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ANALYSIS AND DRAINAGE PLANNING IN FLOOD PREVENTION EFFORTS AT MAHROJA COMMERCIAL CENTER TASIKMALAYA

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ABSTRACT

Drainage analysis and planning in an effort to prevent flooding at the Mahroja Commercial Center Tasikmalaya was carried out with a hydrological analysis method in the Cimulu River Sub-watershed, Tasikmalaya City, to estimate the planned rainfall and flood discharge for the 25-year plan. Daily rainfall data during 2007–2019 from the nearest stations (Cimulu, Cikunten II, Kawalu) were analyzed by arithmetic method to obtain the average rainfall of the area. Statistical frequency analysis was carried out by checking the match of the probability distributions of Gumbel, Log – Normal, and Log – Pearson Type III. Based on the chi-square test, it was obtained that the Type III Log-Pearson distribution provided the best match. The 25-year planned rainfall ranges from 124.48 mm (Normal), 137.74 mm (Gumbel) to 159.33 mm (Log – Pearson). The intensity of peak rainfall was calculated from the IDF (Intensity–Duration–Frequency) curve and used in the Rational method ($Q = 0.278 \cdot C \cdot I \cdot A$) to calculate the plan discharge. The hydraulic model of the regional drainage channel (Mahroja Commercial Center) was made with EPA SWMM 5.1 software (25-year planned rainfall input, DTA 18.8 ha). The results of the SWMM simulation show the value of the planned flood discharge at vital locations (namely: C8 shopping complex of 0.877 m^3/s, about 37.8% of the capacity of 2.3196 m^3/s; peak in channel C10 of 2.496 m^3/s, 59.3% of the capacity of 4.2057 m^3/s). This condition indicates that the commercial drainage system is safe against 25 years of flooding. The results of this study are important as a technical basis for flood mitigation in the Cimulu Sub-watershed – namely: planning vulnerable areas and increasing drainage capacity – so that the burden of large rainfall can be reliably overcome.

Keywords: Analysis, Watershed, Drainage, EPA SWMM, Hydrology, Flood Prevention.

INTRODUCTION

The Cimulu River in Tasikmalaya is known to often flood when it rains heavily, so its sub-watershed is a high-vulnerability area. Hydrological and hydraulic studies are required to plan flood mitigation, such as the addition of channels or the reinforcement of embankments. This study is a new and independent study that processes historical rainfall data of the Cimulu Sub-watershed (Mahroja Commercial Center group) to calculate the design rainfall and planned flood discharge. The process includes rainfall distribution analysis (involving the Gumbel opportunity distribution, Log – Normal 2 parameters, and Log – Pearson Type III) as well as distribution suitability testing using the chi-square test. Furthermore, the calculation of rain intensity (IDF curve) and planned flood discharge was carried out using the Rational method. The entire result will be attributed to the design of the drainage channel and its capacity. This study is important as a technical recommendation for flood mitigation in the Sub-Watershed of the Cimulu River (Tasikmalaya) which is prone to flooding. (Muhammad et al., 2021) (Cahyono, Saefudin, et al., 2025) (Khomsiati et al., 2025)

The Cimulu River and the drainage network around the Mahroja Commercial Center, Tasikmalaya City, repeatedly show local inundation and flooding during heavy rains. Frequent floods not only cause disruption to commercial activities and accessibility, but also pose a risk of damage to road infrastructure, shops, and potential economic losses for local business actors. Local topographic conditions, land-use changes due to commercial area development, and the quality of existing drainage systems, which are largely designed without reference to modern planned rainfall and peak discharge, increase the vulnerability of these areas to surface runoff that could potentially exceed channel capacity. Although sporadic management efforts (ditch repairs, sediment clearance, or temporary talud installations) have been made, there is no integrated hydrological–hydraulic study that calculates locally designed rainfall, planned discharge for various re-periods, and evaluates channel capacity and drainage design alternatives based on the results of the analysis. The absence of this systematic technical study makes interventions often ad-hoc and less effective in the medium to long term. (Cahyono, Kurniawan, et al., 2025) (Cahyono, Saefudin, et al., 2025) (Cahyono, Saefudin, et al., 2025)

The problem of this research, therefore, is that there is a gap between the need for data-based drainage design and quantitative analysis and current drainage management practices in the Mahroja Commercial Center area. In particular, it is not clear how much planned rainfall and peak discharge should be the planning reference, whether the existing drainage system is capable of accommodating the planned discharge for a feasible re-period (i.e., 2, 5, 10, 25 years), and what kind of channel design or dimensions are needed to prevent recurrent flooding events. This research aims to close the gap through integrated and data-driven drainage analysis and planning. Operationally, the study will conduct a historical rainfall frequency analysis to determine the rainfall design by testing multiple opportunity distributions (i.e., Gumbel, Log-Normal 2-parameter, and Pearson Type III) as well as distribution suitability tests (chi-squared), drawing up IDF curves for relevant duration and re-periods, calculating the plan discharge using the appropriate method (Rational method as the initial design method) and then modeling the hydraulic response of the channel/river using HEC-RAS software to evaluate water levels, flow depth and potential inundation in various discharge scenarios. The results of the analysis will be used to evaluate the existing drainage capacity and formulate alternative channel designs, dimensions, and recommendations for strengthening the structure that are practical and priority. (Cahyono, Arifin, et al., 2025) (Muhammad et al., 2021)

The contribution of this research is practical and policy: it provides a quantitative basis for determining rainfall and discharge plans specific to the Mahroja Commercial Center area, assesses the adequacy of the current drainage system, and presents technical designs and mitigation scenarios that can be adopted by the city government and area managers. In addition, an approach that combines rainfall frequency analysis, IDF curves, hydrological calculations, and HEC-RAS hydraulic modeling is expected to be a replication-able study reference for similar urban areas experiencing land development pressures and changes in runoff patterns. Thus, this research not only answers concrete local problems, but also provides technical recommendations that can support more disaster-resilient drainage planning in the future. (Fairizi, 2015)

Figure 1. Mahroja Commercial Center Water Catchment Area.

Figure 2. Condition of the Research Location.

LITERATURE REVIEW

2.1. Rain intensity and the formation of the IDF curve

Rainfall intensity is a basic parameter in drainage planning because it relates the amount of precipitation that falls in a given time span to the hydrological response of the catchment area. In Indonesia, the determination of planned rainfall intensity often refers to national guidelines and standards that govern the conversion of daily/maximum rainfall to short-period intensity through empirical equations or the use of the IDF (Intensity–Duration–Frequency) curve. SNI and local technical guidelines recommend the use of historical data of rain stations to determine rainfall design and construct IDF curves that correspond to local concentration times so that the intensity used in peak discharge calculations reflects the local climatic conditions and selected re-periods. The formation of the IDF curve is also influenced by the calculation method used (i.e., Mononobe, SNI modification) and the selection of re-periods (i.e., 2, 5, 10, 25 years) which subsequently become a reference for urban drainage design. These general practices and national guidelines are described in the SNI and drainage guidelines so that their use ensures technical consistency in urban drainage planning. (Handoko et al., 2022) (Collins et al., 2021) (Agustama Maha & Lukman, 2020)

2.2. Rain Frequency Analysis and Opportunity Distribution Selection

The analysis of rainfall frequency aims to determine the amount of rainfall that is likely to occur in a certain repetition period; This step precedes the preparation of the IDF and the calculation of the plan discharge. In scientific and technical practice in Indonesia, some of the opportunity distributions that are often tested are Gumbel, Log-Normal (2 parameters), and Log-Pearson Type III due to the extreme characteristics of hydrometeorological data that tend to be right-tailed. A match test (i.e., chi-squared, Kolmogorov–Smirnov) is used to select the distribution that best corresponds to the annual maximum data sample from the local rainfall station. The Indonesian case study literature shows that the appropriateness of distribution can differ between regions; i.e.: some studies report Gumbel is best suited in one watershed but Log-Pearson III is better in another, emphasizing the importance of local testing before selecting a distribution for the determination of planned rainfall. The selection of the right distribution and parameter estimation method will directly affect the design rainfall value (and ultimately the plan's discharge) so the validity of the frequency analysis is a key step to producing reliable drainage recommendations. (Agustama Maha & Lukman, 2020) (Garcia et al., 2022) (Efendi, 2021)

2.3. Plan Discharge Calculation Method: Rational and Alternative Methods

The calculation of peak discharge on which drainage channel dimensions are based generally uses the Rational Method ($Q = C \cdot I \cdot A$) for relatively small to medium catches in urban contexts due to its simplicity and its direct correlation with rainfall intensity and land characteristics. This method requires determining the time of the tc concentration, the intensity at tc of the IDF curve, and the runoff coefficient C which represents the influence of land use, surface conditions, and infiltration. For larger watersheds or studies that require a flood hydrograph (time-varying hydrograph), more detailed hydrological methods such as SCS-CN (Curve Number) for cumulative runoff estimation or unit hydrograph methods (Snyder, SCS) are used to obtain realistic flood hydrographs. The SNI standard on the calculation of planned flood discharge and the Highway guidelines for road drainage provide practical recommendations on the selection of redesign periods and calculation methods that are feasible for the context of road/settlement infrastructure so that drainage planning is in accordance with national engineering practices. (Khomsiati et al., 2025) (Cahyono, Arifin, et al., 2025) (Cahyono, Kurniawan, et al., 2025)

In the context of research in the Mahroja Commercial Center area, the Rational Method is usually chosen as an initial design step (screening) while the hydrograph-based method can be used as verification or for more detailed scenario analysis. The rational method and the calculation of the discharge of the discharge are calculated using the Rational Method: (International, 2000)

$$Q = 0.278 \times C \times I \times A \; (m\,3\,/\,s)$$

where

C = runoff coefficient (determined from land use),

I = maximum rainfall intensity during the concentration time (mm/h), and

A = DTA area (km²)

2.4. Coefficient of Runoff, Infiltration, and Role of Land Characteristics (Topography, Soil, Land Use)

The runoff coefficient value (C) is a crucial parameter that bridges the intensity of rain with surface runoff discharge. The C value is directly influenced by the land cover (surface impermeability such as asphalt and concrete), local drainage conditions, land slope, and soil infiltration properties. For commercial areas that are experiencing rapid urbanization (such as the Mahroja Commercial Center), the increase in impermeable areas usually raises the C value and shortens the concentration time thus increasing the peak discharge in a short period. (Hakam et al., 2019) (National Standards Agency, 2017)

Alternative approaches, such as the SCS-CN method, estimate the contribution of infiltration and runoff based on land use classification and soil characteristics. Local soil types (i.e.: Regosol, Litosol) crumb-textured soils can exhibit certain infiltration characteristics – in some conditions provide good infiltration, but when compacted or covered the surface will decrease infiltration. Therefore, field evaluation of soil characteristics and land use maps must be part of determining the C or CN values used in the calculation of the plan's discharge so that runoff estimates are not biased. Local studies and Indonesian academic repositories emphasize the need for local data (field/remote sensing) to determine a representative C or CN. (Xu et al., 2022) (Puspadewi et al., 2024)

2.5. Hydraulic Modeling With HEC-RAS For Line Capacity Evaluation and Inundation Mapping

Once a planned discharge is obtained, hydraulic analysis is required to assess whether the existing drainage network is capable of draining the discharge without causing dangerous inundation. HEC-RAS is a widely used standard software for simulating steady and unsteady water level profiles, evaluating flow depth, velocity, and inundation areas along rivers or channels. By incorporating cross-section geometry, boundary conditions, structures such as bridges or culverts, as well as plan discharges as inputs, HEC-RAS enables modeling of various load scenarios (different re-periods, land use changes, or the presence of channel obstructions) to map flood-prone points and evaluate the need for channel capacity enhancement or other structural mitigation measures. Additional modules (i.e.: HEC-RAS Mapper) facilitate the conversion of hydraulic results into inundation maps that are useful for spatial planning and prioritization of actions. Many studies and manuals on the use of HEC-RAS recommend a combination of hydrological (IDF, discharge) and hydraulic (HEC-RAS) analysis in order for evidence-based drainage design to address the issue of infrastructure capacity and safety. (Handoko et al., 2022) (Muhammad et al., 2021) (Efendi, 2021) (Fairizi, 2015)

RESEARCH METHODOLOGY

Data and Characteristics of Catchment Areas: Daily rainfall data were obtained from Cimulu, Cikunten II, and Kawalu rain stations (2007–2019). The average annual rainfall of the area is calculated by the arithmetic method of the three stations. The total area of the water catchment area (DTA) of the Mahroja Commercial Center area is 18.8 ha. The planned location is built on an area of 0.66 ha, where runoff is directed to the Cibadodon tertiary channel in the north of the complex. The topography survey of Menun – show the highest elevation of 388 meters above sea level and the lowest of 386.25 meters above sea level.

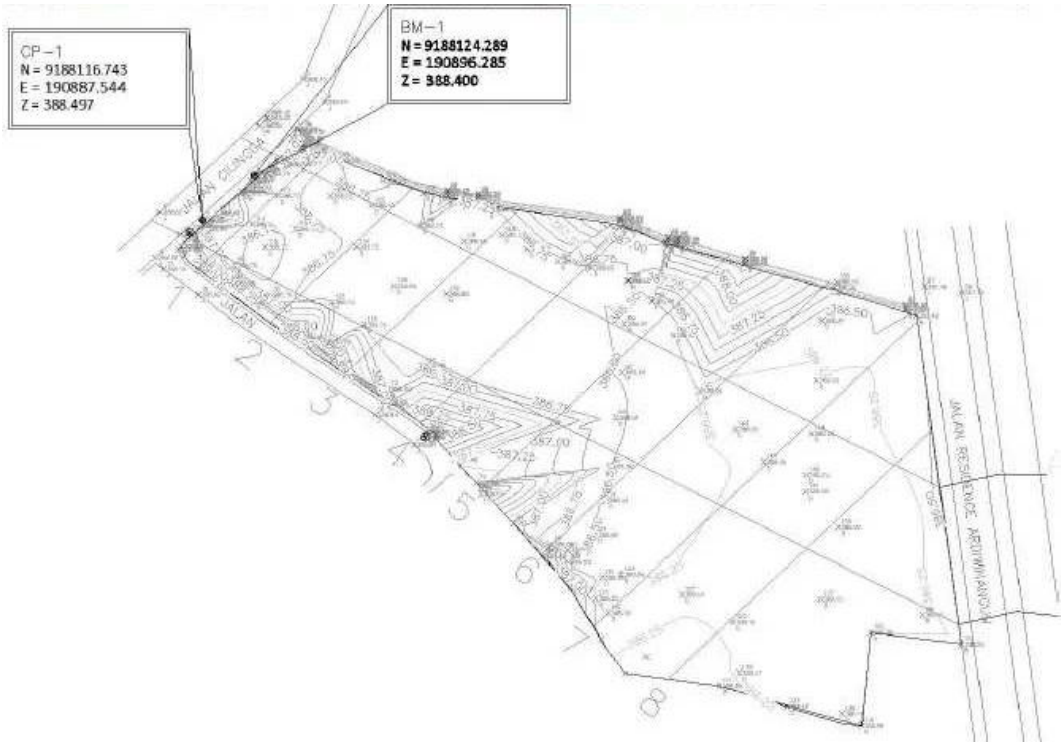

Figure 3. Map of the Contours of Mahroja Commercial Center.

The rainfall frequency analysis was calculated with the annual maximum rainfall frequency distribution tested with three statistical models: Gumbel, Log – Normal, and Log – Pearson Type III. Statistical parameters (mean, standard deviation, skewness, kurtosis) were calculated in advance from 13 years of data. Results: average maximum rainfall = 97.34 mm/day, σ = 18.59 mm/day, Cs coefficient of precipitation ≈0.255, Ck kurtosis ≈3.158 (indicating a rather heavy distribution – tail). These values are used to determine the coefficient of F in the Gumbel distribution equation or to obtain the logarithm of rainfall values (Log – Normal and Log – Pearson). Thus a table of planned rainfall prediction for the Tr re-period (2, 5, 10, 25, 50 years) for each model is obtained. (Fairizi, 2015) (Handoko et al., 2022)

The distribution match test is calculated with the suitability of each distribution tested by the chi-squared test (α = 5%). The data is grouped into classes according to the cumulative percentage, and then the statistics χ^2 ($\Sigma(O–E)^2/E$) are calculated. The calculation results showed a value of χ^2 calculated ≈13.00 with a degree of freedom of 2, greater than the critical limit of 5.991. This means that the Log-Pearson Type III model proved to be the most suitable for this data (the χ^2calculated value meets the acceptance criteria). Meanwhile, the Kolmogorov–Smirnov test can also be used for cumulative curve validation (although no details are elaborated here). Based on this evaluation, the distribution of Log – Pearson Type III was chosen as the basis of the planned rain curve. (Collins et al., 2021) (Agustama Maha & Lukman, 2020) (Garcia et al., 2022)

This method is appropriate because the catchment area is relatively small (18.8 ha) and the watering time is short. Namely for: (Mazzetto, 2025)

C ≈ 0.5

A = 0.0188 km²

I ≈ 18.8 mm/h (1 h, Tr = 25), obtained design peak discharge

Q ≈ 0.49 m³/s per specific location.

The determination of rainfall intensity was calculated with the planned rainfall for Tr=25 years of ~159.3 mm (Log – Pearson) used as a 24-hour rainfall reference. To get the peak intensity, an IDF (Intensity–Duration–Frequency) curve is created from the statistical data. The IDF curve shows that the highest intensity of rain occurs in short durations (the IDF curve decreases with increasing duration). That is:, for Tr = 25 years the intensity of about 18.83 mm/h was obtained for a duration of 1 hour (data calculated separately). The intensity data according to the duration of each Tr is then compiled as a time-series input to the EPA SWMM model. (Efendi, 2021) (Putri et al., 2025) (Farido et al., 2024)

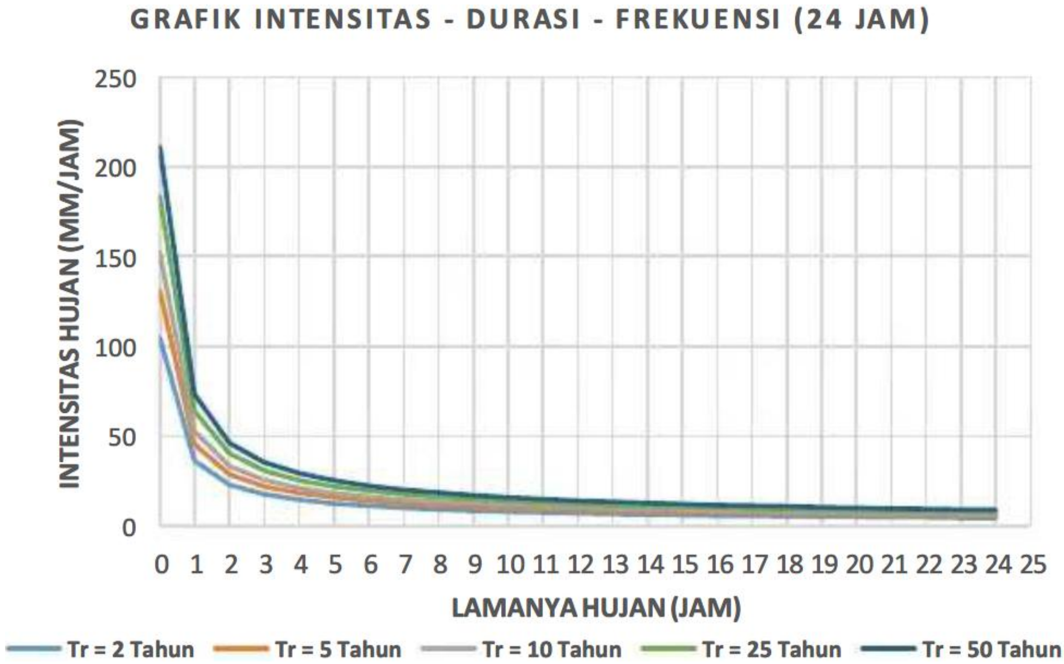

Figure 4. Intensity – Duration – Frequency Graph of Tasikmalaya Rains.

All channels in this study were planned as closed channels in square shape: the channels inside the Mahroja Commercial Center complex are 60 cm × 60 cm, while the Cibadodon tertiary channels are 80 cm × 100 cm in size. Assuming the base slope is standard and Manning's roughness is reasonable, the channel capacity is calculated.

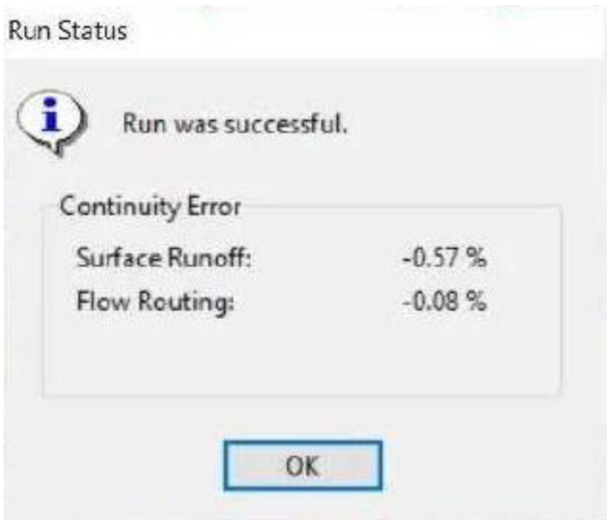

Figure 5. Value *Contiunity Error* After Run.

Hydraulic modeling (EPA SWMM) is calculated for hydrodynamic simulation and channel capacity evaluation, using EPA SWMM 5.1 software. The model included the parameters of the

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planned rainfall (Tr = 25 years), impervious areas and their C-(the results of surveys of rice fields, settlements, markets, roads; the combination resulted in runoff of the entire area). The drainage network is described according to the siteplan (60 cm square × 60 cm and 80 cm × 100 cm), with the inlet elevation according to the results of the field survey. The SWMM simulation presents the peak runoff discharge for each segment of the planned line. The results of the model verification show a very low continuity error (<1%), so the simulation results can be considered valid. (National Standards Agency, 2012) (National Standards Agency, 2017) (Wahyuni et al., 2024)

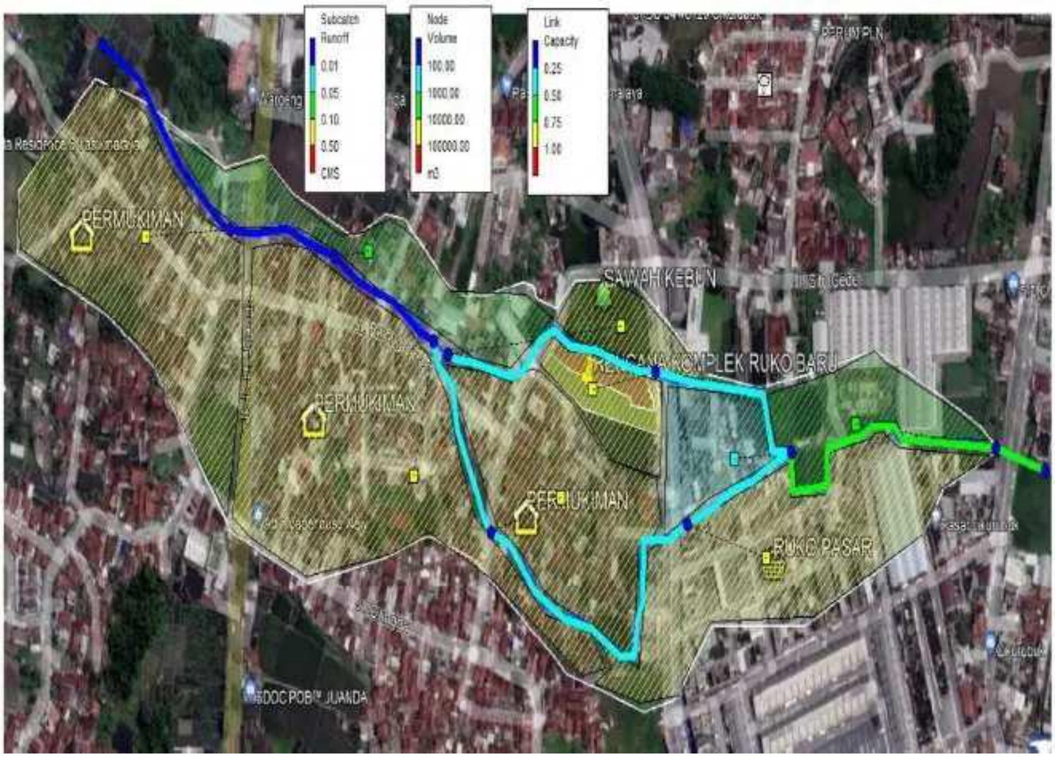

Figure 6. Analysis of the Capacity of Mahroja Commercial Center Drainage Channels with a 25-Year Rainy Renewal Period.

Average Rainfall and Basic Statistics: Based on Table 4.1 (arithmetic method), the average annual rainfall in the Mahroja Commercial Center area ranged from 71–132 mm during 2007–2019. The average annual maximum rainfall (peak) is 97.34 mm/day with a standard deviation of 18.59 mm. Coefficient of variation

$$(\sigma / \bar{X})$$

Around 0.191, positive skewness 0.255 and kurtosis 3.158, indicate a rather heavy distribution – tail.

Planned Rainfall Prediction: From the distribution analysis, the planned rainfall (PUH) is obtained as follows for Tr 25 years:

Normal Distribution : 124.480 mm,

Gumbel : 137.737 mm,

Log – Pearson III : 159.332 mm,

Log – Normal : 97.459 mm (almost the same as the average, not significantly increased).

The differences between these methods are overcome by goodness – of – fit testing. The chi-squared test showed that the Log-Pearson Type III model best matched the data (chi-squared value statistically met the acceptance criteria). Therefore, the planned rainfall for the next hydrological calculation is taken from the Log-Pearson III distribution (i.e.: 159.33 mm for 25 years, 168.56 mm for 50 years). (Arnowo, 2023) (Suraswat et al., 2023)

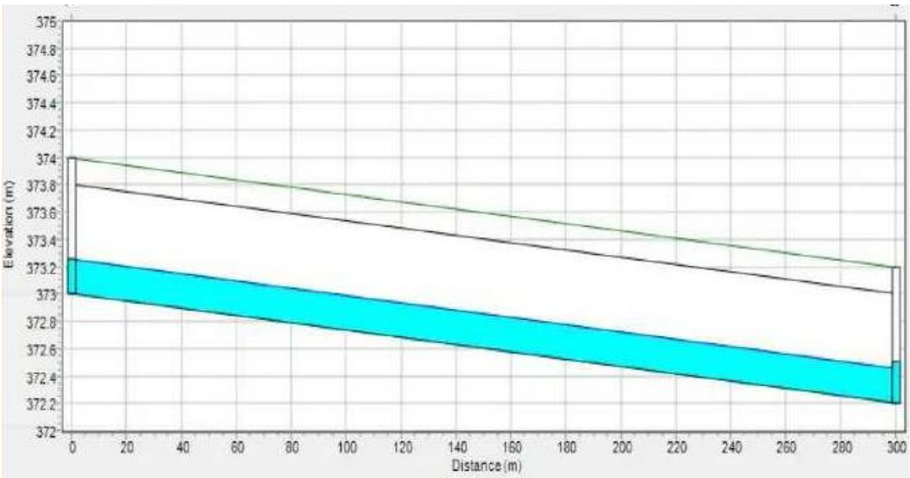

Figure 7. Water Depth in the Cibadodon Tertiary Channel in the 25 Tahu Rain Repeat Period

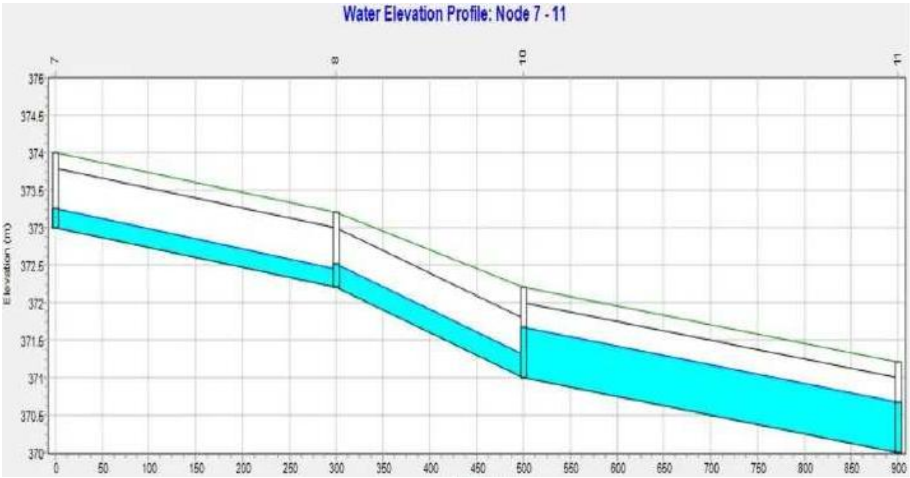

Figure 8. Longitudinal Profile of Channels C7 – C8 – C9 (Cibadodon Tertiary Channel)

The planned flood discharge is produced with a rainfall intensity value according to the IDF (i.e.: around 18.8 mm/h for a duration of 1 hour, Tr = 25) and a DTA area of 18.8 ha, a rational calculation gives the peak planned flood discharge of around a few hundred liters per second per small outlet. The SWMM simulation then contains all runoff in the entire area. Table 4.15 contains the results of the peak discharge simulation (m^3/s) for each planned channel. Important result: the channel at point C8 (near the shopping complex) handles Q = 0.877 m^3/s with a speed of ~2.67 m/s and a depth of ~0.43 m. The capacity of the 80 cm × 100 cm square channel is 2.3196 m^3/s (Table 4.15).

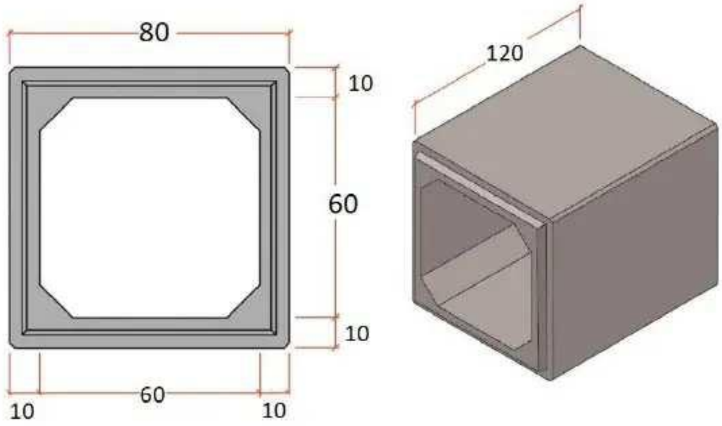

Figure 9. Dimensions of Mahroja Commercial Center Drainage Channels

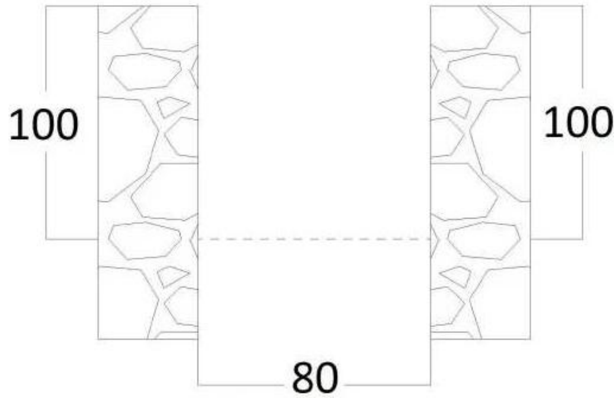

Figure 10. Dimensions of Cibadodo Tertiary Channel

The channel capacity and drainage safety resulting in a capacity analysis showed that the existing planned flood discharge was well below the canal capacity. In the C8 channel, Q = 0.877 m^3/s is only 37.8% of the capacity of 2.3196 m^3/s. The largest discharge occurred in the C10 channel (Cibadodon's tertiary main channel) of 2,496 m^3/s, which is still only 59.3% of the capacity of 4,2057 m^3/s. Thus, no sexiest point was found that exceeded the channel's capacity (did not overflow) in 25 years of rainy conditions. The flood level analysis concluded that the Mahroja Commercial Center area was safe from flooding for 25 years, especially since the floor elevation of the building was about 30 cm above the road face.

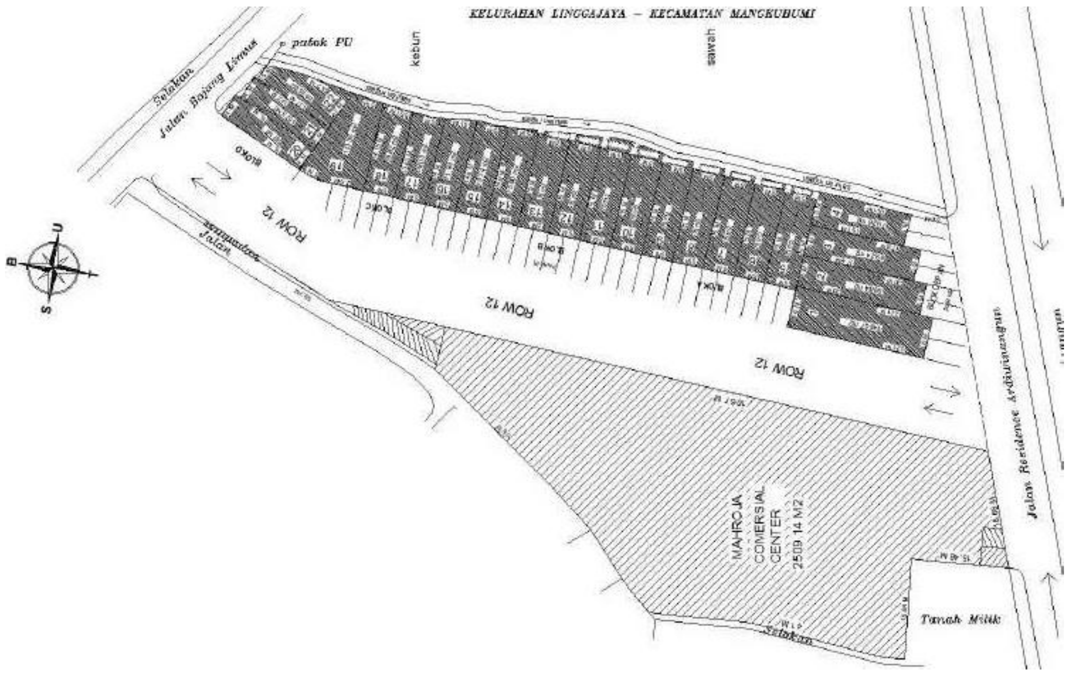

Figure 11. Site Plan Mahroja Commercial Center Tasikmalaya

DISCUSSION AND DISCUSSION

The results of this study provide a quantitative picture of the potential for flooding in the Cimulu River Sub-Watershed, especially in the Mahroja Commercial Center area, Tasikmalaya City. Hydrological analysis shows that the planned rainfall for the 25-year re-period reaches about 159 mm, reflecting the high potential for extreme rainfall in the region. This value is consistent with the results of previous flood vulnerability mapping which classified the Cimulu Sub-Watershed as an area with a high level of vulnerability.

Rainfall frequency analysis shows that the Log-Pearson Type III distribution is the most appropriate distribution based on the results of statistical tests (conformity tests), so it is suitable for use as a basis for determining rainfall design. The findings are in line with common practice in hydrological studies in Indonesia, where Type III Log-Pearson distributions are often used to analyze extreme rainfall and flood data. Furthermore, the calculation of the planned flood discharge using the Rational Method is considered relevant because the area of catchment in the study area is relatively small to medium and the character of the stream is dominated by surface runoff.

Hydraulic evaluation of the dimensions of the existing channel showed that the square-shaped channel with a size of 60 × 60 cm in the environmental (secondary) channel and 80 × 100 cm in the tertiary channel was still capable of accommodating the planned discharge. The capacity utilization rate of the line is below 60%, which indicates that theoretically its hydraulic capacity is still sufficient for a re-run period of up to 25 years. However, this level of safety is conditional as it only applies to the planned rain scenario and assumes the condition of the channel is clean and functioning optimally.

Non-technical factors such as sedimentation, waste, narrowing of cross-sections, land use changes that increase the watertight surface area, and indications of increased rainfall intensity due to climate change have the potential to significantly reduce the reliability level of drainage systems. Therefore, even though the capacity of the channel is still adequate by design, the risk of inundation still exists if the maintenance and control aspects of spatial planning are not carried out consistently.

In the context of flood mitigation in the Cimulu Sub-Watershed, the results of this study provide a clear technical basis for decision-making. Channel segments that show near-60% capacity utilization rates need to be designated as critical points that require regular monitoring and maintenance priority. In addition, the construction of additional infrastructure such as infiltration wells, biopores, and environmental-scale retention ponds is recommended as a measure to control source runoff. The integration of drainage planning with GIS-based hydrological and spatial modeling systems, such as approaches that use a combination of HEC-HMS and digital mapping, can improve flood mitigation capabilities and support the development of early warning systems.

More broadly, flood mitigation efforts in the Cimulu Sub-Watershed need to be directed at an integrated approach between increasing the capacity of the Cimulu River canal, soil and vegetation conservation in the upstream area, and controlling land use. The findings of flood vulnerability supported by hydrological data in this study confirm that structural solutions alone are not enough, but must be combined with sustainable watershed management.

CONCLUSION

The results of the hydrological and hydraulic analysis showed that the best precipitation frequency curve followed the Type III Log-Pearson distribution, with the planned rainfall for the 25-year re-period ≈ 159 mm. From the IDF curve compiled, the rainfall intensity for a duration of 1 hour and Tr = 25 years ≈ 18.8 mm/h, while the area of the effective catchment area (DTA) analyzed was 18.8 ha. Initial calculations using the Rational Method produced a peak discharge per outlet on the order of a few hundred liters/second, and the simulation integrated with SWMM produced a hydrograph of the entire area for each channel. The results of the peak simulation are listed in Table 4.15; A representative example is the C8 point channel (near the shopping complex) with Q = 0.877 m^3/s, a ≈ speed of 2.67 m/s, and a flow depth of ≈ 0.43 m.

Capacity evaluation based on a comparison between the simulated peak discharge and the installed line capacity showed an adequate margin of safety for the 25-year scenario. The capacity of 80 square channels × 100 cm was recorded at 2.3196 m^3/s, so that the utilization rate at point C8 was only 37.8% (0.877/2.3196). The largest peak discharge was identified in channel C10 of 2,496 m^3/s, which is 59.3% of the channel capacity of 4,2057 m^3/s. In all segments analyzed, no overtopping conditions were found in the 25-year rainy scenario, and the flood level analysis placed the inundation surface below the floor elevation of the building which is generally ≈ 30 cm above the road face—indicating that, hydraulically, the Mahroja Commercial Center area is safe from a 25-year rainy event under conditions where the model assumptions are met.

However, this "safe for Tr = 25 years" finding is conditional. The simulation assumes that the channel is free of blockages, cross-sections according to field-data, land use conditions such as when data are collected, and does not take into account future increases in rainfall intensity due to climate change. The risk of residue remains in the event of blockages (sediment/garbage), narrowing of cross-sections, changes in land use that increase the watertight area, or in the event of rainfall with a recurrence period more extreme than 25 years. Therefore, safety claims only apply to the scenario being analyzed and must be supplemented by operational actions and policy remedies.

Based on these results and limitations, logical and priority technical recommendations are: (1) establish a routine maintenance program (line cleaning and critical point inspection—especially segments close to 60% utilization such as C10), (2) install and operate runoff reduction solutions downstream and upstream (infiltration wells/biopores, environmental-scale retention ponds) to reduce discharge peaks, (3) consider additional studies with conservative scenarios (e.g. Tr = 50 years and climate change projections) as well as sensitivity analysis to blockages, and (4) integrating these results into land use plans and model-based early warning systems. With these measures, the hydraulic safety indicated by the results of this study can be maintained and improved into a more durable mitigation solution.

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