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Modeling of Storm Water Management to Synergize Sustainable Development Goals 6, 9, and 11 Framework

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Abstract. Inundation and flooding are problems that often occur in many cities worldwide, including university campuses. This research aims to examine the existing drainage conditions on the Universitas Islam Riau (UIR) campus and identify solutions to overcome inundation and flooding that probably occur on the UIR campus in extreme conditions. The method in this study uses the EPA's SWMM (Storm Water Management Model) 5.2 software simulation program. The results indicate that the current drainage system is unable to handle rain discharge during extreme conditions. In this study, three improvements are set up to analyze hydrological characteristics. The first improvement is the traditional improvement by changing the existing channel dimensions. The second improvement is using Low Impact Development (LID) technology, in which the combination of 14 infiltration wells and 7 Biopore Infiltration Holeare applied. The third improvement is using the combination of 3 LID: Infiltration well, Biopore infiltration Hole, and Rain Water Harvesting (RWH). From the results, runoff in the improvement one was reduced by 21.5%. The second improvement, where 2 LID was used, reduced the runoff by 51.5%; finally, the third improvement reduced the runoff by 57.6%. So, the scenario that is most effective in overcoming inundation or flooding is the third scenario. Furthermore, the improvement is in line with the water conservation strategy. The findings of this research can serve as a valuable resource for future studies, contributing to the advancement of SDGs 6, 9, and 11, specifically targeting better water management, resilient infrastructures, and sustainable cities and communities. Moreover, the result can be a guide for the decision maker, especially on the UIR Campus and Campus worldwide, as an effective strategy for water conservation and to prevent flooding in similar universities.

Keywords: Biopore infiltration holes; Flood management; Infiltration wells; Rainwater harvesting; Sustainable Development Goals (SDGs)

1. Introduction

Significant changes in global climate produce extreme rainfall events (Rahmani and Fatahi, 2023; Tabari, 2020). Piman *et al.* (2016) investigated changes in rainfall in Thailand; the results show that the extreme rainfall resulted in increasing floods. Human activities make flood disasters in urban areas more serious (Farid *et al.*, 2022; Zhu and Chen, 2017). Stagnant water and floods not only disrupt daily activities but also have a detrimental impact on the environment and people's welfare. The value of surface runoff, which is greater than the absorption capacity of the soil, causes inundation immediately

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after the rain occurs. An increase in surface runoff will result in flooding problems. This condition significantly threatened human lives and properties (Guinot *et al.* 2017; Albano *et al.* 2016).

Flood mitigation strategies have been proposed to alleviate these problems (Lee *et al.* 2013; Bubeck, Botzen, and Aerts, 2012). Traditional improvements include changing the drainage dimension, water diversion, and storage project, improving flood prevention ability, and implementing maintenance to the drainage. However, these improvements are generally expensive and can easily lead to excessive drainage of downstream areas (Zhu and Chen, 2017).

In 1972, the concept of Best Management Practices (BMPs) was proposed in the United States. To prevent flooding problems, BMPs apply natural or engineering actions to reduce the runoff (Fei *et al.*, 2023). The concept of Low Impact Development (LID), which originated from BMPs, has been applied and has given promising results in reducing flood disasters. According to Alamdari and Hogue (2022), the LID concept is a technique that emphasizes the preservation of natural hydrological characteristics. The implementation of this concept is by installing small-scale and non-centralized facilities. Some examples of LID Practice are reservoirs, green roofs, rain gardens, bioretention swales, and bioretention Ponds. Combining these practices gives satisfactory results (Lim and Lu, 2016; Silva and Costa, 2016). The LID concept improvement is very flexible to global climate change (Zhu, and Chen, 2017). So, this concept can be easily applied and become a guide for the decision-maker (Zhu and Chen, 2017).

Many numerical models have been proposed to support the LID applications, such as EPA's SWMM, MIKE Urban, and InfoWorks ICM (Pons *et al.*, 2023; Kong *et al.*, 2017). The EPA's SWMM (Storm Water Management Model) has many advantages and is most commonly used (Liu *et al.*, 2022). EPA's SWMM is versatile, applicable for watershed and catchment scale simulations (Randall *et al.*, 2019; Ahiablame and Shakya, 2016), as well as for modeling lab-scale LID facilities. Given its capability to analyze the performance of LID, the application of EPA's SWMM is intriguing in various contexts, including university campuses.

Inundation and flooding problems not only exist in urban areas but also in campus areas. As one of the tertiary institutions committed to environmental sustainability, the Riau Islamic University (UIR) campus realizes the importance of handling this problem. This research aims to examine the existing drainage conditions on the UIR campus and identify solutions to overcome inundation and flooding that probably occur on the UIR campus in extreme conditions. LID concepts such as infiltration wells, biopore infiltration holes, and rainwater harvesting (RWH) and their combination were implemented. In this study, the simulation method using the EPA’s SWMM 5.2 software is used to analyze and plan flood or inundation coping strategies. This study aims to provide a better understanding of the drainage conditions that exist on the UIR campus and to identify effective inundation and flooding strategies.

Thus, this research is expected to improve the quality of infrastructure and water management at the UIR campus and provide valuable insights for developing flood and inundation solutions in urban environments. This research can be a resource for further studies and support SDGs 6, 9, and 11 for better water management, resilient infrastructures, and sustainable cities and communities (The United Nations and The Division for Sustainable Development Goals, 2021).

2. Methods

2.1. Water Conservation

Water management is a critical factor in urban sustainability (Schaffer and Vollmer, 2010). Water conservation is a series of actions to protect, manage, and use water wisely to maintain adequate water availability for human and ecosystem needs. The main goal of water conservation is to reduce water wastage, protect water resources, and minimize negative environmental impacts. Several water conservations that utilize wastewater so that it can be reused are Infiltration wells, Biopore infiltration holes, and Rainwater Harvesting. The benefits of applying water conservation in everyday life are saving resources, saving costs, maintaining water ecosystems, maintaining water scarcity, and reducing environmental pollution. In flooding conditions, it is essential to guarantee the water supply. Hartono *et al.* (2010) identify and develop mitigation strategies for water supply during flood disasters. Moreover, it necessitated the integration of Green Ergonomics in water resources Management (Sabara, Afiah, and Umam, 2022).

2.2. LID and Rainwater Harvesting (RWH)

Sustainable drainage is widely recommended and applied worldwide, such as Low Impact Development (LID) in the United States. Given the substantial interest in LID practices in recent years, researchers have concentrated on evaluating their hydrological performance and hydraulic behavior, particularly in flood management (Wang *et al.* 2017; Damodaram *et al.* 2010). Considering the challenges facing global communities, solving the problem of stormwater management cannot be done without getting closer to achieving Sustainable Development Goals (Cheng *et al.* 2021). In the case of stormwater management, low-impact development (LID) facilities are particularly popular (Ho *et al.*, 2022).

RWH has many contributions to the sustainability of cities and rural areas (De-Sa-Silva *et al.* 2022). An RWH is a strategy for capturing and storing rainwater from roofs, rooftop terraces, and impermeable surfaces (Campisano *et al.*, 2017; Lee *et al.*, 2016). This concept can reduce the runoff. The concept can be applied for small- or large-scale implementation. RWH can serve as either an additional or the primary source of water supply, depending on demand conditions. Moreover, the water from RWH can be used for drinking or non-drinking water. But, in general, RWH is used for non-drinking water. Other advantages of RWH for non-drinking water include the reduction of water stress, being a strategy for adapting to climate change, reduced soil erosion, flood mitigation, and decreased runoff peak flow (De-Sa-Silva *et al.*, 2022).

2.3. *Storm Water Management Model (SWMM)*

Calculate the planned discharge on the drainage channel and channel capacity using the EPA's SWMM 5.2 software tool. SWMM (Storm Water Management Model) is a dynamic simulation model of the relationship between rainfall and runoff developed by the US Environmental Protection Agency. Modeling with SWMM is based on various hydrological processes such as rainfall with variations in time, evaporation on the surface of the water, precipitation in the catchment area, and Infiltration of rainfall that enters the water-unsaturated soil layer, taking into account runoff and drainage systems. Infiltration facilities can significantly reduce surface runoff (Bai *et al.*, 2018).

3. Results and Discussion

3.1. Hydrological Analysis

Maximum daily rainfall is taken from the Sultan Syarif Kasim II Pekanbaru Riau Indonesia meteorological station with an observation period of rainfall from 2012 to 2021. The Design Rainfall intensity value of 153.16 mm was determined using the Chi-Squares and the Smirnov-Kolmogorov method. This value is used for extreme rainfall in the evaluation. In this simulation, we used recurrence periods of 5 years, as shown in Table 1 below.

Table 1 Rainfall Intensities with recurrence periods of 5-year

Duration (t)		Rainfall Intensity (mm)
Minute	Hour	153.16
10	0.17	175.32
60	1.00	53.10
90	1.50	40.52
120	2.00	33.45
180	3.00	25.53

3.2. Existing Conditions

3.2.1. Wastewater discharge

Based on the national standard in Indonesia, each person requires 50 liters of water/day (with 15 for washing, 15 for toilet, and 20 for ablution). The total population on the UIR campus is 30.015 people, so the whole need for clean water on the UIR campus is 1650.75 m^3/day. The calculation of wastewater discharge is based on the consumption of clean water per person per day. The amount of clean water that will become wastewater is estimated at 70% to 80%. The UIR produces a total wastewater of 15.28 m^3/sec, which was obtained by using a maximum value of 80%. The wastewater will flow to the existing drainage.

3.2.2. Rainfall-runoff simulation using EPA's SWMM 5.2

As mentioned above, EPA's SWMM 5.2 was used for the simulation. Based on the elevation, existing building, and existing drainage, the UIR campus is divided into 14 sub-catchments, as shown in Figure 1.

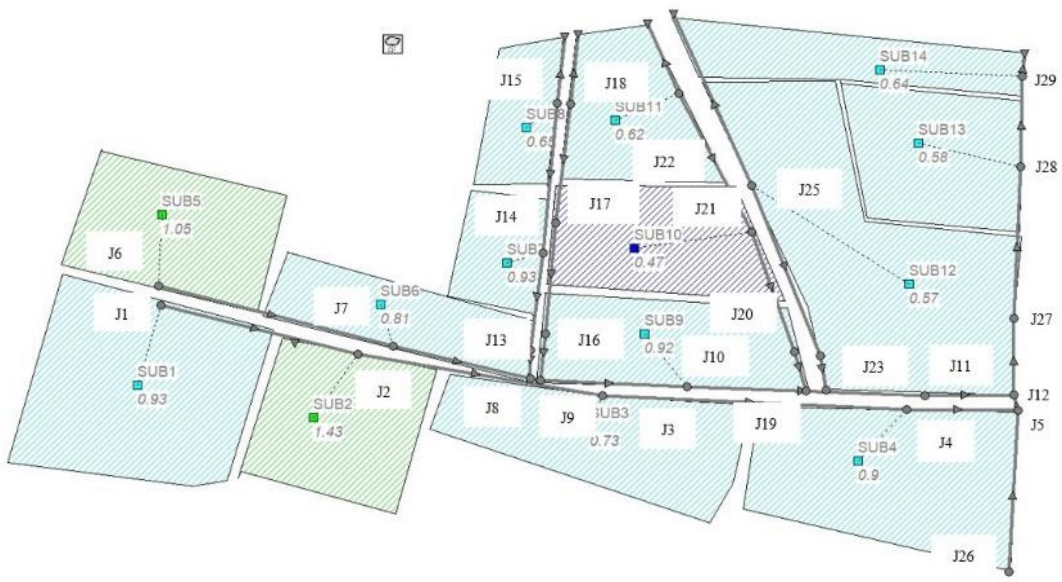

Figure 1 The sub-catchment and junctions modeling for the UIR Campus

The results of runoff from the design rainfall intensity are presented in Table 2. The total runoff is equal to 11.19 m^3/s as the extreme value. Moreover, it found that inundation exists in J12 (7 cm), J14 (7 cm) and J17 (10 cm) as shown in Figure 2. The existing drainage condition cannot accommodate runoff in extreme conditions. So, the UIR campus must implement the improvement.

Table 2 Runoff Debit Each sub-catchments

Sub catchment	Runoff (m3/s)	Sub catchment	Runoff (m^3/s)
SUB 1	0.93	SUB 8	0.65
SUB 2	1.43	SUB 9	0.92
SUB 3	0.73	SUB 10	0.47
SUB 4	0.9	SUB 11	0.62
SUB 5	1.05	SUB 12	0.57
SUB 6	0.81	SUB 13	0.58
SUB 7	0.93	SUB 14	0.64
	TOTAL	11.19 m^3/s	

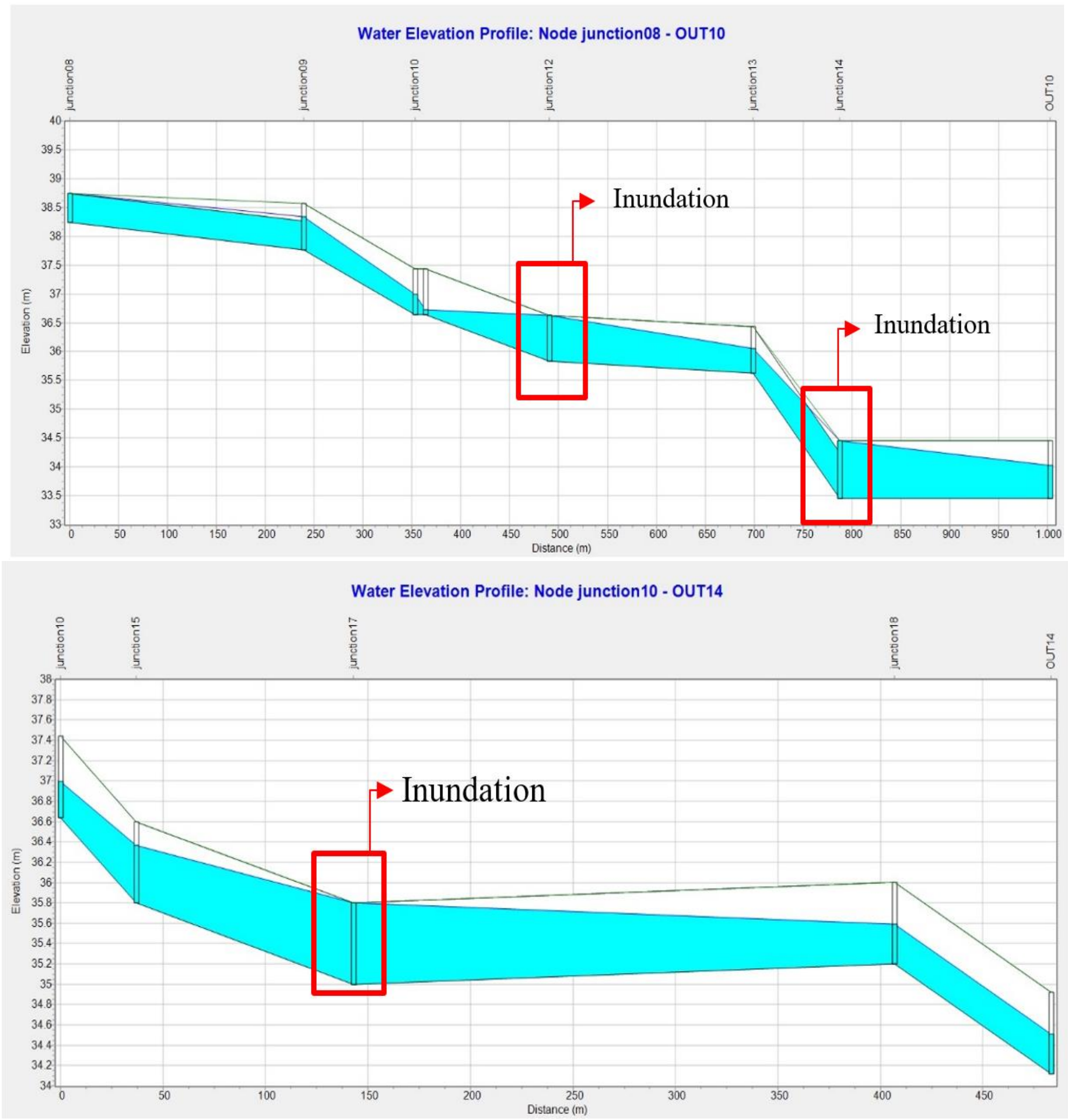

Figure 2 Inundation

3.3. Improvement without LID

In this improvement, the traditional method was applied. This simulation attempts to change the drainage height of a square drainage shape in areas where inundation occurs. The results of the simulation show a change in dimensions at junction J10 (become 0.8 m x 1.2 m), J17 (become 0.8 m x 1.0 m), junction J24 (become 0.8m x 1.2 m), junction J28 (become 0.8 m x 1.2 m) and junction J29 (become 1.0 m x 1.5 m), the runoff was reduced from 11.19 m^3/s to 8.78 m^3/s. Moreover, there is no inundation.

3.4. Improvement using 2 *LID*

The second improvement is combining Infiltration Wells and Biopore Infiltration Holes. The dimensions and geometry of the drainage are the same as the existing conditions. According to Yoga (2023) and Dicky (2023), the value of the soil permeability coefficient (k) on the UIR campus is 6 cm/hour. By using the formula for the Geometry Factor (equation 1) and Infiltration Wells depth (equation 2) :

$$F=\frac{2\pi L+\pi R\, In\, 2}{In\{\frac{L+2R}{2R}+\sqrt{\left(\frac{L}{2R}\right)^2+1}\}} \quad (1)$$

$$H' = \frac{Qsr}{F\,x\,K}\{1-\exp\left(\frac{-F\,x\,K\,x\,Te}{\pi\,R^2}\right)\} \quad (2)$$

It was found that by using a 1.4 m diameter, the value of H'= 1.3 m. The infiltration wells are placed in an area without inundation on each sub-catchment. Another additional improvement is the application of 7 Biopore Infiltration Holes with a radius of 0.1 m and a depth of 1 m. Following the simulation, the runoff decreased from 11.19 m^3/s to 5.42 m^3/s. It is evident that combining different LID techniques proves to be the most optimal solution (Putri *et al.*, 2023).

3.5 Improvement using 3 LID

This improvement applies the combination of Infiltration Wells, Biopore Infiltration Holes, and Rainwater Harvesting (RWH). The application of RWH is aligned with the water conservation strategy.

3.5.1. RWH Locations

From the site observation, the place in which RHW could potentially be applied is sub-catchment 4, sub-catchment 9, and sub-catchment 12. For sub-catchment 4, the potential building is the Pusat Kegiatan Mahasiswa (PKM), with a land area of 46.042 m^2 and a green open space of 25.601m^2. Moreover, for sub-catchment 9, the Al Munawwarah UIR Mosque, with a land area of 43.837 m^2 and a green open area of 21.121 m^2, is very potential for RWH. The last place is in sub-catchment 12, namely the UIR Rectorate building, with a land area of 76.626 m^2 and an open green space of 16.568 m^2.

3.5.2.Building Roof Area

The potential building roof areas to harvest water are presented in Table 3, where the PKM building is the largest area, 2825 m^2.

Table 3 Building Roof Area

NO	Building	Roof Area (m^2)
1	PKM building	2825
2.	Rectorate Building	2493
3.	Al-Munawwarah Mosque	1046

3.5.3.Harvested Water Volume

Furthermore, calculating the amount of water that can be harvested is needed to determine the volume of rainwater storage tanks required. The runoff coefficient accounts for water losses due to impact, evaporation, leakage, and overflow. The runoff coefficient on roofs ranges from 0.75 to 0.95. So, the average maximum roof coefficient, namely 0.85, is used. For the value I, the rainfall intensity is taken with a duration of one and a half hours (5400 seconds), namely 53.097 mm/hour. After determining the volume of water that can be harvested from each building (Table 4), the next step involves planning the size and number of groundwater tanks.

Table 4 Volume of potential rainwater in each building

Location	Time duration	R(mm)	A (m^2)	C	I (mm/h)	Q(m^3/s)	V(m^3)
PKM building	1.30 hours	153.16	2825	0.85	53.0972	0.0357	193
Rectorate Building	1.30 hours	153.16	2493	0.85	53.0972	0.0315	170
Al Munawwarah Mosque	1.30 hours	153.16	1046	0.85	53.0972	0.0132	71
		Total (m^3)					434

The total volume of potential harvested rainwater is 434 m^3. After obtaining the volume of water gathered in each building, it will be applied using groundwater tanks, water tanks, and rain barrels. The number of groundwater tanks, water tanks, and rain barrels that are planned to be implemented can be seen in Table 5. Only 429 m^3 of the potential water can be harvested from the planning.

After the runoff simulation was carried out, the runoff reduced from 11.19 m^3/s to 6.45 m^3/s. Table 6 compares the improvements, and it is evident that Improvement 3 yields optimal results as three LID techniques are applied. However, the application of Rainwater Harvesting (RWH) doesn't show a significant difference compared to Improvement 2 (using 2 LID), with only around a 6% difference. It is coherent with the results found by Bai *et al.* (2018) that the infiltration improvement has the greater reduction of runoff compared to the storage improvement. It will be the proposed program for the decision-maker at UIR Campus. Figure 3 presents the placement of all the improvements proposed in this research.

Table 5 Number of groundwater tanks, water tanks, and rain barrels implemented

Location	Ground Water Tank	Number	Water Tank	Number	Rain barrels	Number
PKM building	Dimension 10 m x 6 m x 3 m	1	Capacity 2 m^3	3	Capacity 0.25 m^3	12
Rectorate Building	Dimension 9 m x 6 m x 3 m	1	Capacity 2 m^3	3	Capacity 0.25 m^3	10
Al Munawwarah Mosque	Dimension 6 m x 3.5 m x 3 m	1	Capacity 2 m^3	2	Capacity 0.25 m^3	10
			Total 429 m^3			

Table 6 Runoff Results

Subcatchment	Runoff (m^3/s)			
	Existing Conditions	Improvement without LID	Improvement using 2 LID	Improvement using 3 LID
1	0.93	1.43	0.78	0.67
2	1.43	0.57	0.58	0.52
3	0.73	0.9	0.53	0.51
4	0.9	0.81	0.2	0.15
5	1.05	0.93	0.39	0.28
6	0.81	0.35	0.29	0.27
7	0.93	0.47	0.21	0.19
8	0.65	0.11	0.06	0.05
9	0.88	0.29	0.25	0.21
10	0.47	0.12	0.1	0.07
11	0.62	1.43	0.78	0.67
12	0.57	0.57	0.58	0.52
13	0.58	0.9	0.53	0.51
14	0.64	0.81	0.2	0.15
Total runoff	**11.19**	**8.78**	**5.42**	**4.74**
Runoff reduction		2.41	5.77	6.45
Runoff reduction (%)		21.5	51.6	57.6

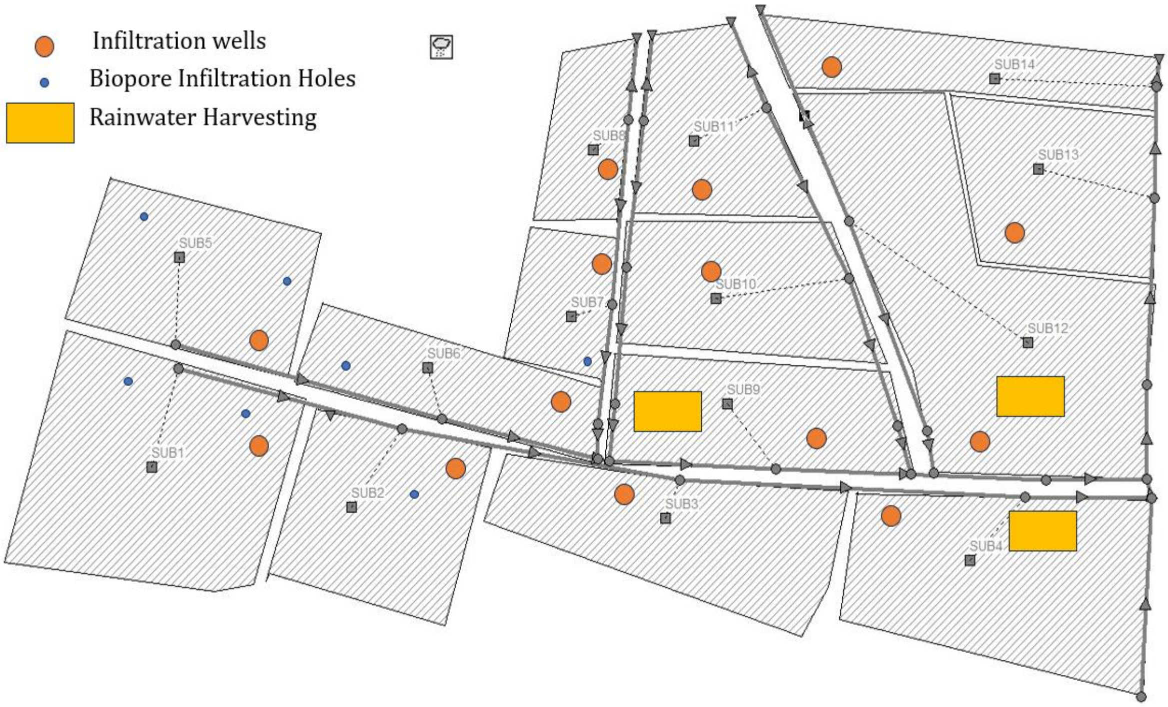

Figure 3 Propose improvements using 3 LID

3.5.4. RWH as an Alternative to Clean Water Needs

As mentioned in the previous section, implementing the RHW can support the need for clean water on the UIR Campus. The need for clean water is 1650.75 m^3, while the RWH provides around 429 m^3 (supporting 26 % of the clean water). Moreover, this paper plans to implement Infiltration Wells and Biopore Infiltration Holes as a strategy for water conservation, aligning with Sustainable Development Goal (SDG) 6. SDG 6 focuses on ensuring the availability and management of clean water and sanitation, aiming to conserve water use. This aligns with the 2030 target of significantly improving water use efficiency across all sectors and ensuring sustainable water use and supply to address water scarcity. This emphasizes the crucial role of technology in achieving Sustainable Development Goals (Berawi, 2017).

4. Conclusions

Based on the results, the existing drainage conditions on the UIR campus cannot accommodate runoff in extreme conditions. So, the UIR campus must implement the improvement. The traditional improvement (changing the drainage height) can reduce the runoff from 11.19 m^3/s to 8.78 m^3/s. Moreover, there is no inundation by using this improvement. The improvement by combining Infiltration Wells and Biopore Infiltration Holes and maintaining the existing drainage dimensions reduced the runoff from 11.19 m^3/s to 5.42 m^3/s. The combination of Infiltration Wells, Biopore Infiltration Holes, and Rainwater Harvesting (RWH) reduces the runoff reduced from 11.19 m^3/s to 6.45 m^3/s. It is evident that the last improvement gives optimal results because 3 LID was applied. Moreover, the application of RWH is aligned with the water conservation strategy. RWH can provide 26 % of the clean water needed on the UIR Campus. This research supports SDGs 6, 9, and 11 for better water management, resilient infrastructures, and sustainable cities and communities. Furthermore, the result can be a resource for further studies and a guide for the decision maker, especially on the UIR Campus and Campus worldwide, as an effective strategy for water conservation and to prevent flooding in similar universities.

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