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DRAINAGE ANALYSIS AND PLANNING IN FLOOD PREVENTION EFFORTS IN GRAND MADANI MOJOKERTO HOUSING

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ABSTRACT

This study analyzes flood levels for the 2025 re-period in the Grand Madani Housing area, Gunung Gedangan Village, Mojokerto City. The study includes hydrological and hydraulic analysis using 10 years of rainfall data (2014 – 2023) from Mojosari Station, topographic analysis (Sungai Sadar watershed) and soil type (Sub – Sadar watershed), as well as drainage design based on the Rational method, HEC – RAS,. The rainfall distribution was tested using the Log Normal, Pearson Log Type III, and Gumbel methods, and tested for compatibility with the chi-square test. The results showed that the distribution of Pearson Log Type III was most consistent with the data (kurtosis statistical value $\gamma k = 3.247$). The planned rainfall for T = 2 years is 165.7 mm, and T = 100 years is 329.3 mm (Normal Log), which is used to calculate the rainfall intensity (Talbot, Ishiguro, Sherman method) and the planned flood discharge by the Rational method ($Q = 0.278 \cdot C \cdot Cs \cdot I \cdot A$). The planned flood discharge obtained is 9,399 m³/s, greater than the existing channel capacity of 8,053 m³/s, so channel replanning is required. Hydraulic simulations using HEC – RAS 5.1 showed that the proposed drainage design (30 cm × 40 cm cover box) was able to accommodate the design rainfall (25-year re-period) without overflow. The study contributes to residential flood mitigation through the calculation of adequate plan discharge and drainage design recommendations, as well as the use of hydrodynamic models to ensure the performance of the channel to the standard.
Keywords: Analysis, Drainage, HEC – RAS, Rain, Flood Prevention, Housing.

INTRODUCTION

Mojokerto City is located in the lowlands of East Java, where most of the Sub-Watershed area of the Sadar River has a low slope slope (< 8%) reaching 83% of the total area. The sloping topography and crumb-textured Regosol/Litosol soil types facilitate surface runoff during heavy rains. Grand Madani Housing stands in Magersari Village in the Sungai Sadar area, which if not supported by adequate drainage can be vulnerable to flooding. Therefore, hydrological and hydraulic analyses need to be carried out to determine the planned flood discharge and design drainage channels that are safe for housing. The methods used include statistical analysis of rainfall (probability distribution), calculation of rainfall intensity, hydrological modeling (Rational method), and hydraulic simulation (HEC – RAS, HEC – RAS) to assess existing drainage capacity and design. This study aims to produce data on planned rainfall, planned flood discharge, and drainage channel design recommendations that can mitigate flood risk in the residential area. (Cahyono, Kurniawan, et al., 2025) (Muhammad et al., 2021)

Figure 1. Research Location.

The location of the study is Grand Madani Housing, Gunung Gedangan Village, Mojokerto City, which is located upstream of the Sungai Sadar Sub-watershed. Monthly rainfall data for the 2014 – 2023 period was obtained from the Mojosari Climatology Observation Station, Mojokerto. The average annual rainfall for the last 10 years is 172.2 mm with annual variations (data processed). The topography of the Sub-watershed of Sungai Sadar is mostly (89.71 km²) at an elevation of 0 – 100 m above sea level, with a peak of 3,150 m above sea level. Slope analysis shows that 83.0% of the area is plain/sloping land (0 – 8%). The soil types in the region are generally Regosol and Litosol with a crumbly texture, which affects infiltration and runoff coefficients. In addition, river discharge data was obtained from AWLR observations at Sadar Stations (2017 – 2023) for preliminary studies.

Figure 2. Mojokerto Watershed.

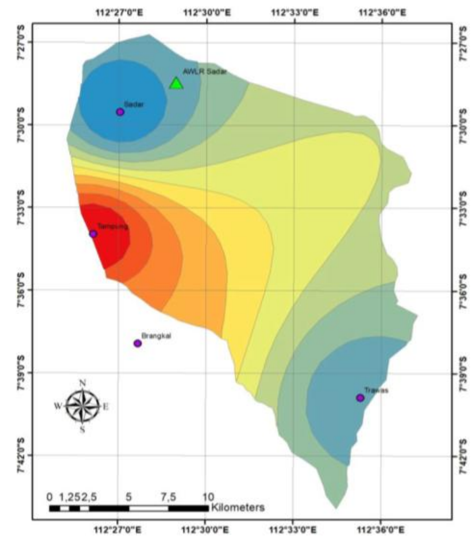

Figure 3. Maximum Rainfall Map of Mojokerto Watershed.

LITERATURE REVIEW

2.1. Rainfall Intensity

Rainfall intensity is defined as the amount of rainfall per given unit of time, which indicates the degree of rainfall intensity (e.g. mm/hour) over a given duration range. In general, the shorter the duration of rain, the higher the intensity, and conversely the longer the duration of rain, the smaller the intensity. The determination of the planned intensity (maximum) often refers to the IDF (intensity-duration-frequency) curve or the empirical equation. For example, according to SNI 2415:2016, the Mononobe equation can be used as follows: (Khomsiati et al., 2025) (Cahyono, Arifin, et al., 2025)

$$I = R24 / 24 \, x \, (24 / tc)^{2/3}$$

With R24 is the annual maximum daily rainfall for a given re-enactment period and tc is the concentration time (hours). This formula takes advantage of the annual maximum daily rainfall data and converts it into the average intensity at the duration of the time tc. The rainfall intensity value (I) obtained is then used in further hydrological analysis, such as runoff discharge calculations. (Cahyono, Saefudin, et al., 2025)

2.2. Debit Plan

The plan discharge is the peak flow discharge calculated for a certain re-release period (e.g. 10 or 25 years) and is used as a reference in channel/drainage planning. By definition, a plan discharge is the amount of flow that will flow through the drainage system based on a predetermined re-period. One of the common methods of calculating plan discharge is the rational method, which is with the formula: (Cahyono, Arifin, et al., 2025) (Muhammad et al., 2021)

$$Qp = C \, x I \, x A$$

In consistent units (e.g. m³/sec if I is expressed mm/h, A in ha, C unitless). Here I is the intensity of rain at the time of concentration (mm/h), A the area of the catchment (ha), and C the runoff coefficient. The runoff coefficient C describes the proportion of rain that becomes a surface stream: C is close to 0 if the soil is well infiltrated (most of the rain is seeping in) and C is close to 1 if almost all of the rain becomes runoff. For example, a value of C = 0 means that all rain is infiltrated, while C = 1 means that all rain becomes runoff. The soil conditions in the study area (crumb-textured Regosol and Litosol) tend to favor a relatively high infiltration capacity, so the runoff coefficient tends to be smaller. Thus, if the intensity of rain exceeds the infiltration capacity of the soil, the rest of the rain will be surface runoff according to the value of C. Plan discharge calculations often refer to national standards (e.g. SNI 03-2415:1991 and SNI 2415:2016) and other empirical methods, but the basic principle is the relationship between planned rainfall, catchment area characteristics (area, slope, land use), and land characteristics (infiltration capability). (Efendi, 2021) (Fairizi, 2015) (Collins et al., 2021) (Garcia et al., 2022)

2.3. Flow Modeling with HECRAS

HEC-RAS (Hydrologic Engineering Center's River Analysis System) is software developed by the U.S. Army Corps of Engineers for hydraulic analysis of rivers and open channels. HEC-RAS is able to calculate one-dimensional flow (steady flow) and one- and two-dimensional non-constant flow (unsteady flow), and is equipped with sediment transport modules and water quality modeling. With an interactive graphical interface, HEC-RAS allows designers and researchers to input channel geometry, cross-section profiles, boundary conditions, as well as define inflows (e.g. planned flood discharge) to then simulate the distribution of water levels and flow velocities along rivers or channels. In Indonesia, HEC-RAS is often used to model inundation and flow in open channels as a step to validate drainage design or flood studies. For example, the input of channel geometry and runoff discharge from hydrological calculations can be used as HEC-RAS inputs to check the depth and area of inundation as well as channel capacity in flood conditions. HEC-RAS also provides inundation mapping facilities (HEC-RAS Mapper) and channel design features (e.g. channel stability analysis) so that the simulation results can be analyzed quantitatively and qualitatively in the water field. The most widely used versions of HEC-RAS are the 5.x and 6.x generations, which are constantly updated by HEC to support advanced hydrodynamic simulations. (Fairizi, 2015) (Muhammad et al., 2021) (Collins et al., 2021) (Khomsiati et al., 2025) (Agustama Maha & Lukman, 2020)

RESEARCH METHODOLOGY

3.1. Rainfall Analysis with Probability Distribution and Match Test

The analysis of the annual rainfall distribution aims to determine the daily maximum rainfall with a specific repetition period. The three distributions tested were Log Normal, Pearson Log Type III, and Gumbel. Statistical parameters (logarithmic mean, standard deviation, coefficient of variation, skewness, kurtosis) are calculated from 10 annual data of maximum rainfall. Based on the statistical criteria of the distribution (skewness and kurtosis requirements), only the Type III Pearson Log method met ($\gamma k \approx 3.247$ met the criteria). Next, a goodness – of – fit chi – square test was performed for the distribution of Pearson III Logs. The results of the chi–square test (value χ^2 – hit = 3.7 with a degree of freedom of 1) are smaller than χ^2 – table = 9.487 ($\alpha = 0.05$), so the distribution of Pearson Log III is accepted as a representation of the rainfall distribution. (Muhammad et al., 2021) (Cahyono, Saefudin, et al., 2025) (Fairizi, 2015) (Handoko et al., 2022)

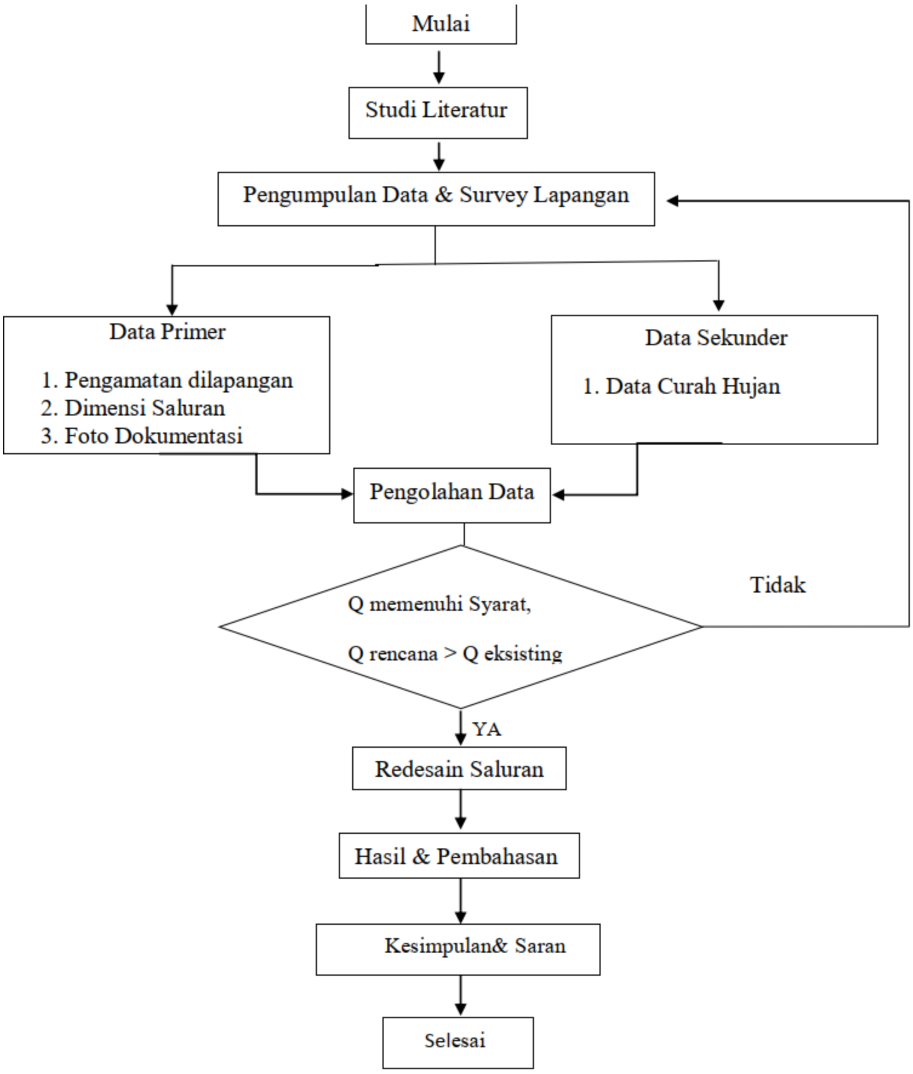

Figure 4. Flood Analysis Flow Chart.

3.2. Rain Intensity and Discharge Plan

From the selected distribution, the amount of planned rainfall for the re-period (e.g. T = 2, 5, 10, 25, 50, 100 years) is calculated with the equation of the standard normal curve (Gauss K value). For example, for T = 2 years a rainfall of 165.7 mm was obtained. Furthermore, the intensity of rain (mm/minute or mm/h) for short durations (minutes – hours) is calculated using the Talbot, Ishiguro, and Sherman methods, which relate the duration of rain to intensity (example calculation in the Intensity Duration Table). From the intensity-duration (GID) graph compared to the three intensity methods, the coefficients used to calculate the flood discharge are shown. (Collins et al., 2021) (Agustama Maha & Lukman, 2020)

Table 1. Monthly Rainfall Data for Mojokerto City for the 2014 – 2023 Period.

No.	Year	Jan	Feb	March	April	May	June	July	Ags	Sep	Oct	Nov	Some	Sum
1	2014	142	130	174	172	216	100	71	58	24	210	238	166	1701
2	2015	76	332	204	274	293	78	142	1	70	158	105	67	1799
3	2016	149	215	451	106	203	77	109	102	226	151	152	194	2135
4	2017	51	0	39	241	148	87	98	197	48	104	142	207	1361
5	2018	128	91	109	186	166	60	86	0	0	14	186	218	1244
6	2029	131	321	108	245	171	61	58	255	63	92	293	158	1955
7	2020	200	222	145	355	374	296	67	101	155	163	426	164	2667
8	2021	149	206	285	251	316	163	40	108	185	191	534	318	2744
9	2022	203	245	215	349	179	144	10	23	60	195	204	155	1982
10	2023	180	226	182	349	163	144	190	126	251	548	427	287	3072

3.3. Calculation of Flood Discharge Plan

The planned flood discharge is calculated by the Rational Method:

$$Q = 0,278 \cdot C \cdot C$$

$$s \cdot I \cdot A$$

with units I in mm/h, A km². Runoff coefficient C
C for the combined multunite settlement area is taken 0.75 (according to the guideline table). The catch coefficient of Cs (e.g. 0.833) takes into account infiltration. The catchment area is calculated from field data. For example, with (Garcia et al., 2022)

$$Qe = 8,053\ m^3/s$$

(discharge value of existing channels) and

$$C = 0,75$$

$$I = 75,795\ mm/jam$$

(value from GID T = 2 years) obtained A ≈ 0.510 km². For the overall catchment area up to the residential outflow point, A = 75,795 km² (large watershed survey data) was used. With the (Efendi, 2021)

$$C = 0,75$$

$$Cs = 0,833$$

$$I = 0,51$$

mm/min (equivalent to 30.6 mm/h) Obtained planned flood discharge

$$Qr \approx 9,399\ m^3/s$$

Drainage Channel Design and Analysis
The design of the primary drainage channel is assumed to be in the form of a square cross-section (closed channel) with a width of 0.30 m and a height of 0.40 m. The cross-sectional area of the channel = 0.12 m² and a wet circumference of 1.1 m. Based on the difference in elevation of the 300 m long (Δh = 0.13 m), the slope of the So channel is very low. Using the Manning formula, the flow density is estimated to be ~0.40 m/s (based on the table of the density values for So < 1%). The discharge of the existing channel is calculated: (Suraswat et al., 2023)

$$Qs = A \cdot v = 0.12 \times 0.40 = 0.048\ m^3/s$$

This value is smaller than the planned flood discharge of 9,399 m³/s, so the existing channel is unsafe and needs to be widened. Therefore, a redesign of the channel dimensions was carried out. (Arnowo, 2023)

Table 2. Frequency Analysis Results.

Duration (minutes)	Replay Period (mm/min)					
	2	**5**	**10**	**25**	**50**	**100**
5	114,314	200,492	275,654	390,461	489,534	599,388
10	85,557	150,056	206,309	292,235	366,385	448,603
20	59,665	104,645	143,875	203,797	255,507	312,844
30	47,325	83,002	114,119	161,648	202,664	248,142
40	39,873	69,933	96,149	136,195	170,752	209,069
60	31,071	54,494	74,923	106,128	133,056	162,914
80	25,907	45,438	62,471	88,490	110,943	135,839
120	19,940	34,972	48,083	68,109	85,391	104,553

Furthermore, hydraulic modeling was carried out using HEC – RAS (version 5.x) for steady flow. The geometry of the channel (cross – section) and slope is input according to field conditions. The value of steady flow input discharge is (Wahyuni et al., 2024)

$$Q = 9{,}399\ m^3/s$$

included in Upstream Reach. The downstream boundary condition is assumed to be normal depth. The simulation produces a water level profile of the channel and checks the depth of flow against the elevation of the channel. (Sutaryono et al., 2021)

3.4. Residential Drainage Analysis with HEC – RAS

For the housing scale, a simulation of the drainage network was carried out using HEC – RAS. The model includes a 6-hour rain intensity for a 25-year re-period, a residential catchment area of 0.510 km², as well as a network of collectors and inlets according to the site plan (U – Ditch channels 30 cm × 40 cm).

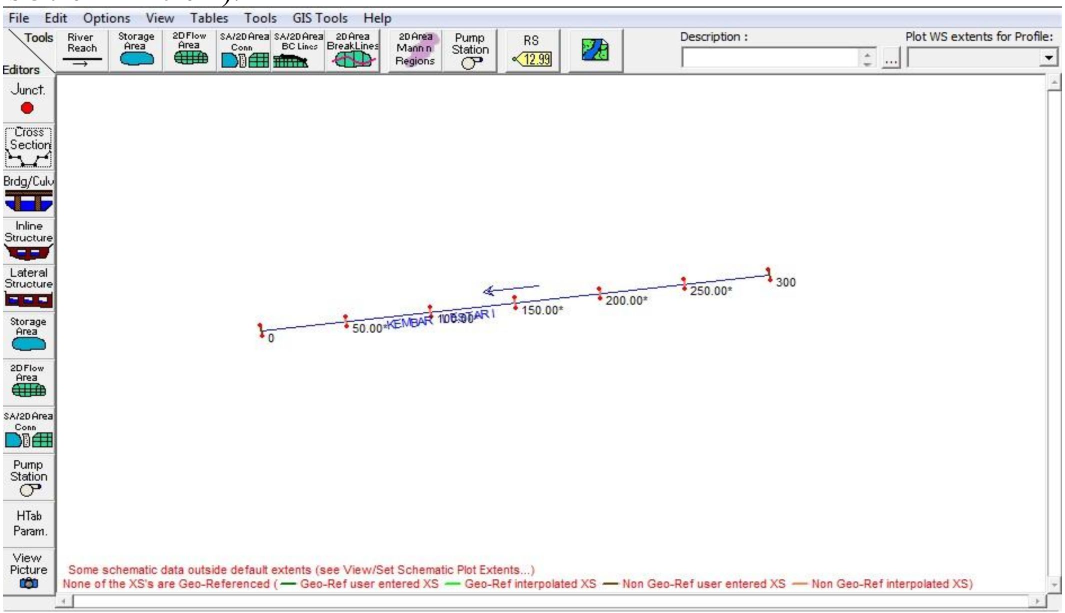

Figure 5. River Channel Scheme.

The results of the steady flow simulation show a continuity error < 1%, indicating a valid model. The visual output (simulated map) shows most of the channels with the flow stored in capacity (blue – green color), while the problematic channels are marked yellow – red (overflow). From the simulation, the maximum runoff discharge per channel and the depth of water at critical points were obtained. (Efendi, 2021)

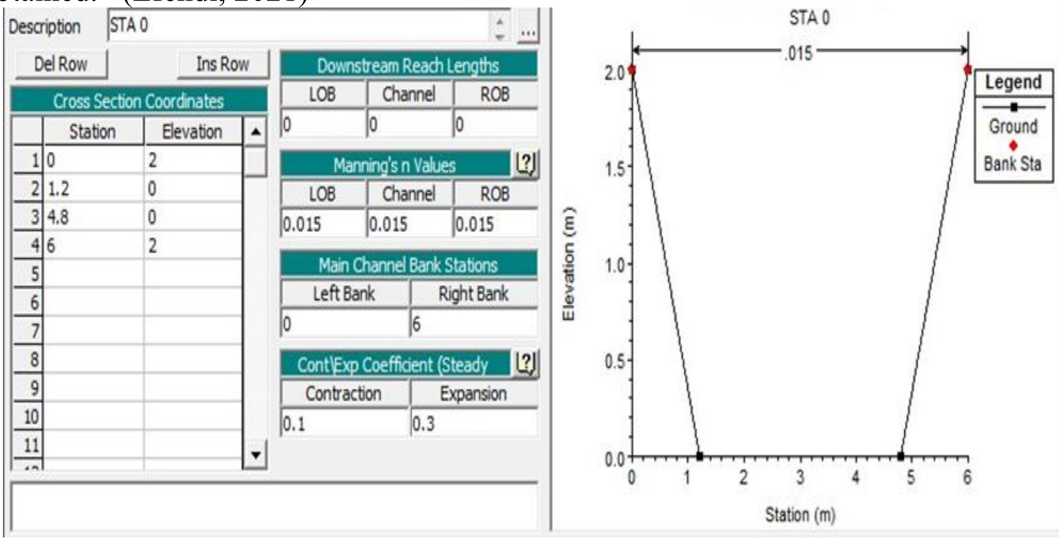

Figure 6. The screen editor looks latitude after being rated for STA 0 + 000.

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DISCUSSION AND DISCUSSION

Distribution and Discharge Plan. Rainfall data from 2014 – 2023 have been processed to determine the distribution of the t. The Normal Log dispersivity analysis table (skewness $\gamma_3 = -0.111$, kurtosis $\gamma k = -$) shows the distribution condition is not met. In contrast, the distribution of Pearson Type III Logs met the criteria ($\gamma_3 = -0.111$, $\gamma k = 3.247$). The results of the chi-square test for LP3 state

$$\chi \, hitung\, 2 = 3.7 < \chi \, tabel\, 2 \; (9,487)$$

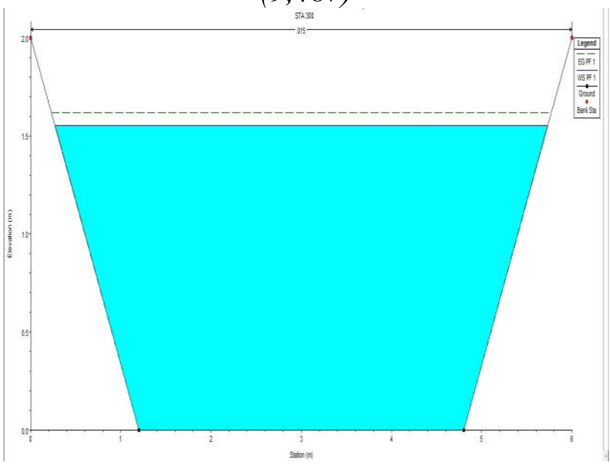

Figure 7. STA Cross Section Display 0+300.

so that the distribution is accepted. Based on the LP3 curve, the daily rainfall is planned:

T = 2 years = 165,7 mm
T = 5 years = 212,2 mm
T = 10 years = 241.6 mm
T = 25 years = 274.3 mm
T = 50 years = 303.2 mm
T = 100 years = 329.3 mm

With the intensity of rainfall of the 2-year re-period (I ≈ 75.795 mm/h for a duration of 1 hour) and a catchment area of 75.795 km², the flood discharge of the Rational method plan is calculated.

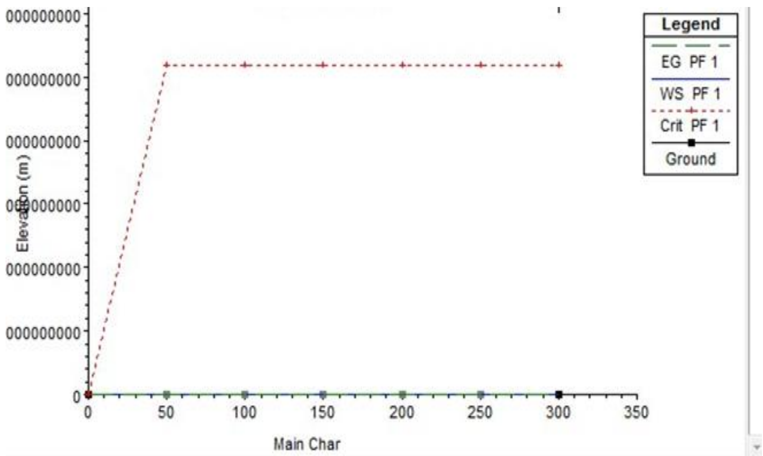

Figure 8. Results of Water Level Profile Calculation in Snjang Sungai.

$$Qr = 0.278 \times 0.75 \times 0.833 \times 75.795 \times 0.51 = 9.399 \; m^3/s$$

This discharge far exceeds the capacity of the existing channel

A = 0.12 m²

v ≈ 0.40 m/s,
Qs ≈ 8,053 m³/s
Channel capacity analysis shows

$$Qs < Qr$$

So the current channel is inadequate and requires cross-section expansion. The HEC – RAS simulation shows that the water level of the channel is below the cross-sectional edge at the planned discharge of 9.399 m³/s, so the new cross-section design (adjusted for Qr) is flood-safe. The HEC – RAS analysis revealed a planned flood discharge in the nearest residential area of 0.877 m³/s with a channel capacity of 2,320 m³/s (37.8% of capacity). The maximum discharge on the Sadar River reaches 2,496 m³/s with a canal capacity of 4,2057 m³/s (59.3%). These results show that the residential drainage network is sufficiently resistant to rainfall (no critical overflow occurs), but the concave points need to be monitored for local intensity/discharge. The water depth at the lowest point of the Sadar River basin for 25 years of rain was recorded.

The results of the selected rainfall distribution (Log Pearson Type III) are consistent with the characteristics of the tropical monsoon of Java, where the distribution of rainfall intensity tends to be similar to log – normal type III. The chi-squared test confirms the suitability of the curve. The planned discharge of 9,399 m³/s reflects the need for a larger primary line than the existing dimensions. Geological conditions (Regosol soils) with moderate infiltration and residential area use (impervious) are considered in C and Cs. Results show a high runoff coefficient (C = 0.75), triggering large discharges upstream of the housing.

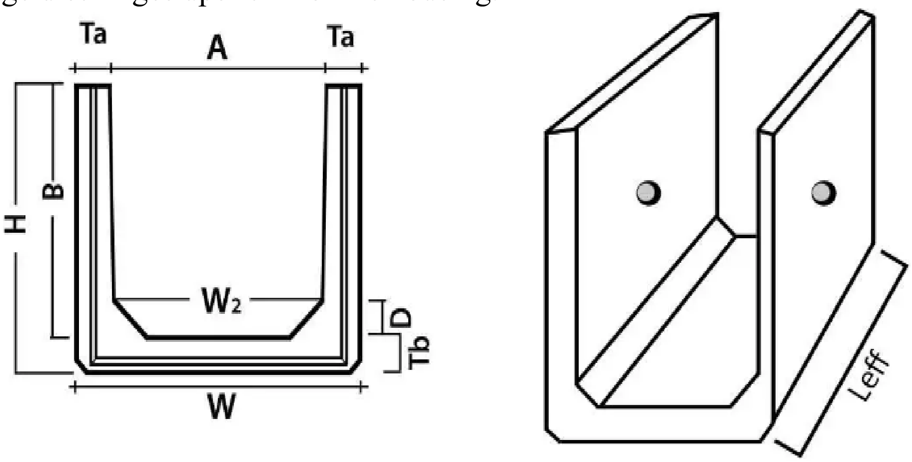

Figure 9. Dimensions of Residential Drainage. U Ditch Width 30 cm and Height 40 cm. Channel Length 120 cm.

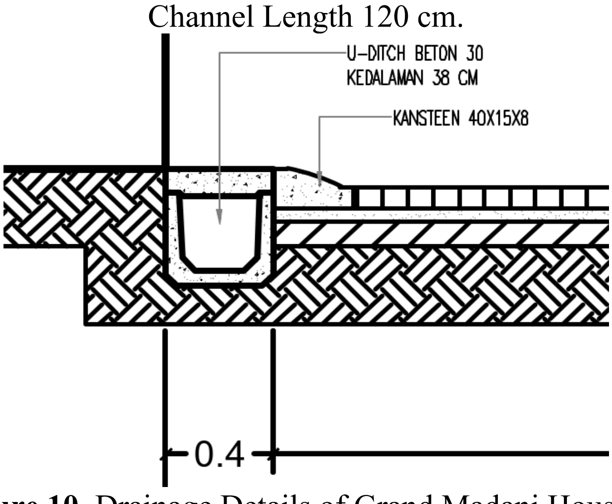

Figure 10. Drainage Details of Grand Madani Housing.

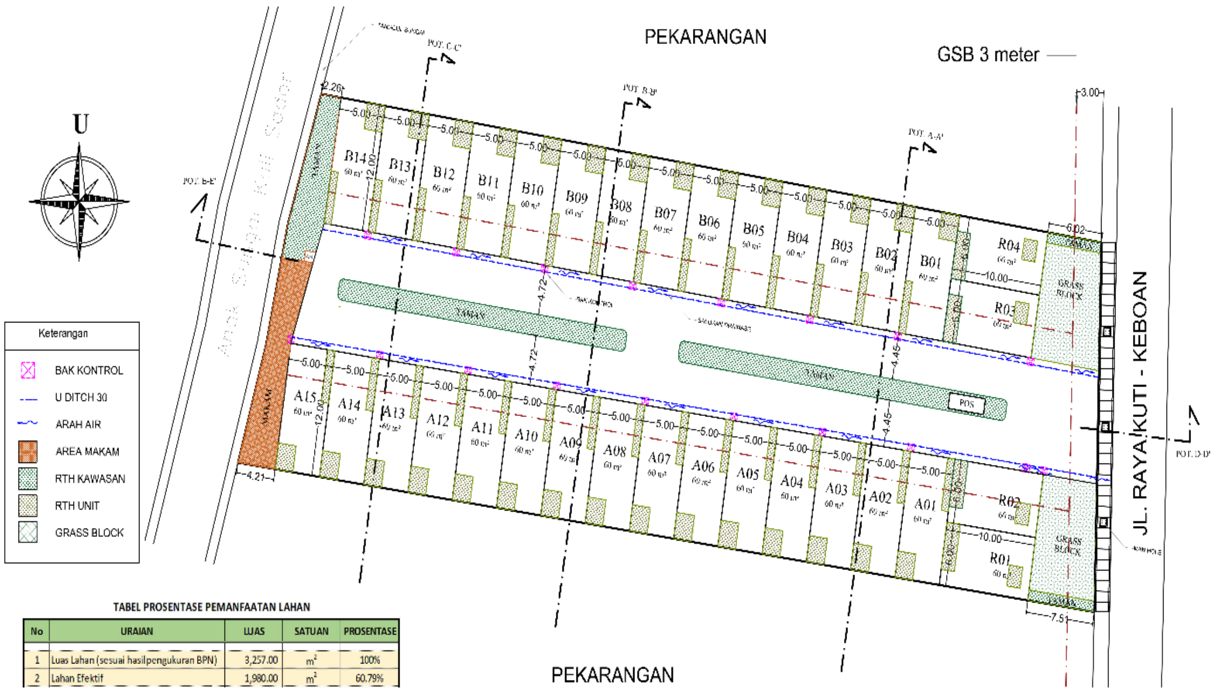

Figure 11. Grand Madani Housing Site Plan.

In drainage studies, the square channel cross-section (30 cm × 40 cm) is currently only safe for a discharge of ~ 8 m³/s. Cross-section expansion, or the addition of a new channel, is recommended to meet Qr. The use of HEC – RAS as design verification is important to ensure that the standard of safe depth is achieved in 25-year flood conditions. The HEC – RAS method provides a local-scale runoff overview of housing with actual network simulations, helping to evaluate the potential flood point (overflow) to the Sadar River channel. For example, the simulation shows most of the channels in a safe state (blue – green) and provides design discharge data for each channel segment.

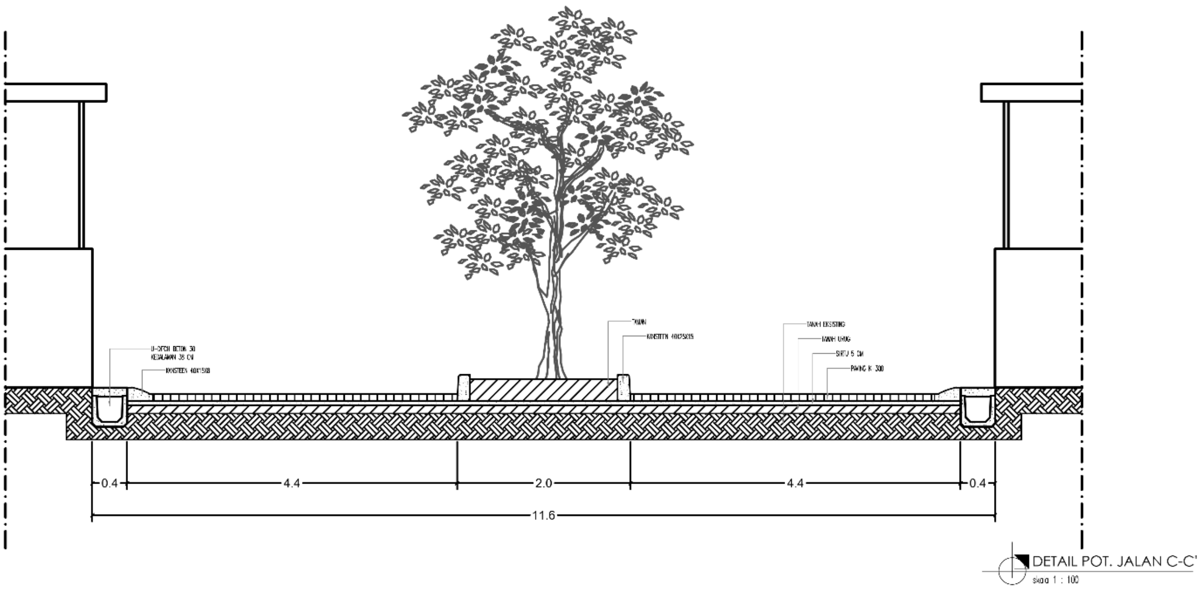

Figure 12. Grand Madani Housing Drainage Plan.

The contribution of this study to residential flood mitigation is: (1) determination of planned flood discharge based on robust rainfall statistical analysis, (2) identification of existing channel capacity shortages and recommendations for new dimensions, (3) the use of the HEC – RAS model to predict water levels, and HEC – RAS for detailed analysis of residential channels. These steps can be used by city governments and housing developers to design flood-resistant drainage systems.

For example, the expansion of the dimensions of the primary channel or the use of additional infiltration wells may be considered. The results of the analysis are also useful for inundation control (drainage silaturahm) and flood risk mitigation at the micro level with a scientific basis.

CONCLUSION

The flood research of the Grand Madani Housing planning project has yielded several conclusions. First, the distribution of Pearson Log Type III rainfall is best suited for Mojokerto data (chi test – passed square). Second, the 2-year planned rainfall of ~165.7 mm (based on distribution) results in the rainfall intensity used for the calculation of the planned discharge. The calculated planned flood discharge (Rational method) of 9,399 m^3/s far exceeds the capacity of the existing channel (8,053 m^3/s). This indicates the need to redesign the primary drainage channel to make it safe. Third, hydraulic simulations (HEC – RAS) confirm that the proposed drainage design can accommodate the design rainfall without critical overflow. Fourth, the results of analysis and calculation for the dimensions of the U Ditch that can be used in the Grand Madani Housing in overcoming the need for drainage storage are the U Ditch Width of 30 cm and Height of 40 cm with a Channel Length of 120 cm. Finally, the study emphasizes the importance of plan discharge calculation and topographic/soil type analysis for flood mitigation. The application of research results in the form of replanning of channel dimensions and improving drainage infrastructure is expected to be effective in reducing flooding in residential areas.

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