

Stormwater Runoff Control Analysis Using Rain Garden Implementation in the Drainage System of GKB, Universitas Negeri Malang

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ABSTRACT

Climate change and rapid urbanization have intensified stormwater runoff in urban areas, including Malang City, while conventional drainage systems often lack the capacity to manage excess flow. This study aims to design and evaluate a rain garden model as a sustainable green infrastructure for reducing stormwater runoff in the GKB area of Universitas Negeri Malang, which frequently experiences inundation of up to 20 cm. The methodology involved rainfall analysis, probability distribution testing, and peak discharge estimation to determine the design parameters. The rain garden's performance was assessed by comparing its storage capacity with the calculated runoff volume. Results indicate that for a two-year return period (0.134 m³/s), the proposed rain garden can fully accommodate runoff within its designed capacity. These findings demonstrate the potential of rain gardens as an effective nature-based solution to improve drainage efficiency and enhance urban flood resilience.

INTRODUCTION

In recent years, the population of Malang City has experienced relatively stable growth, with an average annual increase of 0.33% and a total population exceeding 885,000 inhabitants (Badan Pusat Statistik Kota Malang, 2024). This growth is strongly supported by the role of Malang as an educational hub that attracts a significant number of newcomers, particularly students from various regions across Indonesia. Such conditions pose additional challenges in the provision of green spaces and spatial planning, considering the limited land area available in the city (Susanti et al., 2024).

Universitas Negeri Malang (UM) is one of the major higher education institutions located at Jalan Semarang No. 5, Malang City. One of the most active and high-mobility areas within the UM campus is the Gedung Kuliah Bersama (GKB), which serves as a shared academic facility for students from multiple departments. The high intensity of daily activities in this area requires adequate infrastructure to ensure accessibility and mobility. However, during the rainy season, the GKB area frequently experiences waterlogging, indicating that stormwater does not flow properly into the drainage system (Rahman et al., 2023). This condition highlights the urgent need for more effective surface water management within the campus environment.

Climate change in recent decades has led to an increase in extreme rainfall events, particularly in urban areas (Nugroho & Habiballoh, 2023). The Meteorology, Climatology, and Geophysics Agency (BMKG) reported that approximately 67% of regions in Indonesia have the potential to experience annual rainfall exceeding 2,500 mm (BMKG, 2024). Climate projections for the period of November–December 2024 through 2025 also indicate a heightened risk of

disasters associated with rainfall levels expected to surpass normal conditions. In the case of the GKB UM area, the dominance of impervious materials such as paving limits stormwater infiltration into the soil, resulting in runoff accumulation that can cause water depths reaching up to 20 cm (Rahman et al., 2023).

Various strategies have been developed to address stormwater runoff issues. One emerging approach is the rain garden system, a vegetated infiltration space designed to capture and absorb stormwater naturally through soil layers and vegetation (Kasprzyk et al., 2022). Rain gardens have been widely adopted in several developed countries, including the United States and parts of Europe (Chen et al., 2024). A study conducted in Wroclaw, Poland, demonstrated that this system can infiltrate up to 72% of total stormwater runoff, while also accommodating high-intensity rainfall events without overflow (Burszta-Adamiak et al., 2023). In contrast, most studies in Indonesia still rely heavily on conventional approaches such as open channels and concrete drainage systems (Rachmat et al., 2024).

Therefore, this study aims to design and analyze a rain garden model specifically for the GKB area of Universitas Negeri Malang as a sustainable stormwater management alternative. The research seeks to evaluate the relationship between rainfall intensity, runoff discharge, and rain garden storage capacity to determine its feasibility and hydrological performance under various design depths. The concept is expected not only to reduce the load on conventional drainage infrastructure but also to provide additional benefits such as enhancing biodiversity and improving soil absorption capacity (Wang et al., 2024). Plant selection must also consider specific ecological performance objectives, including pollutant removal, infiltration efficiency, interception improvement, and other ecosystem functions (Dudrick et al., 2024). Thus, rain gardens serve not only as stormwater management infrastructure but also play a crucial role in supporting environmental sustainability (Rashid et al., 2022).

RESEARCH METHODS

Study Location

This study was conducted at Universitas Negeri Malang (UM), focusing on the GKB area, one of the main academic centers with high mobility. Field observations and secondary data indicate that this area frequently experiences flooding during the rainy season, especially in zones with impervious surfaces such as sidewalks, parking lots, and pedestrian pathways (Rahma et al., 2023). The study aims to evaluate rain garden performance in reducing runoff and mitigating inundation within the campus (Rahman et al., 2023). Flood mapping identified several critical zones as priority areas for intervention. **Figure 1.** shows the campus inundation distribution map, with the GKB area classified as having relatively high flood intensity.

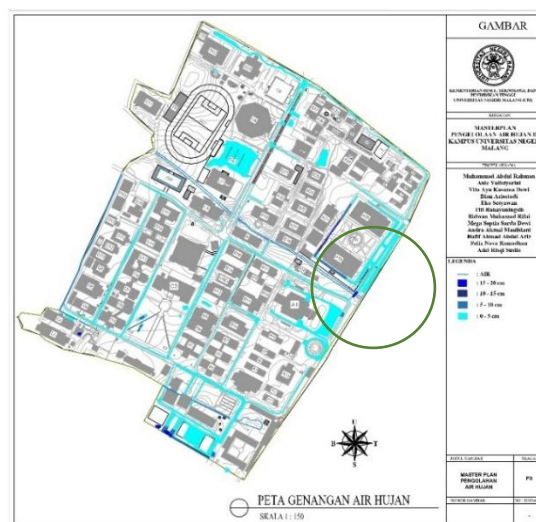


Figure 1. Rainwater Inundation Map at UM Campus

Data Collection

The data collected in this study include rainfall records over the last 10 years (2015–2024), obtained from three rainfall stations in Malang City, namely Ciliwung Station, Sukun Station, and Dau Station, managed by BMKG Malang. Additional supporting data consist of soil permeability coefficients determined through laboratory testing using the Falling Head Permeability Test, watershed (catchment area) boundaries derived from topographic map analysis, and land use data collected from field surveys. Soil conditions were analyzed under both saturated and unsaturated states, while vegetation types and artificial surface layers at the study site were documented as additional considerations in the rain garden design.

Regional Rainfall Analysis

The average rainfall at the study site is a key component in planning flood control strategies. This study employed the Thiessen Polygon method to determine the regional average rainfall values. The method integrates rainfall data from multiple gauging stations around the study area by accounting for the catchment area coverage of each station. The regional average is then calculated proportionally based on the contribution of each polygon's area. The calculation was performed using the following equation:

$$P = \frac{A_1 \cdot P_1 + A_2 \cdot P_2 + A_3 \cdot P_3}{A_1 + A_2 + A_3} \quad (1)$$

Where P is the average regional rainfall (mm), P_1 , P_2 , P_3 are the rainfall values at stations 1, 2, and 3 (mm), and A_1 , A_2 , A_3 are the respective areas of influence or polygon areas (km²).

Distribution Fit Test Analysis

The distribution fit test was conducted to evaluate the degree of conformity between the frequency distribution of the sample data and the probability distribution function assumed to represent the data. For this purpose, statistical methods such as the Chi-Square Test and the Kolmogorov–Smirnov Test were employed as evaluation tools to assess the goodness-of-fit of the selected distributions (Adriani et al., 2021).

Flood Discharge Analysis

Flood discharge refers to the volume of water expected to flow through the drainage channel during the designed flood period. The determination of flood discharge is a crucial step in the planning and design of drainage systems. The method applied to calculate the magnitude of runoff discharge is the Rational Method, expressed by the following equation (Sari et al., 2023):

$$Q = 0,278 \times C \times I \times A \quad (2)$$

Where Q is the flood discharge (m³/s), C is the runoff coefficient, I is the rainfall intensity (mm/hour), and A is the catchment area (km²).

Rain Garden Planning and Modeling

The hydraulic analysis in this study was carried out by evaluating several parameters, including the contribution of runoff volume (V_{ab}), infiltrated water volume (V_{rsp}), and storage volume ($V_{storasi}$). The analysis referred to the Indonesian National Standard SNI 03-2453-2002, as the functional characteristics of rain gardens are comparable to infiltration wells, which are designed to optimize direct infiltration of stormwater into the soil from surface runoff (Saputra & Josephine, 2022).

$$V_{ab} = 0,855 \times C \times A \times R \quad (3)$$

Where V_{ab} is the runoff contribution volume to be accommodated by the rain garden (m³), C is the runoff coefficient, A is the catchment area (m²), and R is the average daily rainfall (mm).

$$V_{rsp} = \frac{te}{24} \times A_{total} \times K \quad (4)$$

Where V_{rsp} is the volume of stormwater infiltrated into the rain garden (m³), te is the effective rainfall duration (hours), A_{total} is the combined surface area of the base and walls of the rain garden (m²), and K is the soil permeability coefficient (m/day).

The storage volume ($V_{storasi}$) represents the difference between the total runoff volume contributing to flooding and the amount of water that successfully infiltrates into the soil through the rain garden. The larger the storage capacity, the more effective the rain garden will be in capturing and infiltrating stormwater, thereby minimizing flood potential (Suripin, 2004).

$$V_{storasi} = V_{ab} - V_{rsp} \quad (5)$$

The effectiveness of the rain garden is then expressed as the ratio between the infiltrated water volume and the total runoff volume, as follows:

$$Effectiveness = \left(\frac{V_{rsp}}{V_{ab}} \right) \times 100\% \quad (6)$$

To further assess the optimal performance of the rain garden, a comparison is made between the runoff contribution volume (V_{ab}) and the infiltrated water volume (V_{rsp}) (Tiwery, 2020). After obtaining the analytical results, a visual model of the rain garden was developed using SketchUp software to provide a clear representation of the proposed design.

RESULTS AND DISCUSSION

Regional Rainfall Analysis

The rainfall analysis was conducted by determining the spatial distribution of rainfall stations in Malang City using the Thiessen Polygon method. This method divides the study area based on the relative proximity to each rainfall station to calculate the weighted average rainfall. Each station has an area of influence that serves as a weight in the regional rainfall calculation. The mapping result of each station's area of influence is presented in **Figure 2**. This approach is considered representative for describing rainfall distribution in regions where rainfall stations are unevenly distributed.

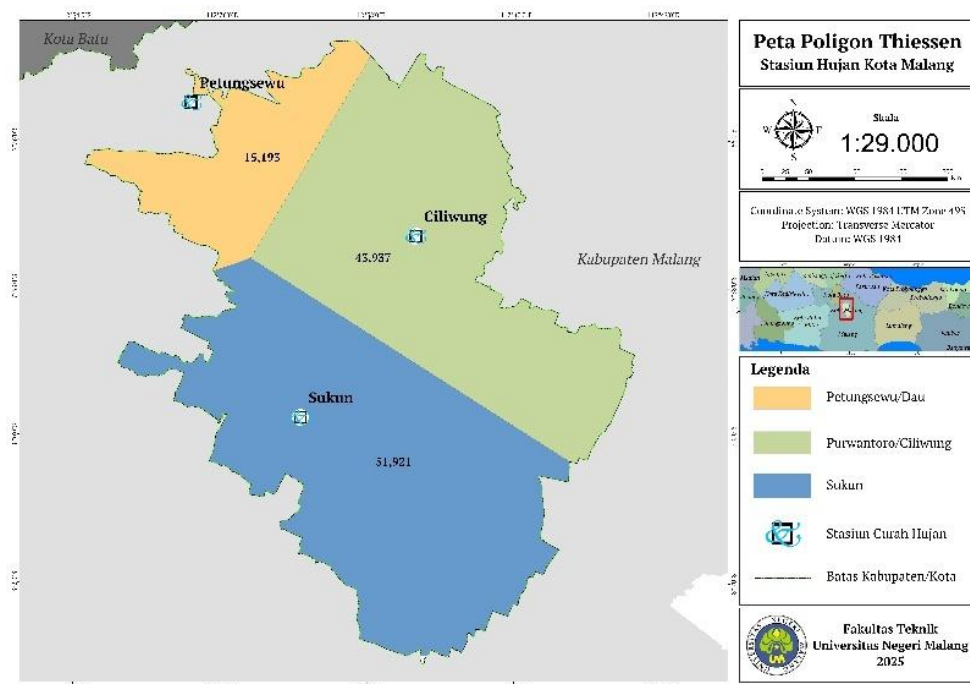


Figure 2. Thiessen Polygon Map of Malang City

The output of the Thiessen Polygon method provides the areal coverage of each rainfall station. The size of each influence area indicates the relative contribution of that station's rainfall data to the study site. A larger area of influence implies a greater contribution in the calculation of the average rainfall at the GKB UM area. The areas of influence for the three rainfall stations used in this study are presented in **Table 1**.

Table 1. Area of Influence of Rainfall Stations

Rainfall Station	Area (km ²)	Kr
Ciliwung	43.94	0.40
Sukun	51.92	0.47
Dau	15.19	0.14
Total	11.05	1.00

Considering catchment area influences, annual maximum rainfall was computed using the weighted average of 2015–2024 station data to obtain representative values for the study area. The results are presented in **Table 2**.

Table 2. Annual Maximum Rainfall Data (2015–2024)

Year	Ciliwung Station	Kr	Sukun Station	Kr	Dau Station	Kr	Annual Maximum Rainfall
	(mm)		(mm)		(mm)		(mm)
2015	96	0,40	170	0,47	65	0,14	126.357
2016	64	0,40	122	0,47	75	0,14	92.622
2017	104	0,40	132	0,47	105	0,14	117.228
2018	97	0,40	94	0,47	95	0,14	95.324
2019	82	0,40	135	0,47	93	0,14	108.284
2020	97	0,40	144	0,47	135	0,14	124.173
2021	123	0,40	133	0,47	95	0,14	123.845
2022	115	0,40	82	0,47	105	0,14	98.203
2023	102	0,40	134	0,47	80	0,14	113.951
2024	94	0,40	146	0,47	110	0,14	120.501

Goodness-of-Fit Test Analysis

Rainfall distribution type was determined using the coefficient of variation (Cv), coefficient of skewness (Cs), and coefficient of kurtosis (Ck), which describe data variability and distribution shape. These parameters guided the selection of the most suitable probability distribution model, with Normal, Log-Normal, Gumbel, and Log Pearson III tested. The calculated parameter values from annual maximum rainfall data are presented in **Table 3** to support model selection.

Table 3. Selection of Distribution Type

Type Distribution	Requirements	Result	Description
Gumbel	Cs = 1.14	1.14 Cs -0.514	Non-compliant
	Ck = 5.4	5.4 Ck 2,627	Non-compliant
Normal	Cs ≈ 0	0 Cs -0.514	Non-compliant
	Ck = 3.0	3 Ck 2,627	Non-compliant
Log Pearson III	Cs ≠ 0	Cs -0.600	Compliant
Log Normal	Cs = Cv ³ + 3Cv	0.081 Cs 0.074	Non-compliant
	Ck = Cv ⁸ + 6Cv ⁶ + 15Cv ⁴ + 16Cv ² + 3	3.012 Ck 3.000	Non-compliant

Based on the analysis results, the distribution that meets the statistical requirements is the Log Pearson III distribution, as indicated by the coefficient of skewness (Cs) that complies with its distribution characteristics. Therefore, the Log Pearson III distribution was adopted as the basis for frequency analysis in calculating rainfall intensity and design flood discharge in the subsequent stages.

Distribution Fit Test Analysis

A distribution fit analysis was performed to evaluate the suitability of the Log Pearson Type III frequency distribution, ensuring that the hydrological model accurately represents observed data. The Chi-Square and Kolmogorov-Smirnov tests were applied, and the results are summarized in **Table 4**.

Table 4. Plan Rainfall Conclusion

Chi-Square Test		Uji Smirnov-Kolmogorov	
X ² Count	X ² Critical ($\alpha = 5\%$)	D max	D Critical ($\alpha = 5\%$)
3,000	5,991	0,100	0,409
Representative		Representative	

Based on both tests at a 5% significance level, the Log Pearson Type III distribution was accepted and considered appropriate to represent the observed data set. This analysis provides a crucial foundation for the subsequent stage of flood discharge estimation as a simulation of stormwater runoff.

Flood Discharge Analysis

Flood discharge analysis requires the calculation of rainfall intensity as a key parameter. The intensity values were determined using the Mononobe method, which considers the relationship between rainfall duration, return period, and statistical distribution derived from historical data. The calculated rainfall intensities for various return periods are illustrated in **Figure 3**, which demonstrates an increasing intensity trend with longer return periods.

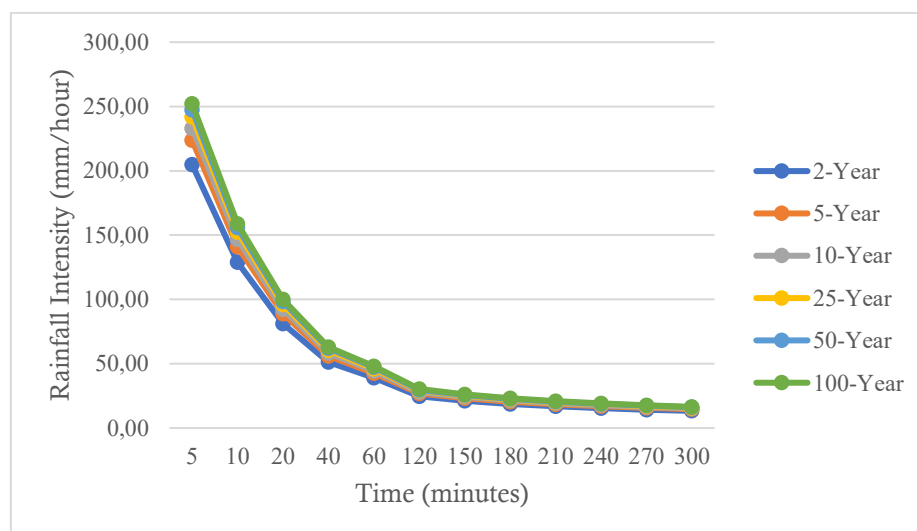


Figure 3. IDF Rainfall Curve at the Study Location

Flood discharge was then computed using the Rational Method, taking into account the runoff coefficient (C), rainfall intensity (I), and catchment area (A). The calculation was performed

for several return periods to obtain a range of flood discharges, which serve as the design basis for infiltration systems such as rain gardens. The runoff coefficient (C) was determined according to land-use characteristics within the GKB Universitas Negeri Malang area, which comprises building structures, green spaces, and paved surfaces used for mobility access and parking. The results of the flood discharge analysis are summarized in **Table 5**.

Table 5. Flood Discharge for Specific Return Periods

Tr	C	I (mm/hour)	A (km ²)	Q (m ³ /s)
2	0.733	161.177	0.00408	0.134
5	0.733	175.944	0.00408	0.146
10	0.733	183.147	0.00408	0.152
25	0.733	190.312	0.00408	0.158
50	0.733	194.634	0.00408	0.162
100	0.733	198.311	0.00408	0.165

The results of the hydrological analysis indicate that surface runoff discharge varies according to the rainfall return period. For a 2-year return period, the calculated peak discharge is 0.134 m³/s, and this value progressively increases for higher return periods. These discharge values serve as key parameters in designing the rain garden capacity to effectively accommodate and infiltrate runoff.

Rain Garden Planning

The rain garden is designed to manage stormwater runoff by enhancing infiltration into the soil and reducing surface flow. In this study, a hydraulic analysis was conducted to determine the storage capacity of the rain garden, which was designed based on the hydrological and soil characteristics of the GKB UM area. The rain garden placement is planned within existing green spaces, thereby avoiding modifications to paved areas or building footprints. The designated locations and planned sites are visually illustrated in **Figure 4**.



Figure 4. Planned Locations of Rain Gardens in the GKB UM Area

The determination of rain garden locations and land allocation was carried out by considering technical and functional aspects, such as proximity to runoff sources, ground elevation, and the availability of open space. Once the locations were identified, dimensional

planning was conducted based on the required storage capacity and the effective infiltration area. The rain garden design types are presented in **Table 6**, comprising four design variations differentiated by depth. The planned depths are 0.8 m, 0.7 m, 0.6 m, and 0.5 m, which directly influence the cross-sectional wall area and the total vertical surface area functioning as storage and infiltration media.

Each variation maintains a fixed base area of 1.5 m², while the wall area varies from 4 m² to 2.5 m² as the depth decreases. Consequently, the total rain garden area, which is the sum of the base and wall areas, ranges from 5.5 m² at a depth of 0.8 m to 4 m² at a depth of 0.5 m. These differences were designed to evaluate the storage capacity of each design in accommodating runoff volumes as well as adapting to spatial constraints at the existing site.

Table 6. Rain Garden Effectiveness Analysis

Length (P)	Width (l)	Depth (H)	Base Area (Ah)	Wall Area (Av)	Total Area (Atotal)
m	m	m	m ²	m ²	m ²
1.50	1.00	0.80	1.50	4.00	5.50
1.50	1.00	0.70	1.50	3.50	5.00
1.50	1.00	0.60	1.50	3.00	4.50
1.50	1.00	0.50	1.50	2.50	4.00

Rain Garden Effectiveness Analysis

The effectiveness analysis was conducted to evaluate the ability of the rain garden to infiltrate stormwater runoff within the study area. Effectiveness was calculated by comparing the volume of stormwater successfully retained and infiltrated in the rain garden (V_{rsp}) with the volume of runoff contributing to ponding or surface flow (V_{ab}). The infiltration performance achieved by the rain garden design meets the minimum standard recommended by SNI 03-2453-2002 for small-scale urban drainage systems, indicating that the model is feasible for implementation within the campus area, where V_{ab} is determined using the following equation:

$$\begin{aligned}
 V_{ab} &= 0,855 \times 0,733 \times 0,00408 \times 112,673 \\
 &= 0,288 \text{ m}^3
 \end{aligned}$$

These values indicate the runoff volume that must be managed through the infiltration system. To evaluate the infiltration capacity of the rain garden, the calculation of V_{rsp} was carried out by considering the infiltration time, storage area, and soil permeability. A similar analytical approach has been adopted in previous research Saputra & Josephine (2022), which applied comparable parameters to assess rain garden infiltration performance. Based on the Falling Head Permeability Test, the native soil in the GKB UM area was found to have a permeability value (K) of 0.03494 m/hour under unsaturated conditions. This soil condition represents the natural base layer of the rain garden, while the artificial media layer is expected to have a higher permeability according to relevant literature. With an effective infiltration time of 1.555 hours, referring to the SNI guidelines, and a storage area of 0.00408 m², the volume infiltrated by the planned rain garden at a depth of 0.80 m was obtained as follows:

$$\begin{aligned}
 V_{rsp} &= \frac{1,555}{24} \times 132 \times 0,0349 \\
 &= 0,299 \text{ m}^3
 \end{aligned}$$

The recap of rain garden performance across different depth scenarios is presented in Figure 5. The design with a depth of 0.80 m demonstrated the highest capacity in accommodating runoff for the 2-year return period, as the calculated infiltration volume exceeded the generated runoff volume. In contrast, the depth variations of 0.70 m, 0.60 m, and 0.50 m exhibited lower storage capacity, resulting in a portion of runoff being discharged into the existing drainage channels and subsequently conveyed to the receiving water body.

Table 7. Rain Garden Effectiveness at 0.80 m Depth

Return Period (Years)	Vab (m ³)	Vrsp (m ³)	Storage Volume (m ³)	Effectiveness
2	0.288	0.299	-0.011	100%
5	0.315	0.299	0.003	95%
10	0.328	0.299	0.015	91%
25	0.341	0.299	0.028	88%
50	0.348	0.299	0.036	86%
100	0.355	0.299	0.043	84%

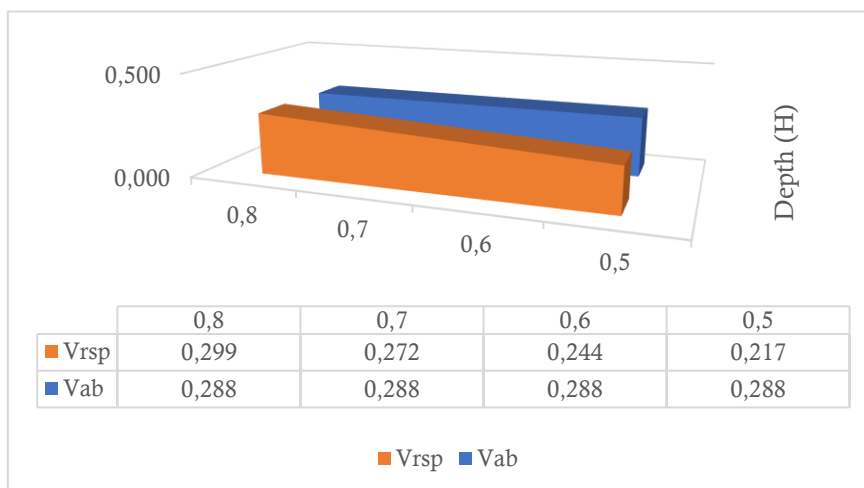


Figure 5. Rain Garden Effectiveness at Different Depths

The findings of this study are consistent with previous research emphasizing the importance of integrated stormwater management approaches. For instance, Annisa, et al. (2016) highlighted that combining rain gardens with other green infrastructure components, such as bioswales and permeable pavements, can significantly enhance infiltration capacity and reduce peak runoff in urban areas. Similarly, Annisa & Prasetya (2017) found that integrating rain gardens into existing drainage networks improved overall system resilience and minimized surface flooding. These findings align with the present study, where the proposed rain garden model demonstrates the potential to be integrated into the GKB UM drainage system as a sustainable and adaptable stormwater management component. Therefore, the integration of rain gardens with existing drainage infrastructure represents a practical step toward achieving sustainable urban hydrology and supports the broader concept of Low Impact Development (LID).

Rain Garden Modeling

The determination of dimensions and design parameters for each rain garden type was further developed through three-dimensional modeling. This visualization aims to provide a clear

representation of the physical structure, media layer arrangement, and practical feasibility of on-site implementation. The modeling process adopted the most effective configuration, with a total depth of 80 cm, which allows sufficient accommodation of runoff volumes while maximizing infiltration under local hydrological conditions.

The composition of media layers was sequentially arranged according to their hydrological and ecological functions. A 20 cm top soil layer serves as the primary growing medium for vegetation while facilitating initial rainwater absorption. Directly below, a 20 cm fine sand layer was applied to enhance infiltration rates and maintain media moisture. Subsequently, a 15 cm coarse sand layer acts as a transition zone to prevent intermixing between materials and to direct water flow toward the lower layer. At the base, a 15 cm gravel layer provides structural support and facilitates water conveyance toward the drainage outlet. Additionally, a 10 cm ponding area at the surface was incorporated to temporarily retain stormwater prior to infiltration. The arrangement and thickness of these layers follow design approaches developed in previous studies on vegetation-based infiltration systems (Tang et al., 2024).



Figure 2. Rain Garden Modeling with Bougainvillea Plants

CONCLUSION

The results of this study indicate that the stormwater runoff discharge in the GKB UM area with a two-year return period reaches $0.134 \text{ m}^3/\text{s}$. The implementation of rain gardens with a base area of $1.50 \text{ m} \times 1.00 \text{ m}$ per unit demonstrated varying levels of performance across different depths. Among the variations, the 0.80 m depth proved to be the most reliable configuration, as it was able to accommodate the entire runoff volume with sufficient infiltration capacity, supported by a storage volume (V_{ab}) of 0.288 m^3 and an infiltration volume (V_{rsp}) of 0.299 m^3 . These findings emphasize that a rain garden designed with a depth of 0.80 m can serve as a practical green infrastructure approach for stormwater management within the campus area.

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