subcatchments produced quite high water runoff. One approach that can be applied to reduce surface runoff is through the implementation of Low Impact Development (LID). The main objectives of the LID principle include reducing runoff (peak volume), replenishing groundwater, increasing infiltration and assessing water quality (Shafique & Kim, 2015). In this study, several types of LID practices were implemented, including rain barrels, rain gardens, bioretention, and permeable pavement.

The following are the criteria for determining the number of LID units required at the study site, including:

1. Rain Barrel

The rain barrel used has a capacity of 800 litres with a height of 1520 mm and a diameter of 850 mm. The size was chosen based on the availability of land for installing the rain barrel on a house. The water entering the rain barrel is assumed to come from a roof with an area of 100 m².

2. Rain Garden

The rain garden is designed with an area of 12.5 m and is located in the yard of the house. The water entering the rain garden is assumed to come from a roof with an area of 60 m².

3. Bio Retention

Bio retention is designed with various sizes depending on the available open land area in each subcatchment, such as 40 m², 60 m², and 100 m². The water that enters bio retention comes from runoff in open land areas.

4. Permeable Pavement

Permeable pavement was designed in subcatchment 25 with an area of 280 m^2 and subcatchment 26 with an area of 400 m^2. Water entering the permeable pavement is rainwater that falls directly onto the road surface

After all subcatchments were equipped with runoff control through the implementation of Low Impact Development (LID), the simulation process was repeated using PCSWMM software to evaluate changes in runoff volume. The purpose of this simulation was to assess the effectiveness of LID in reducing the amount of runoff previously generated by each subcatchment. The total surface runoff after the implementation of LID strategies in each subcatchment is presented in the following table:

Table 4. Number of LID uses

Subcatchment	Rain Barrel		Rain Garden		Bio Retensi		Permeable Pavement		% Total Area Covered
	Number of Unit	Unit Area (m²)	Number of Unit	Unit Area (m²)	Number of Unit	Unit Area (m²)	Number of Unit	Unit Area (m²)	
S1	7	0.57	30	12.5	3	60	-	-	13.12
S2	8	0.57	30	12.5	3	60	-	-	14.5
S3	12	0.57	22	12.5	1	30	-	-	10.51
S4	11	0.57	24	12.5	-	-	-	-	10.18
S5	10	0.57	25	12.5	-	-	-	-	10.47
S6	12	0.57	30	12.5	1	60	-	-	11.18
S7	16	0.57	35	12.5	9	40	-	-	15.48
S8	8	0.57	30	12.5	2	60	-	-	12.62
S9	8	0.57	27	12.5	1	60	-	-	11.46
S10	20	0.57	35	12.5	-	-	-	-	9.09
S11	19	0.57	23	12.5	4	60	-	-	13.37
S12	9	0.57	20	12.5	6	60	-	-	17.59
S13	30	0.57	27	12.5	5	60	-	-	10.95
S14	30	0.57	35	12.5	3	60	-	-	10.4
S15	20	0.57	30	12.5	4	60	-	-	13.23
S16	21	0.57	34	12.5	-	-	-	-	9.14
S17	26	0.57	28	12.5	1	60	-	-	8.79
S18	17	0.57	24	12.5	-	-	-	-	8.69
S19	8	0.57	23	12.5	3	100	-	-	14.8
S20	6	0.57	14	12.5	-	-	-	-	10.02
S21	6	0.57	15	12.5	5	60	-	-	22.77
S22	7	0.57	13	12.5	-	-	-	-	9.72
S23	8	0.57	11	12.5	6	60	-	-	23.96
S24	-	0.57	-	12.5	7	100	-	-	34.86
S25	80	0.57	130	12.5	10	100	5	280	12.67
S26	95	0.57	150	12.5	17	100	7	400	8.26

Table 5. Subcatchment runoff summary LID

Subcatchment	Total Infil	Total Runoff	Runoff Coeff
	mm	mm	
S1	10.03	27.69	0.333
S2	11.12	20.85	0.251
S3	9.69	27.67	0.333
S4	10.64	25.05	0.301
S5	10.99	23.19	0.279
S6	10.7	24.91	0.299
S7	10.17	22.49	0.27
S8	10.48	24.87	0.299
S9	10.72	24.67	0.296
S10	9.29	30.46	0.366
S11	8.19	31.84	0.383
S12	9.09	27.22	0.327
S13	6.63	39.04	0.469
S14	8.19	34.53	0.415
S15	9.1	28.33	0.34
S16	9.38	29.58	0.355
S17	7.74	36.56	0.439
S18	9.01	32.78	0.394
S19	10.2	26.58	0.319
S20	10.5	26.08	0.313
S21	10.62	17.03	0.205
S22	10.12	27.06	0.325
S23	8.65	22.9	0.275
S24	12.34	4.29	0.051
S25	7.84	45.9	0.552
S26	4.77	61.61	0.74

The application of the Low Impact Development (LID) approach across all subcatchments showed a significant impact in reducing surface runoff volume and runoff coefficient values. Simulation results after the implementation of LID show a reduction in runoff volume of up to 64% compared to existing conditions. This reduction reflects the effectiveness of the LID strategy in increasing the water absorption capacity of the land, thereby reducing the amount of rainwater that directly becomes runoff. This also indicates that the LID system plays an important role in supporting more sustainable rainwater management.

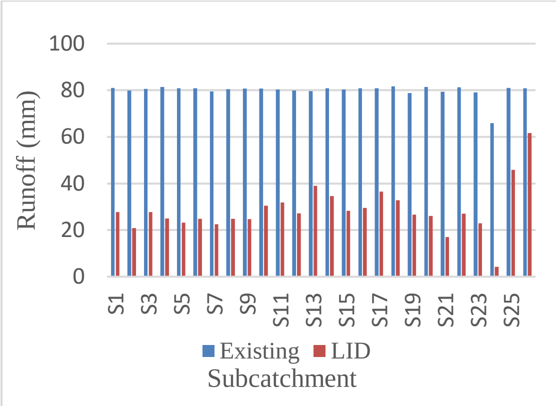

Figure 5. Total runoff graph

The zerorunoff concept tested in the subcatchment shows that after the implementation of LID, the runoff value did not reach zero or come close to zero. This condition is influenced by additional flow from the water supply areas, namely subcatchments 25 and 26, the limited performance of LID units due to the lack of available land, and rainwater falling directly onto the road surface, which continues to generate runoff into the drainage channels. Therefore, retention ponds are still needed to accommodate the volume of water that cannot be controlled by LID units or that falls directly onto the road surface. The hydrograph for the entire drainage system in the area is also shown in the figure 6.

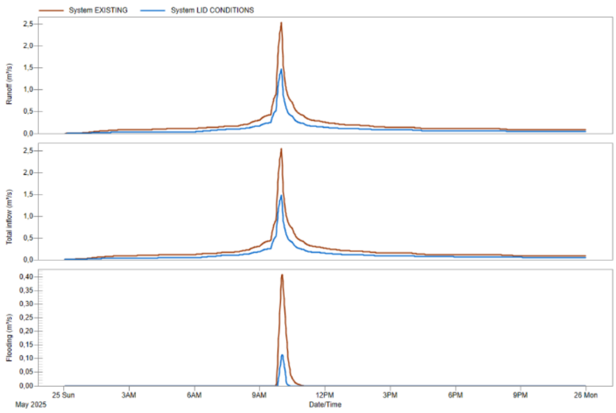

Figure 6. Drainage network system graph

The drainage system graph refers to the flow system throughout the drainage network, showing a comparison between the existing system (red line) and after the implementation of LID (blue line) with runoff, total inflow, and flooding values. The runoff graph (m^3/s) shows the surface runoff discharge in the subcatchment. The total inflow graph (m^3/s) shows the amount of flow entering the drainage channel. The flooding graph (m³/s) shows the flood discharge or excess runoff that cannot be accommodated by the channel. After the implementation of LID, there was a decrease in these three parameters. This is due to the effectiveness of the Low Impact Development (LID) system in retaining and accommodating surface runoff. However, the runoff and flooding values still do not reach zero, so infrastructure such as retention ponds is still needed to accommodate the remaining runoff, and there are still some drainage channels that exceed their capacity.

V. CONCLUSION

1. Based on hydrological analysis from two rainfall stations, namely Cibiru Station and Cileunyi Station, it was found that the log normal distribution was the most appropriate distribution, with a 2-year return period rainfall of 83.22 mm. For modelling purposes in PCSWMM, SCS Type I design rainfall with a 15-minute time interval was used.
2. The drainage system modelling using PCSWMM in the Bumi Harapan Residential was constructed with a configuration consisting of 26 subcatchments, 108 junctions, 133 conduits, 1 pump, and 2 outfalls. The simulation results show that all subcatchments produce fairly high surface runoff values, with an average of 79.92 mm. The highest runoff value was found in Subcatchment S18 at 81.63 mm, while the lowest value was found in Subcatchment S24 at 65.89 mm.
3. To reduce runoff volume, a Low Impact Development (LID) approach was implemented, which included the use of rain barrels, rain gardens, bioretention, and permeable pavement. After re-simulating the model with LID elements incorporated, the results showed that the highest runoff value was in Subcatchment S26 at 61.61 mm, while the lowest value was in Subcatchment S24 at 4.29 mm. Overall, the application of LID reduced runoff volume by 64% compared to the existing conditions.

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