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Analysis of Drainage Channel Dimensions at Villa Terracotta in Badung Regency

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ABSTRACT

The development of Villa Terracotta in Ungasan Village, South Kuta District, Badung Regency faces potential water ponding problems due to a drainage system that does not conform to the existing topographic conditions. This study aims to evaluate drainage capacity and design an appropriate channel dimension to prevent overflow. The research applies a quantitative approach using hydrological and hydraulic analysis. Design rainfall was determined using the Gumbel distribution after conducting Smirnov–Kolmogorov and Chi-square goodness-of-fit tests. Rainfall intensity was calculated using the Mononobe method, while hydraulic performance of the drainage system was simulated using the EPA-SWMM model. The study area covers 0.27 ha with elevations ranging from 109.5 m to 111.5 m above sea level. The calculated rainfall intensity ranges from 24.84 mm/h for a 2-year return period to 54.78 mm/h for a 50-year return period with a rainfall duration of 1 hour. Simulation results show that the downstream channel has a maximum flow depth of 0.43 m. A channel dimension of 0.30 m width and 0.55 m height produces a freeboard of 27.9%, which falls within the recommended safety range of 5%–30%, indicating that the designed channel is hydraulically safe against overflow.

Keywords: Rainfall; EPA-SWMM; Drainage

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1. INTRODUCTION

The increase in tourism infrastructure development in tourist destination areas has led to changes in land use that affect local hydrological conditions. The conversion of land from natural infiltration areas to impervious surfaces can increase surface runoff, reduce infiltration capacity, and increase the potential for waterlogging and flooding [1]. One example is the development of Villa Terracotta in Ungasan Village, South Kuta District, Badung Regency, which, if not accompanied by proper drainage planning, has the potential to cause hydrological problems, particularly during the rainy season.

The main problem encountered at the villa development site is the potential for water ponding due to a drainage system that was not designed in accordance with the existing topographic conditions. Inaccurate consideration of land slope based on topographic contour measurements can impede surface flow, preventing rainwater runoff from being optimally conveyed to the drainage outlet. This condition may disrupt both construction activities and the operational phase of the villa area, as well as cause environmental impacts.

The effort required to address these problems involves the planning and design of drainage channel dimensions that take into account topographic conditions and the hydrological characteristics of the catchment area. One software tool widely used for such planning is EPA-SWMM (Environmental Protection Agency–Storm Water Management Model), which has been proven capable of accurately simulating surface runoff and drainage channel performance [2].

The theoretical framework underlying this study covers several key aspects, namely: the analysis of design rainfall using the Gumbel and Log Pearson Type III distributions to determine rainfall magnitudes for specific return periods [3]. Subsequently, a goodness-of-fit test using the Smirnov–Kolmogorov method was conducted to ensure the suitability of the selected distribution models with the historical rainfall data [4]. Furthermore, the relationship among categorical variables was tested using the Chi-Square method to evaluate the interdependence of factors influencing surface runoff [5]. Furthermore, daily rainfall was transformed into hourly rainfall using the Mononobe method as the basis for determining the design rainfall intensity [6]. Finally, hydrological and hydraulic modeling was performed using EPA-SWMM to simulate the hydrological response of the catchment area to rainfall and to assist in planning optimal drainage channel dimensions [7].

The novelty of this study lies in the integrated application of contour-based topographic analysis using actual field data with hydrological–hydraulic modeling employing EPA-SWMM at the site scale of a tourism villa area. Unlike previous studies that generally design drainage systems at the area scale using assumptions of ideal land slopes, this study explicitly considers the irregularity of natural land slopes derived from detailed topographic measurements as the basis for determining surface flow directions and drainage channel dimensions. In addition, EPA-SWMM is utilized as a preventive drainage design tool through the simulation of various flow scenarios under existing topographic conditions, resulting in a design that is adaptive to local hydrological risks and supports sustainable tourism area development.

With this approach, it is expected that the results of this study will provide appropriate drainage planning recommendations to support sustainable villa area development, adaptive to hydrological risks, and with minimal negative impacts on the surrounding environment.

2. RESEARCH METHOD

The study was conducted at the Villa Terracotta development area located in Ungasan Village, South Kuta District, Badung Regency, Bali. The study area covers approximately 0.27 ha. The research was carried out from October 2025 to January 2026.

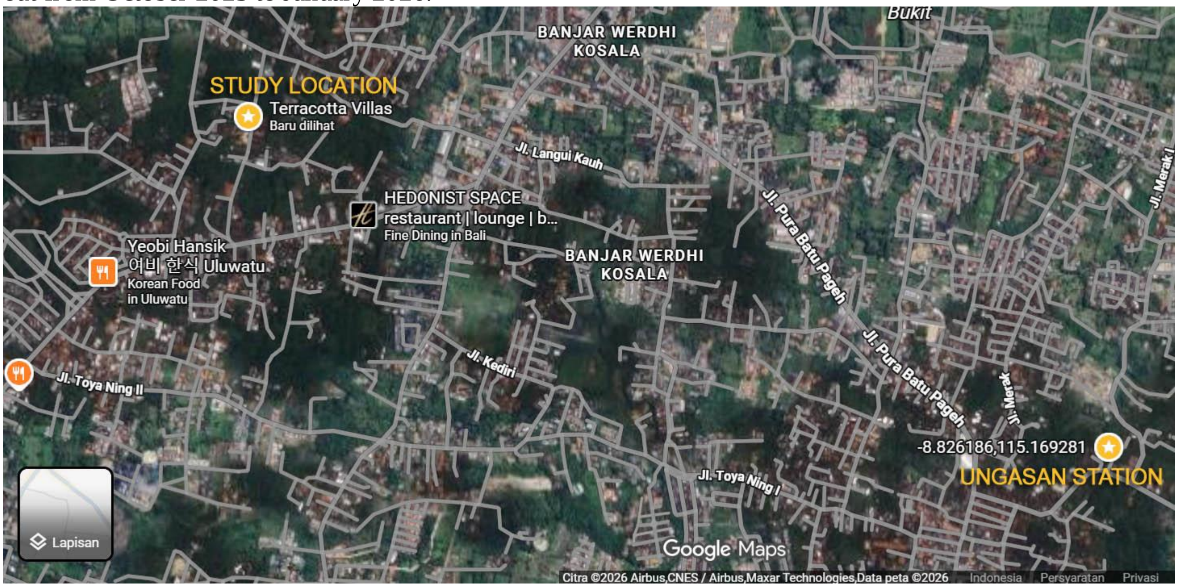

Figure 1. Location of the Study Area and Rainfall Station

Data collection in this study consisted of primary and secondary data. Primary data are data collected directly by the researcher from original sources for specific research purposes, such as through surveys, field measurements, interviews, or direct observations conducted by the researcher. Secondary data are data obtained from existing sources or previously collected by other parties, such as documents, books, journal articles, or official reports, which are then reused for the purposes of the present study [8]. The primary data used in this study include topographic data in the form of land contours and elevations obtained from field measurements, as well as site plan data of the villa area and the catchment area size. Existing drainage channel dimensions obtained through field observation. Meanwhile, the secondary data used in this study consist of daily rainfall data obtained from the Ungasan Rainfall Station, located at coordinates 8°49'34.27" S and 115°10'9.41" E. The rainfall data were provided by the Balai Wilayah Sungai Bali–Penida.

In hydrological studies, the selection of daily rainfall data as observational samples must consider a sufficiently long period to ensure representativeness of the rainfall characteristics in the study area. Several studies have established specific observation periods as research samples, such as the use of maximum daily rainfall data over the last 25 years for frequency and design rainfall intensity analysis [9]. Accordingly, the sample used in this study consists of rainfall data recorded over the most recent 25-year period at the Ungasan Rainfall Station. This sample was selected to represent local rainfall characteristics and to support the hydrological analyses conducted.

This study employs a quantitative research approach by applying hydrological and hydraulic modeling to analyze the response of the catchment area and to evaluate the performance of the drainage system under design rainfall conditions. The quantitative approach is used to systematically process numerical data related to rainfall, catchment characteristics, and drainage channel capacity. Hydrological analysis is conducted to determine the design rainfall and runoff characteristics within the study area, while hydraulic modeling is used to simulate the flow behavior within the drainage network. Through this approach, the interaction between rainfall, surface runoff, and drainage system capacity can be quantitatively assessed to determine whether the existing drainage infrastructure is capable of accommodating the design flood discharge [10].

The research procedure was carried out through several stages, beginning with topographic measurements of the study area using a total station to obtain detailed elevation and contour data. The results of the topographic survey were used to generate a contour map to describe the elevation characteristics and surface flow direction of the study area. The contour map shows that the elevation of the study area, indicating that the surface runoff generally flows toward the downstream drainage channel.

Figure 2. Topographic Map of the Study Area

Design rainfall analysis was performed using the Gumbel distribution and the Log Pearson Type III distribution to determine rainfall magnitudes for specific return periods [11]. The resulting daily rainfall was then transformed into hourly rainfall using the Mononobe method as the basis for determining design rainfall intensity [12]. The results of the topographic measurements and all subsequent analytical results were integrated into hydrological–hydraulic modeling using the EPA-SWMM software to simulate runoff and flow behavior within the drainage network under design rainfall conditions [13]. In this study, the SWMM model was applied as a design simulation tool to evaluate the hydraulic performance of the drainage system. Due to the absence of observed discharge and flow depth data in the study area, calibration and validation of the model could not be performed. Therefore, the simulation results are primarily used to assess the hydraulic capacity of the drainage system in conveying flow under design rainfall conditions.

The testing methods were applied to ensure the reliability and validity of the analytical and modeling results. A rainfall distribution goodness-of-fit test was conducted using the Smirnov–Kolmogorov method to evaluate the suitability of the selected rainfall distribution models against historical rainfall data. In addition, the relationships among categorical variables were examined using the Chi-Square method to assess the interdependence of factors influencing surface runoff [14]. The performance of the drainage system was evaluated by analyzing the results of EPA-SWMM simulations through a comparison between runoff discharge and the designed channel capacity [15]. As a safety measure, the channel safety factor was calculated by applying a freeboard height ranging from 5% to 30% of the design flow depth to account for hydrological uncertainties and to enhance the reliability of the drainage system against potential excess runoff [16].

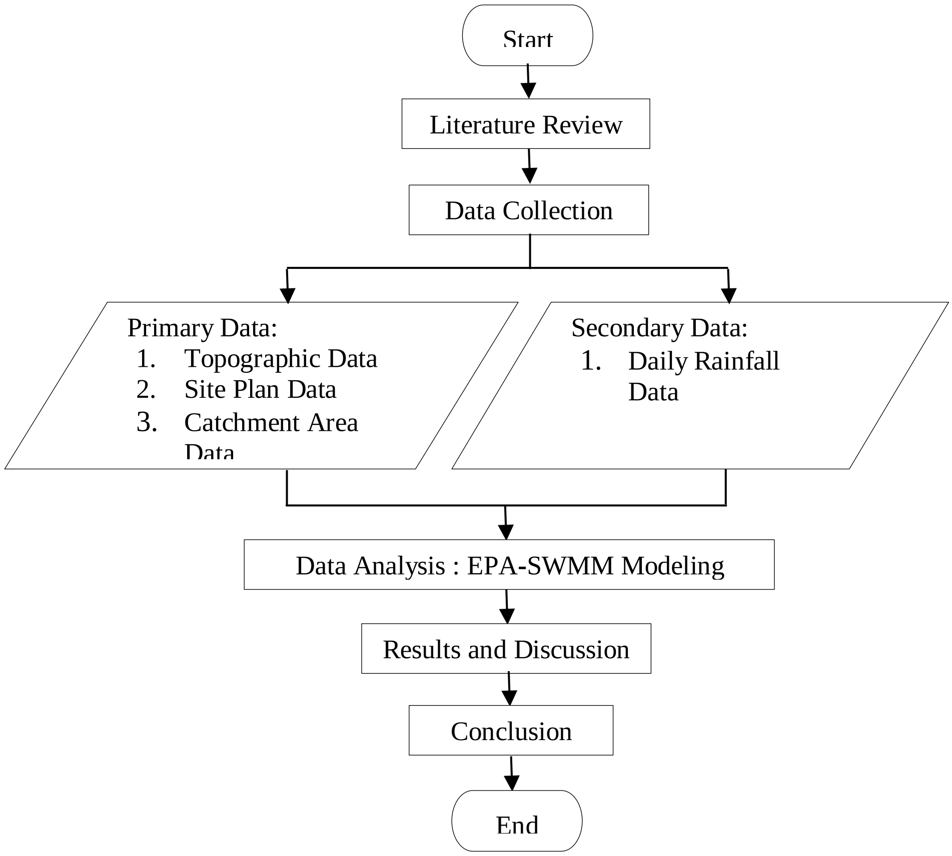

Figure 3. Flowchart

3. RESULTS AND DISCUSSION

3.1. Topographic Measurement Results

Field topographic measurements are a crucial step in hydrological and hydraulic studies, as they provide actual elevation and contour data that serve as essential inputs for numerical modeling. The Total Station instrument is capable of simultaneously measuring angles and distances and producing accurate three-dimensional coordinates; therefore, it is widely used in topographic surveys to generate representative site maps. The resulting coordinate data are subsequently processed using mapping software to produce contour maps required for hydrological modeling and surface flow simulations, such as those conducted using EPA-SWMM [17].

The objective of a terrestrial topographic survey is to obtain elevation and contour maps of the study area, which serve as a fundamental basis for construction planning. Measurements conducted using a total station produce a distribution of relative elevations with respect to the ground surface, which is essential for determining land slope and flow direction [18]. The following figure presents the topographic survey of Villa Terracotta:

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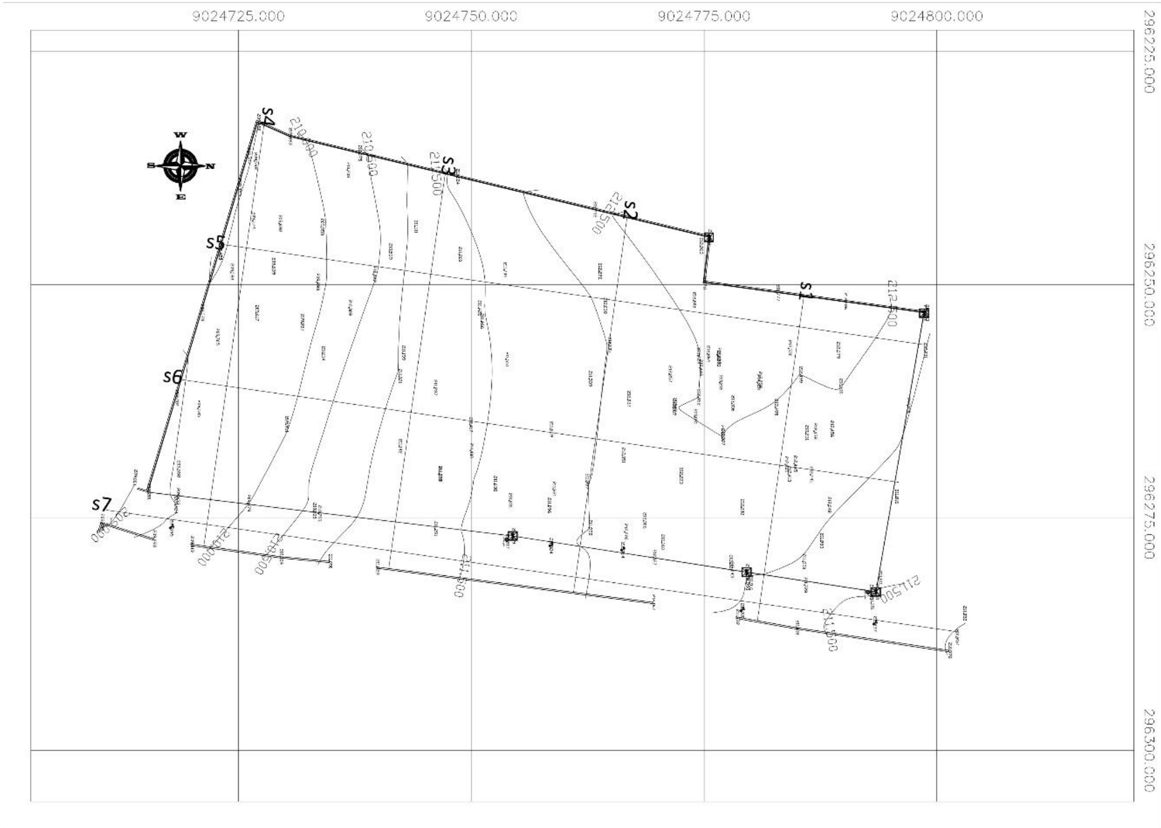

Figure 4. Topographic Plan

The topographic survey produced data on land area, surface contours or elevations, and measurement drawings. The Villa Terracotta site covers an area of 0.27 ha, with the lowest elevation at 109.5 m above sea level and the highest elevation at 111.5 m above sea level. The elevation interval used is 0.5 m.

3.2. Results of Rainfall Frequency Analysis Using the Gumbel Distribution

Rainfall data from the Ungasan Rainfall Station were used, consisting of annual maximum rainfall data from 1992 to 2016, covering a 25-year period (N = 25). The rainfall data are presented in the graph below.

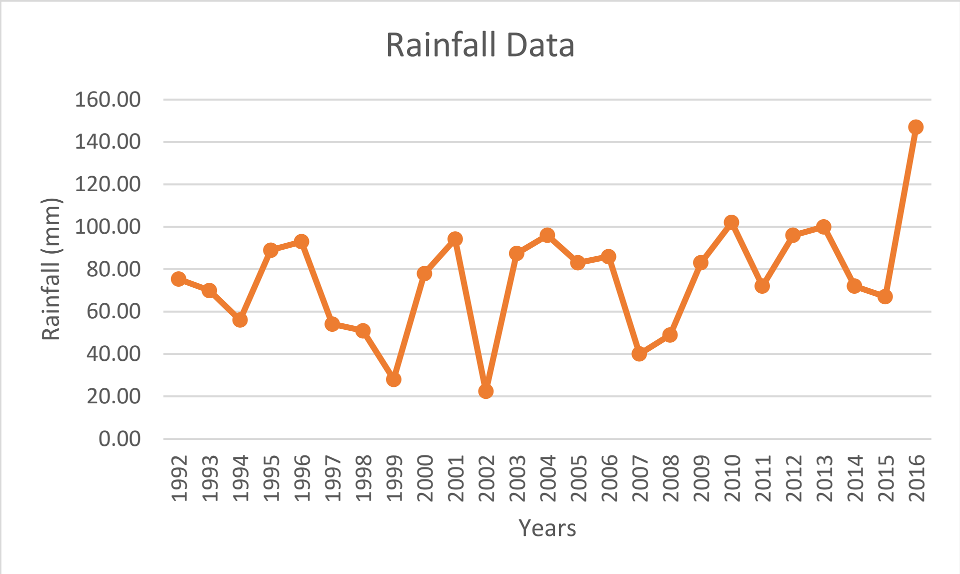

Figure 5. Maximum Rainfall Data From 1992 To 2016

Rainfall frequency analysis was conducted using the Gumbel distribution method to identify the characteristics of extreme rainfall based on the available annual maximum rainfall data [19]. The rainfall data are considered representative of the hydrological conditions of the study area. The results of the design rainfall analysis using the Gumbel distribution are presented in Table 1.

Table 1. Results of Design Rainfall Analysis Using the Gumbel Distribution Method

No	Return Period (Years) (Tr)	Reduction Factor (Y_{Tr})	Frequency Factor (K)	Design Rainfall (X_{Tr}) (mm)
1	2	0.37	-0.15	71.64
2	5	1.50	0.89	99.33
3	10	2.25	1.58	117.67
4	25	3.20	2.44	140.83
5	50	3.90	3.09	158.02

The statistical analysis results indicate that the mean annual maximum rainfall ($\overline{X}$) is 75.66 mm, with a standard deviation (S) of 26.67 mm. These values indicate a relatively significant interannual variation in rainfall, reflecting fluctuations in extreme rainfall events within the study area.

In the Gumbel method analysis, the mean reduction factor (Yn) was found to be 0.5309, and the standard deviation reduction factor (Sn) was 1.0915. These reduction factors were used to calculate the reduced variate, which subsequently served as the basis for determining the magnitude of design rainfall.

Based on the obtained statistical parameters and reduction factors, the analysis was then extended to determine design rainfall for specific return periods (2, 5, 10, 25, and 50 years). The design rainfall values were calculated by combining the mean, standard deviation, and the Gumbel reduced variate corresponding to each designated return period.

3.3. Results of Rainfall Frequency Analysis Using the Log Pearson Type III Distribution

The frequency analysis of rainfall was subsequently carried out using the Log Pearson Type III distribution to describe the characteristics of extreme rainfall based on the available annual maximum rainfall data. This method was selected because it accounts for data skewness, making it more representative for hydrological data that do not follow a symmetric distribution [20]. The dataset used in this analysis consisted of 25 observations (N = 25). The results of the design rainfall analysis using the Log Pearson Type III distribution are presented in Table 2.

Tabel 2. Hasil Analisis Hujan Rancangan Metode Distribusi Log Pearson Type III

No	Return Period (Years) (Tr)	Frequency Factor (K)	Design Rainfall (Log Y_{Tr})	Design Rainfall (X_{Tr}) (mm)
1	2	0.19	1.88	76.26
2	5	0.84	2.00	100.19
3	10	1.09	2.05	110.97
4	25	1.29	2.08	120.60
5	50	1.39	2.10	125.70

All rainfall data were first transformed into logarithmic form, followed by statistical analysis of the transformed dataset. Based on the calculations, the logarithmic mean ($\bar{Y}$) was found to be 1.85, while the logarithmic standard deviation (S) was 0.18.

Furthermore, the analysis yielded a skewness coefficient (Cs) of –1.19. This negative skewness indicates that the rainfall distribution is skewed to the left, meaning that extreme rainfall events tend to occur more frequently below the logarithmic mean value. This condition reinforces the importance of using the Log Pearson Type III distribution, as this method explicitly incorporates the effect of data skewness in the determination of design rainfall.

The statistical parameters obtained were then used to determine the frequency factor (K) based on the skewness coefficient and the selected return periods. The frequency factor was subsequently combined with the logarithmic mean and standard deviation to calculate the design rainfall in logarithmic scale. Finally, the design rainfall values were obtained by applying the antilogarithmic transformation, resulting in design rainfall depths expressed in actual rainfall units.

3.4. Smirnov-Kolmogorov Test for the Gumbel Distribution

The goodness of fit test was conducted using the Smirnov–Kolmogorov method to evaluate the suitability of the Gumbel distribution for the analyzed annual maximum rainfall data. The dataset used in this test consisted of 25 observations (N = 25) with a significance level of 5%.

Based on the test results, the maximum deviation (Δmax) was found to be 0.13, while the critical deviation ($\Delta critical$) was 0.27. According to the acceptance criterion of the Smirnov–Kolmogorov test, a distribution is considered acceptable when $\Delta max < \Delta critical$.

The results indicate that the value of Δmax is smaller than $\Delta critical$ ($0.13 < 0.27$); therefore, the null hypothesis (H_0) is accepted. It can be concluded that the Gumbel distribution is acceptable and appropriate for representing the distribution pattern of annual maximum rainfall data in the study area.

3.5. Smirnov-Kolmogorov Test for the Log Pearson Type III Distribution

The goodness of fit test was conducted using the Smirnov–Kolmogorov method to assess the suitability of the Log Pearson Type III distribution for the analyzed annual maximum rainfall data. The dataset used in this test consisted of 25 observations (N = 25) with a significance level of 5%.

Based on the test results, the maximum deviation (Δmax) was 0.11, while the critical deviation (Δcritical) was 0.27. According to the Smirnov–Kolmogorov test criterion, a distribution is considered acceptable when Δmax < Δcritical.

The comparison results show that Δmax is smaller than Δcritical (0.11 < 0.27); therefore, the null hypothesis (H_0) is accepted. It can be concluded that the Log Pearson Type III distribution is acceptable and appropriate for representing the distribution of annual maximum rainfall data in the study area.

Since the Smirnov–Kolmogorov tests indicate that both the Gumbel and Log Pearson Type III distributions are acceptable, the analysis is subsequently continued using the Chi-square goodness of fit test for both distributions.

3.6. Chi-Square Goodness-of-Fit Test for the Gumbel Distribution

The goodness of fit test was performed using the Chi-square (χ^2) method to evaluate the suitability of the Gumbel distribution for annual maximum rainfall data. In this test, the data were divided into five class intervals, resulting in equal expected frequencies (EF) of 5 observations per class, with a total of 25 data points. The results of the Chi-square test for the Gumbel distribution are presented in Table 3.

Table 3. Chi-square Test for the Gumbel Distribution

No	Intervals					EF	OF	EF - OF	(EF - OF)² / EF
1			P	<	51.06	5.00	5.00	0.00	0.00
2	51.06	<	P	<	64.82	5.00	2.00	3.00	1.80
3	64.82	<	P	<	79.10	5.00	6.00	-1.00	0.20
4	79.10	<	P	<	99.33	5.00	9.00	-4.00	3.20
5			P	>	99.33	5.00	3.00	2.00	0.80
					Σ	25.00	25.00	0.00	6.00

Based on the calculations, the observed frequencies (OF) varied among the class intervals. The differences between the expected and observed frequencies (EF − OF) were then used to compute the value of $(EF - OF)^2 / EF$ for each class. The sum of these values yielded a calculated Chi-square value (χ^2calc) of 6.0.

The calculated Chi-square value was subsequently compared with the critical Chi-square value (χ^2cr) at a 5% significance level and the corresponding degrees of freedom, which was 7.815. The comparison indicates that χ^2calc < χ^2cr (6.0 < 7.815).

Since the test criterion is satisfied, the null hypothesis (H_0) is accepted, indicating that the Gumbel distribution is acceptable and appropriate for representing the distribution of annual maximum rainfall data in the study area. Therefore, the Gumbel distribution is suitable for use in frequency analysis and in the determination of design rainfall for specified return periods.

3.7. Chi-Square Test for the Log Pearson Type III Distribution

The goodness of fit test was conducted using the Chi-square (χ^2) method to assess the suitability of the Log Pearson Type III distribution for annual maximum rainfall data. The test was performed by dividing the data into five class intervals, with each class having an expected frequency (EF) of 5 observations, resulting in a total of 25 data points. The results of the Chi-square test for the Log Pearson Type III distribution are presented in Table 4.

Table 4. Chi-square Test for the Log Pearson Type III Distribution

No	Intervals					EF	OF	EF - OF	(EF - OF)² / EF
1			P	<	51.73	5.00	5.00	0.00	0.00
2	51.73	<	P	<	64.18	5.00	2.00	3.00	1.80
3	64.18	<	P	<	79.81	5.00	6.00	-1.00	0.20
4	79.81	<	P	<	100.19	5.00	10.00	-5.00	5.00
5			P	>	100.19	5.00	2.00	3.00	1.80
					Σ	25.00	25.00	0.00	8.80

Based on the calculations, variations in the observed frequencies (OF) were obtained for each class interval. The differences between the expected and observed frequencies (EF − OF) were used to compute the values of $(EF - OF)^2 / EF$ for each class. The sum of these values yielded a calculated Chi-square value (χ^2calc) of 8.8.

The calculated Chi-square value was then compared with the critical Chi-square value (χ^2cr) at a 5% significance level and the corresponding degrees of freedom, which was 5.991. The comparison indicates that χ^2calc > χ^2cr (8.8 > 5.991).

According to the Chi-square test criteria, this result leads to the rejection of the null hypothesis (H_0). Thus, it can be concluded that the Log Pearson Type III distribution is not acceptable or less suitable for representing the distribution of annual maximum rainfall data in the study area based on the Chi-square test. Therefore, this distribution is not recommended for use in frequency analysis and design rainfall estimation in this study when evaluated solely on the basis of the Chi-square test results.

Since the Chi-square test for the Log Pearson Type III distribution was rejected, the Gumbel distribution was selected for the subsequent design rainfall analysis, which was further applied in the hourly rainfall analysis.

3.8. Results of Rainfall Intensity Analysis Using the Mononobe Method

Short duration rainfall intensity analysis is an essential step in the calculation of design flood discharge and the development of Intensity–Duration–Frequency (IDF) curves. One of the empirical approaches widely used in the literature is the Mononobe method, which enables the transformation of maximum daily rainfall data into rainfall intensities for specific hourly durations. This method is often applied alongside other empirical formulas (e.g., Sherman or Talbot) to estimate design rainfall intensities and to support the design of drainage systems or other hydrological structures, as demonstrated in rainfall intensity studies conducted in Bantul Regency and Sukarame [21]. The results of the hourly rainfall analysis using the Mononobe method are presented in Table 5.

Table 5. Results of Hourly Rainfall Analysis Using the Mononobe Method

No	Duration (Minute)	Return Period (Years)				
		2	5	10	25	50
1	60	24.84	34.44	40.79	48.82	54.78
2	120	15.65	21.69	25.70	30.76	34.51
3	180	11.94	16.56	19.61	23.47	26.34
4	240	9.86	13.67	16.19	19.38	21.74
5	300	8.49	11.78	13.95	16.70	18.73
6	360	7.52	10.43	12.35	14.79	16.59

Based on the Mononobe rainfall intensity analysis, rainfall intensities were obtained for rainfall durations ranging from 60 to 360 minutes with return periods of 2, 5, 10, 25, and 50 years. The results show that rainfall intensity decreases as rainfall duration increases for the same return period. For instance, at a rainfall duration of 60 minutes, the calculated rainfall intensities range from 24.84 mm/h for a 2-year return period to 54.78 mm/h for a 50-year return period. Meanwhile, for a longer duration of 360 minutes, the rainfall intensities decrease significantly, ranging from 7.52 mm/h to 16.59 mm/h.

This pattern indicates that short-duration rainfall events tend to produce higher rainfall intensities compared to long-duration events. Such characteristics imply that short and intense rainfall events have a greater potential to generate rapid surface runoff in urban drainage systems. As a result, drainage infrastructure must be designed to accommodate high peak intensities that typically occur during short-duration storm events.

This relationship occurs because rainfall energy tends to be concentrated over shorter periods during extreme storm events, resulting in higher rainfall intensities. Conversely, when rainfall occurs over longer durations, the total rainfall is distributed over time, leading to lower hourly intensities. A similar trend is observed for return periods, where rainfall intensity increases as the return period becomes longer. This indicates that rainfall events with lower probabilities of occurrence are associated with more extreme rainfall magnitudes. These results reflect the typical characteristics of extreme rainfall events in the study area and are consistent with commonly observed rainfall intensity–duration relationships in hydrological analysis.

The hourly rainfall intensities derived from the Mononobe method were subsequently used as rainfall input in the hydrological–hydraulic modeling using the EPA-SWMM model to simulate runoff generation and flow behavior within the drainage system.

3.9. EPA-SWMM Modeling

Modeling using EPA-SWMM can be applied not only to the evaluation of existing drainage systems but also to the planning and design of new drainage systems in residential areas based on hydrological data and drainage network geometry. This approach provides a more realistic simulation of runoff discharge and channel flow compared to simple empirical methods, thereby supporting more comprehensive and informed design decisions [22].

In urban drainage studies, EPA-SWMM is commonly used to simulate runoff processes and the hydraulic behavior of drainage networks, including the evaluation of design alternatives such as Low Impact Development (LID) practices. By incorporating hourly rainfall data and the physical characteristics of the

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drainage network, the model is capable of identifying overflow locations and providing improvement recommendations based on the simulation results [23].

In this study, the drainage channel dimensions in the EPA-SWMM model were designed with a channel width of 0.30 m and a channel height of 0.55 m. In addition, inputs included the catchment area, channel length, and the rainfall intensity results obtained from the Mononobe method. A 25-year return period was adopted for the design. The channel slope was specified to be not less than 1% and not greater than 3%.

3.10. Results of EPA-SWMM Analysis (Flow Depth)

One of the outputs of EPA-SWMM modeling is flow depth. Under maximum discharge conditions, the water surface elevation can be evaluated to determine whether overtopping of the drainage channels occurs. The results of the EPA-SWMM modeling related to flow depth are presented in Figure 3.

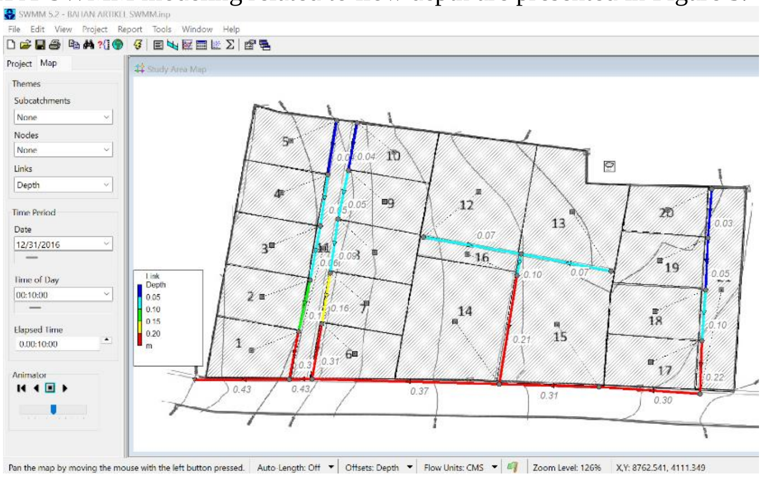

Figure 6. Results of Flow Depth Analysis

The hydrological–hydraulic modeling results obtained using EPA-SWMM 5.2 show a varied spatial distribution of flow depth (link depth) across the drainage network in the study area. The highest flow depths are observed in the main channels located in the downstream section of the network, indicated by red colors in the model output, with values ranging from approximately 0.30 m to 0.43 m. In contrast, the connecting channels in the central part of the drainage network exhibit moderate flow depths ranging from about 0.07 m to 0.21 m, represented by light blue to green colors. Meanwhile, channels located in the upstream section generally show relatively low flow depths, mostly below 0.10 m.

These results indicate that the hydraulic load within the drainage network increases progressively toward the downstream section. The relatively high flow depths observed in the downstream channels suggest that these segments receive accumulated runoff contributions from multiple upstream subcatchments. Although the channels are still capable of conveying the generated runoff, the flow depths approaching the channel capacity indicate that the downstream segments experience higher hydraulic stress compared to the upstream and middle sections of the network.

This spatial pattern reflects the fundamental principle of flow accumulation in urban drainage systems, where runoff generated from upstream areas is progressively collected and conveyed through downstream channels. As runoff travels through the drainage network, the contributing catchment area increases, resulting in larger discharge and consequently greater flow depth within the downstream channels. This condition explains why hydraulic loading tends to be concentrated in the lower part of the drainage network. Therefore, the downstream channels represent the most critical sections in terms of drainage performance and potential inundation risk. To improve the hydraulic performance of the system and reduce the potential for overflow, mitigation measures such as increasing channel dimensions or improving downstream drainage capacity may be required.

3.11. Results of EPA-SWMM Analysis (Flow Discharge)

In addition to flow depth, EPA-SWMM modeling also produces results in the form of flow discharge. The results of the EPA-SWMM flow discharge analysis are presented in Figure 4.

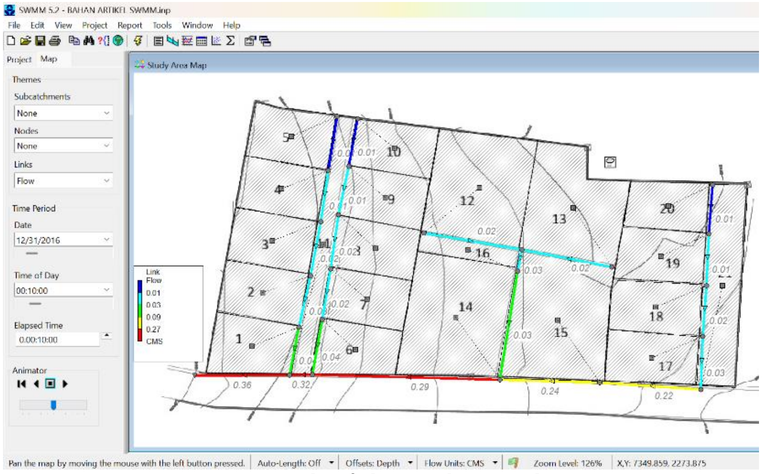

Figure 7. Results of Flow Discharge Analysis

The EPA-SWMM 5.2 simulation results show a varied spatial distribution of flow discharge (link flow) across the drainage network in the study area. The highest discharges are observed in the main channels located in the downstream section of the network, with values ranging from approximately 0.22 m³/s to 0.36 m³/s, as indicated by yellow to red colors in the model output. In contrast, channels located in the central part of the drainage network exhibit moderate discharges ranging from about 0.02 m³/s to 0.09 m³/s, represented by light blue to green colors. Meanwhile, the upstream channels generally display relatively low discharges, typically ranging from 0.01 m³/s to 0.03 m³/s.

This distribution indicates that the downstream channels function as the main receivers of runoff generated from upstream and midstream areas. The relatively large discharge values observed in these downstream segments suggest that the hydraulic load within the drainage system becomes increasingly concentrated toward the outlet of the network. Although the channels are still capable of conveying the simulated flow, the increasing discharge magnitude indicates that the downstream segments play a critical role in maintaining the overall performance of the drainage system.

This pattern reflects the principle of runoff accumulation within urban drainage systems. As rainfall occurs over multiple subcatchments, the generated runoff is progressively collected and conveyed through the drainage network toward downstream channels. Consequently, the contributing drainage area increases along the flow path, resulting in larger discharge values in downstream segments. In addition, variations in discharge within the central part of the network are influenced by differences in subcatchment characteristics, including catchment area, surface imperviousness, and local drainage connectivity. Therefore, the downstream channels represent critical points within the drainage system where hydraulic capacity must be carefully evaluated to prevent potential overflow or localized flooding.

3.12. Results of EPA-SWMM Analysis (Flow Velocity)

In addition to flow depth and flow discharge, EPA-SWMM modeling also provides results in terms of flow velocity. The results of the EPA-SWMM flow velocity analysis are presented in Figure 5.

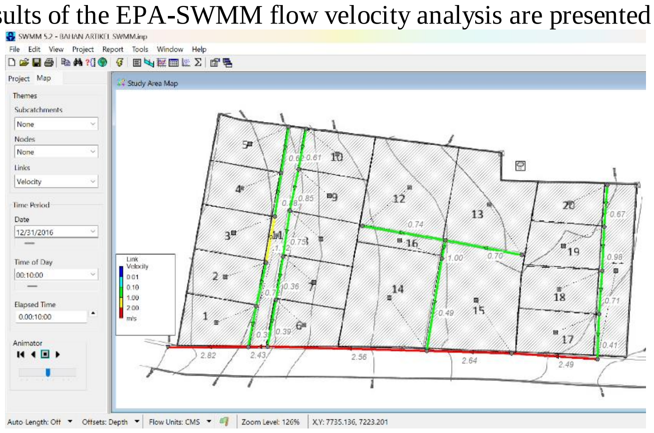

Figure 8. Results of Flow Velocity Analysis

The EPA-SWMM 5.2 simulation results show a varied spatial distribution of flow velocity (link velocity) across the drainage network in the study area. The highest velocities are observed in the main channels located in the downstream section of the network, ranging from approximately 2.40 m/s to 2.80 m/s, as indicated by red colors in the simulation output. In the central part of the network, the flow velocities range from about 0.70 m/s to 1.00 m/s, represented by green colors. Meanwhile, the upstream channels generally exhibit lower flow velocities, approximately 0.30 m/s to 0.60 m/s.

This distribution indicates a progressive increase in flow velocity from upstream to downstream within the drainage network. Such a pattern reflects the accumulation of runoff from multiple subcatchments, which increases the discharge and flow energy toward the downstream sections. Consequently, the downstream channels experience higher hydraulic loads compared to the upstream segments. In contrast, the upstream channels convey relatively smaller discharges, resulting in lower flow velocities.

The simulated flow velocities were compared with the flow velocity criteria for drainage channels based on the Peraturan Menteri Pekerjaan Umum Republik Indonesia No. 12/PRT/M/2014 [24]. According to this regulation, the minimum allowable velocity for drainage channels is 0.6 m/s, which represents the minimum velocity required to prevent sediment deposition and the growth of aquatic vegetation within the channel. The maximum allowable velocity depends on the channel lining material, which is approximately 0.7 m/s for earth channels, 2 m/s for stone masonry channels, and 3 m/s for concrete-lined channels. In this study, the analyzed drainage system consists of concrete channels, indicating that the allowable maximum velocity is 3 m/s.

The maximum flow velocity in the drainage network reaches approximately 2.80 m/s, which is still below the allowable maximum velocity for concrete channels. This condition indicates that, from a hydraulic perspective, the flow velocity remains within the safe range and does not pose a significant risk of structural damage due to erosion. However, several upstream segments exhibit flow velocities close to or slightly below the recommended minimum velocity, ranging from 0.30 m/s to 0.60 m/s. Such conditions may increase the potential for sediment deposition, particularly in channel segments with relatively mild slopes.

Overall, the flow velocity modeling results indicate that most channel segments operate within the velocity range recommended by the drainage design standards. Nevertheless, downstream channels require attention because their velocities approach the allowable maximum limit, while some upstream segments may experience sedimentation due to relatively low flow velocities. Therefore, periodic evaluation of the hydraulic performance of the drainage system is necessary to ensure that the channels continue to function effectively in conveying surface runoff.

3.13. Freeboard Calculation

The freeboard design is intended to prevent water overtopping caused by excessive flow discharge and water surface fluctuations. The recommended freeboard generally ranges from 5% to 30% of the flow depth [25].

According [26], the optimal dimensions of drainage channels along urban ring roads are determined not only by the design flood discharge but also by the provision of a freeboard of 0,20 m to prevent overtopping during heavy rainfall events, thereby enabling the drainage system to convey stormwater runoff effectively without causing surface inundation on the roadway.

The calculation of freeboard is required to provide a safety factor for drainage channels, considering uncertainties in flow discharge magnitude, water level fluctuations due to variations in rainfall intensity, and the potential for channel blockage by sediment and debris. The freeboard calculation is presented as follows:

Freeboard = channel height – flow depth
= 0,55 m – 0,43 m = 0,12 m
Freeboard percentage = 0,12 m / 0,43 m x 100% = 27,9%

This value falls within the recommended range of 5%–30%, indicating that the channel satisfies the hydraulic safety criteria against overflow. The presence of adequate freeboard provides additional capacity to accommodate fluctuations in discharge during peak rainfall events, thereby reducing the risk of overtopping. Similar recommendations have been reported in drainage design studies, where maintaining sufficient freeboard is considered an important factor in ensuring hydraulic safety and operational reliability of drainage channels. Therefore, the obtained result indicates that the designed channel is hydraulically adequate to convey runoff generated from the design rainfall without causing flooding in the surrounding area [27].

4. CONCLUSION

Based on the results of the drainage channel dimension analysis for Villa Terracotta in Badung Regency using the EPA-SWMM program, it can be concluded that the Villa Terracotta site covers an area of 0.27 ha, with the lowest elevation of 109.5 m above sea level and the highest elevation of 111.5 m above sea level, and an elevation interval of 0.5 m.

In the design rainfall analysis using the Gumbel method, the mean reduction factor (Yn) was obtained as 0.5309, and the standard deviation reduction factor (Sn) was 1.0915. Meanwhile, the design rainfall analysis using the Log Pearson Type III method produced a skewness coefficient (Cs) of –1.19, indicating that the rainfall data distribution is negatively skewed.

The Kolmogorov–Smirnov goodness-of-fit test results indicate that both the Gumbel and Log Pearson Type III distributions are acceptable; therefore, the analysis was continued using the Chi-square test. Based on the Chi-square test results, the Log Pearson Type III distribution did not meet the acceptance criteria, and thus the Gumbel distribution was selected as the basis for the design rainfall analysis.

The hourly rainfall analysis using the Mononobe method shows that for a 60-minute duration, rainfall intensity ranges from 24.84 mm/h for a 2-year return period to 54.78 mm/h for a 50-year return period. For a longer duration of 360 minutes, rainfall intensity decreases to values ranging from 7.52 mm/h to 16.59 mm/h.

The hydrological and hydraulic modeling results obtained using EPA-SWMM 5.2 indicate variations in flow depth (link depth) across the drainage network, with maximum depths in the main downstream channels ranging from approximately ±0.30 m to 0.43 m. The highest flow discharges in the same segments reach 0.22 m^3/s to 0.36 m^3/s, while the maximum flow velocities range from 2.40 m/s to 2.80 m/s.

Based on these modeling results, the planned drainage channel dimensions are 0.30 m in width and 0.55 m in height. The calculated freeboard is 0.12 m, corresponding to 27.9% of the flow depth, which falls within the recommended range of 5%–30%. Therefore, from a hydraulic perspective, the drainage channel is considered safe against potential overflow.

The results of this study offer considerable potential for further development, both in terms of methodology and practical application. Future research may incorporate climate change scenarios, particularly the increasing intensity of extreme rainfall events, to evaluate the long-term performance of drainage systems. In addition, the implementation of Low Impact Development (LID) practices, such as bioretention systems, infiltration wells, and permeable pavements, can be modeled using EPA-SWMM to assess their effectiveness in reducing surface runoff.

Further studies may also integrate water quality modeling, allowing drainage systems to be designed not only for flood control but also for sustainable urban environmental management. Consequently, the modeling approach employed in this study can be applied and further developed for residential areas, villa complexes, and other tourism-related developments with similar hydrological characteristics.

CONFLICT OF INTEREST STATEMENT
Authors state no conflict of interest.

REFERENCES

[1] D. Indriastuti, "Analysis of Runoff due to The Change in Land Use at The Watershed of Upstream Ciliwung," 2016. doi: https://doi.org/10.22146/jcef.26576.

[2] R. Mahendra, B. Mohammad, and P. Linda, "Aplikasi EPA SWMM 5.1 pada Perencanaan Sistem Drainase Kawasan Perumahan Aura Park Kecamatan Dau Kabupaten Malang," *Jurnal Teknologi dan Rekayasa Sumber Daya Air*, vol. 4, no. 1, pp. 460–470, Oct. 2023, doi: 10.21776/ub.jtresda.2024.004.01.039.

[3] W. Nurzanah, M. S. Iskandar, R. Gunawan, and D. S. D. Tara, "Analisis Perhitungan debit banjir rencana di bendung karet bandar sidoras," *Jurnal VORTEKS*, vol. 3, no. 1, pp. 190–198, Apr. 2022, doi: 10.54123/vorteks.v3i1.154.

[4] R. Andayani and Z. F. Umari, "Debit Banjir Rancangan DAS Selabung Dengan HSS Nakayasu," 2022.

[5] A. C. Damayanti, L. M. Limantara, and R. Haribowo, "Analisis Debit Banjir Rancangan dengan Metode HSS Nakayasu, HSS ITB-1, dan HSS Limantara pada DAS Manikin di Kabupaten Kupang," 2022. [Online]. Available: https://jtresda.ub.ac.id/

[6] R. Faizal, N. A. Prsetya, Z. Alstony, and A. Rahman, "Evaluasi Sistem Drainase Menggunakan Storm Water Management Model (SWMM) dalam Mencegah Genangan Air di Kota Tarakan," 2019.

[7] A. Husaini, Fasdarsyah, T. M. Hafli, M. Fahmi, R. Mirsa, and A. Jalil, "Analisis Kapasitas Saluran Drainase Terhadap Debit Maksimum Di Kota Lhokseumawe Dengan Menggunakan Software SWMM 5.1," vol. 6, no. 2, pp. 24–27, 2022.

[8] M. H. Nurul, N. Indah, R. Virda, H. Rully, and H. Harmonedi, "Identifikasi Variabel Penelitian, Jenis Sumber Data dalam Penelitian Pendidikan," *Dinamika Pembelajaran : Jurnal Pendidikan dan bahasa*, vol. 2, no. 2, pp. 256–270, May 2025, doi: 10.62383/dilan.v2i2.1563.

[9] A. F. Siti and W. Eka, "Analisis Hidrologi Untuk Penentuan Metode Intensitas Hujan Di Wilayah Kecamatan Bogor Barat, Kota Bogor," 2020.

[10] V. T. Chow, D. R. Maidment, and L. W. Mays, "Applied Hydrology," 1988.

[11] Philipus, S. Gatot Eko, and I. Laksmi, "Karakteristik Distribusi Curah Hujan Di Wilayah Sungai Mesuji - Sekampung," 2020.

[12] A. H. P. Nadya, L. Anisah, and S. Jupriah, "Perbandingan Metode Mononobe dan Metode Van Breen Untuk Pengukuran Intensitas Curah Hujan Terhadap Penampang Saluran Drainase," 2021.

[13] T. W. Frenki, "Analisis Jaringan Drainase Menggunakan EPA-SWMM Pada Kawasan Pabrik Garmen, Di Kabupaten Garut," 2023.

[14] E. Zainal and Zufrimar, "Distribusi Probabilitas Curah Hujan Pada Daerah Aliran Sungai Kuranji," vol. 11, no. 01, pp. 17–26, 2021.

[15] A. A. M. Baitullah, "Pemodelan Sistem Drainase Perkotaan Menggunakan SWMM," 2020.

[16] I. M. Arifin, M. I. Yusup, and F. S. P. Pangesti, "Perencanaan Sistem Drainase SMKN 1 Kragilan Kabupaten Serang," *Jurnal Lingkungan dan Sumberdaya Alam (JURNALIS)*, vol. 5, no. 1, pp. 61–72, Apr. 2022, doi: 10.47080/jls.v5i1.1912.

[17] M. F. M. Rizky and R. Ridwana, "Pengukuran Topografi Untuk Pembangunan Penampungan Air Bersih (Studi Kasus: Daerah Rajamandala, Kabupaten Bandung Barat)," 2021. [Online]. Available: http://ejournal.unikama.ac.id/index.php/JPIG/

[18] A. Sulistivo, D. S. Harahap, and K. Kunci, "Survey Topografi Perencanaan Pembangunan Gedung Kuliah Terpadu STAIN Sultan Abdurrahman Kepulauan Riau," *JTSIP*, vol. 1, no. 2, 2022, [Online]. Available: https://jurnal.uisu.ac.id/index.php/JTSIP
.

[19] F. A. Asyari, H. Pristianto, A. Farida, A. Pamudjianto, and F. Desembardi, “Perencanaan Saluran Drainase Jalan Tawes Kelurahan Klamasen Distrik Mariat Kabupaten Sorong,” 2025, [Online]. Available: http://doi.org/xxx

[20] A. D. Cahyani and F. Saves, “Analisis Kapasitas Tampung Saluran Drainase dalam Menampung Debit Limpasan Hujan pada Wilayah Penjaringan Asri Surabaya,” *Jurnal Sains Dan Teknologi (JSIT)*, vol. 5, no. 3, pp. 473–486, 2025, doi: 10.47233/jsit.v5i2.3748.

[21] T. Widyasari and N. Achmad, “Kurva Intensitas Durasi Frekuensi Hujan Kabupaten Bantul Dengan Menggunakan Metode Mononobe,” 2023.

[22] A. M. P. Luiz, A. Ussy, and A. Runi, “Aplikasi EPA SWMM 5.1. pada Perencanaan Sistem Drainase Kawasan Perumahan El Banna City Kecamatan Karangploso Kabupaten Malang,” *Jurnal Teknologi dan Rekayasa Sumber Daya Air*, vol. 5, no. 1, pp. 27–36, Jan. 2025, doi: 10.21776/ub.jtresda.2025.005.01.004.

[23] T. H. Billah, P. Linda, and A. Ussy, “Evaluasi Saluran Drainase pada Kelurahan Tulusrejo Kata Malang Menggunakan Aplikasi SWMM 5.2,” *Jurnal Teknologi dan Rekayasa Sumber Daya Air*, vol. 4, no. 1, pp. 438–449, Oct. 2023, doi: 10.21776/ub.jtresda.2024.004.01.037.

[24] “Peraturan Menteri Pekerjaan Umum Republik Indonesia Nomor 12 /PRT/M/2014 Tentang Penyelenggaraan Sistem Drainase Perkotaan”.

[25] B. Yegal, “Drainase Perkotaan,” 2021. [Online]. Available: www.rcipress.rcipublisher.org

[26] N. Salim, “Evaluasi Dan Desain Saluran Drainase Pada Jalan Lingkar Di Perkotaan (Studi Kasus Jalan Wonorejo-Kedungjajang Kabupaten Lumajang),” 2021.

[27] Y. Kakerissa, A. Doloksaribu, J. Paresa, and A. Asmar, “Perencanaan Drainase Perkotaan Pada Perumahan,” vol. 8, no. 3, 2019.

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