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FLOOD POTENTIAL ASSESSMENT OF THE WAY URANG SUB-WATERSHED BASED ON PEAK DISCHARGE USING THE RATIONAL METHOD

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ABSTRACT

Peak discharge is a key indicator for assessing flood potential in a river basin. This study estimates peak discharge in the Way Urang sub-watershed, Pesawaran, Lampung, by integrating remote sensing and Geographic Information Systems (GIS) to derive physical parameters that control surface runoff. The Rational Method was applied, combining the runoff coefficient (C), rainfall intensity (I), and drainage area (A). The runoff coefficient was calculated using the Cook Method, which takes into account soil type, slope gradient, vegetation density, and drainage density. Rainfall intensity was derived from daily records using the Mononobe equation, with time of concentration estimated from the Kirpich formula. Data sources include Sentinel-2 imagery, DEMNAS, rainfall records from 2014 to 2023, and field measurements. The results show a peak discharge of 217.19 m³/s for a basin area of 20.20 km², with a coefficient of variation (C) of 69.20% and an intensity (I) of 55.89 mm/h. High runoff reflects the combined effects of low-infiltration soils, steep slopes, and high annual rainfall. Morphometric measurements yielded a total channel cross-sectional area of 27.91 m² and an estimated bankfull discharge of ~9.53 m³/s, indicating that the channel capacity is far below the peak discharge. This imbalance suggests a high flood potential in downstream areas, particularly in Bunut Village. The findings underscore the importance of integrating spatial data, field surveys, and remote sensing to analyze watershed physical characteristics and to support more effective, spatially informed flood planning and mitigation.

***Keywords**: Peak Discharge; Runoff Coefficient; Remote Sensing; GIS*

A. INTRODUCTION

A watershed is a topographically bounded area that collects precipitation and other water inputs and conveys them through a connected drainage network to a single outlet. Each watershed is separated from adjacent regions by ridgelines and mountain crests that form natural divides (Saidi & Berd, 2013). Effective planning and management of watersheds require a robust understanding of their physical characteristics, because those characteristics regulate infiltration, surface runoff, and streamflow responses to rainfall (Shekar, 2024; Asdak, 2023).

Floods generally occur when streamflow rises well above typical levels due to sustained or intense rainfall in the headwaters or localized parts of the basin, such that runoff exceeds the capacity of existing channels and overtops onto adjacent areas (Direktur Jenderal Rehabilitasi Lahan dan Perhutanan Sosial, 2009). Among hydrologic indicators, peak discharge is especially informative for evaluating flood potential because it encapsulates the basin's integrated response to storm forcing (Kebede et al., 2020).

Recent advances in remote sensing, image processing, and the availability of spatial datasets have substantially improved the analysis of watershed systems (Wu et al., 2019). In particular, the integration of remote sensing with Geographic Information Systems (GIS) enables efficient, semi-automated detection, extraction, and analysis of basin physical characteristics relevant to runoff generation (Dandawate, 2013; Gunawan et al., 2020). Numerous studies have estimated peak discharge by combining remotely sensed inputs with GIS-based spatial analysis of basin properties (Risky et al., 2018). The Rational Method is widely used for small catchments ($\leq$ 50 km^2) because it relates peak discharge to three measurable components: runoff coefficient, rainfall intensity, and drainage area, and is straightforward to implement with spatial data (Hadisutanto, 2010).

Importantly, a high calculated peak discharge does not by itself confirm flooding. To assess flood hazard, the computed peak must be evaluated against the channel's bankfull capacity, derived from field-based morphometric measurements. Exceedance of bankfull capacity is a primary indicator of flood potential (Asdak, 2023). Against this backdrop, the present study aims (i) to estimate peak discharge in the Way Urang sub-watershed using the Rational Method parameterized by GIS-derived basin characteristics, and (ii) to analyze bankfull capacity from field morphometry and compare it with the estimated peak discharge to evaluate flood potential. Anticipating the principal findings, our results indicate that the estimated peak discharge notably exceeds the field-derived bankfull capacity in downstream reaches, implying elevated flood hazard and underscoring the value of integrating spatial data with field surveys to support evidence-based flood mitigation and planning.Berisi tentang latar belakang penelitian, pentingnya penelitian dan tujuan penelitian.

B. METHOD

1. Study Area

The study was conducted in the Way Urang sub-watershed, a tributary of the Way Ratai basin in Pesawaran Regency, Lampung Province (Indonesia). The sub-watershed covers 20.2 km² and spans three villages: Bunut (downstream), Pesawaran Indah and Paya (midstream), and Harapan Jaya (upstream). The study area boundary is shown in Figure 1.

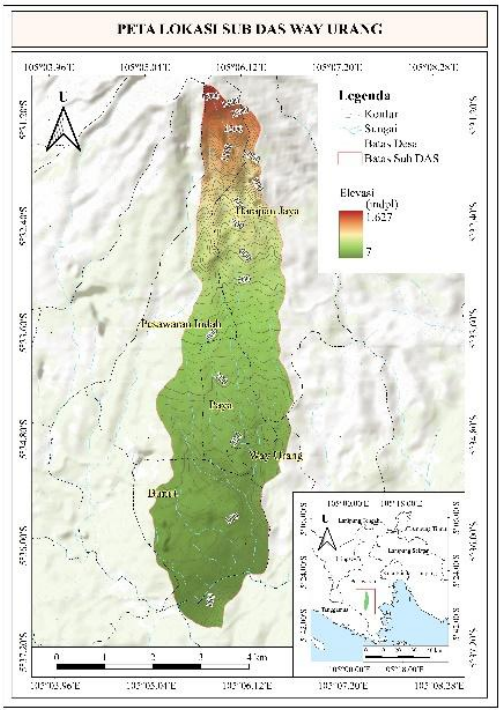

Figure 1. Research Location Map

2. Data Sources

This study utilized Sentinel-2 Level-2A surface reflectance imagery acquired on October 10, 2024 (path 122, row 62) as the primary source for deriving the NDVI vegetation index map. DEMNAS served as the primary elevation dataset to produce slope and drainage-density maps. Secondary data comprised daily rainfall records from the Bunut rain gauge (2014–2023), which were used to compute rainfall intensity and time of concentration. Soil type data (Hydrologic Soil Group, HSG) informed the selection of field sites for infiltration-rate measurements. Watershed boundaries and administrative layers were used to delineate and visualize the study area.

3. Data Analysis

3.1 Deriving Maps of Watershed Physical Characteristics

Slope and channel length were derived from DEMNAS processing. The extracted total channel length was used to compute drainage density, defined as the ratio of total channel length to sub-watershed area:

$$Dd = \frac{L}{A}$$

Where:

Dd : drainage density (mil/mil^2)

L : total channel length (mil)

A : sub-watershed area (mil^2)

The vegetation index (NDVI) map was produced from Sentinel-2 Level-2A imagery. NDVI was computed from the near-infrared (NIR) and red bands as:

$$NDVI = \frac{NIR + Red}{NIR - Red}$$

Field measurements of vegetation density were then conducted at 25 sampling sites distributed across five classes: no vegetation, very low, low, moderate, and high. Each plot measured 20 × 20 m, and 25 vertical fisheye photographs were acquired per plot. Images were analyzed with the Gap Light Analyzer (GLA) to estimate canopy cover. A regression model was developed to relate Sentinel-2 NDVI values to field-measured canopy cover. Because NDVI values in the range −1 to +1 provide only a generalized signal of vegetation, calibration with field data was performed to ensure representativeness of actual conditions. The model was validated using correlation and regression diagnostics, and subsequently applied to classify NDVI into vegetation-density classes. Another factor influencing peak discharge is soil infiltration capacity. Sampling locations were selected with reference to the Hydrologic Soil Group (HSG) classification. Infiltration analyses were conducted at six sites, representing the dominant soil types: dystric alluvial soil, lithic andosol, luvic gleysol, dystric cambisol, eutric cambisol, and lithic cambisol. A double-ring infiltrometer was used to determine the infiltration rate for each soil type.

3.2. Runoff Coefficient Map Construction

Mapping units are the smallest spatial units with relatively homogeneous physical characteristics, serving as the basis for computing the runoff coefficient. These units were produced by overlaying four primary parameters: slope class, vegetation density class, infiltration capacity, and drainage density class. Each parameter was categorized and assigned a score; the scores were then summed to obtain a composite score for each mapping unit. The composite scores were subsequently classified into four surface-runoff classes (Table 1). To get the sub-watershed–scale mean runoff coefficient (C), the coefficient for each mapping unit was multiplied by an area weight (the ratio of the unit's area to the total watershed area). The final coefficient was calculated as an area-weighted mean:

$$C = \frac{\sum_{i=1}^{n} C_i A_i}{\sum_{i=1}^{n} A_i}$$

Where:

C : the runoff coefficient for mapping unit i.

A : the area of unit i.

Table 1. Watershed characteristics influencing surface runoff (Chow, 1998)

Watershed Characteristics	Watershed characteristics that cause surface runoff			
Relief	Rough steep terrain with an average slope generally >30% (40)	Hilly with an average slope between 10-30% (30)	Wavy, with an average slope between 5-10% (20)	Relatively flat land, slope 0-5% (10)
Soil Infiltration (Soil Type)	Rock with a thin soil layer (<2.5 mm/hour) (20)	Clay (2.5-15 mm/hour) (15)	Sandy loam, silty loam, loam, clayey loam (15-28mm/hour) (10)	Sand, loamy sand (>28 mm/hour) (5)
Cover Vegetation	No effective cover crops or the like (0 – 10%) (Low-density) (20)	Little to moderate cover crops, cultivated agriculture, and natural cover of 10-50% (Medium-density vegetation) (15)	50-90% well covered by trees and grass (High-density vegetation) (10)	90-100% well covered by woody plants and the like (Very high-density vegetation) (5)
Surface Storage (Drainage Pattern and Stream Channel Density)	Drainage density >5 miles/mile² (20)	Drainage density 2-5 miles/mile² (15)	Drainage density 1-2 miles/mile² (10)	Drainage density <1 mile/mile² (5)

3.3. Rational Peak Discharge Calculation

Peak discharge was estimated using the Rational formula:

$$Qp = 0{,}278\ CIA$$

Where:

Qp : peak discharge (m^3/s)

C : the runoff coefficient

I : rainfall intensity (mm/hours)

A : the sub-watershed area (km^2)

Rainfall intensity was determined via the time of concentration (Tc) for the basin, defined as the travel time from the hydraulically most distant point (headwaters) to the outlet. Tc was computed with the Kirpich (1940) equation:

$$Tc = 0.0078 \times (L0.77) \times (S-0.385)$$

Where:

Tc : time of concentration (hours)

L : main-channel length (km)

S : channel slope (m)

Rainfall intensity (I) was then derived from daily rainfall using the Mononobe relation (Suripin, 2005):

$$I = \frac{R24}{24} x \left(\frac{24}{Tc}\right)^{\frac{2}{3}}$$

Where:

I : intensitas curah hujan (mm/hours)

R24 : the 24-h maximum rainfall (mm)

Tc : time of concentration (hours)

3.4. River Morphometry Measurements

Morphometric surveys were conducted to estimate channel capacity under near-bankfull conditions. Cross-sectional width was delineated to the bankfull (flood mark) limits, and each section was partitioned into segments; segment widths and depths were measured to compute segmental areas. Total cross-sectional area was obtained by summation:

$$A = A1+A2+A3+\ldots\ldots+An$$

Where:

A : the total cross-sectional area

A1, …, An : are the areas of individual segments

Bankfull discharge was calculated with the Manning equation:

$$Q = A \times \frac{1}{n} \times R^{\frac{2}{3}} \times S^{\frac{1}{2}}$$

Where:

Q : discharge (m^3/s)

n : Manning's roughness coefficient

A : cross-sectional area (m^2)

R : hydraulic radius (m)

S : the energy slope (m/m)

C. RESULTS AND DISCUSSION

The Way Urang sub-watershed in Lampung exhibits varied topography, ranging from flat to undulating (Figure 2). The Way Urang sub-watershed can be divided into three zones based on slope: a Flat Zone (slope < 3%), which is located in the downstream area, particularly around Bunut Village. This zone is a lowland plain formed by sedimentation from the Way Urang River and its tributaries; Undulating Zone (slope 3-15%) this zone is located in the middle section with gently sloping terrain and is generally used for agriculture and settlements; Steep Zone (slope > 15%) this zone is located in the headwaters, especially in the Bukit Barisan Mountains. Very steep slopes characterize this zone. The Way Urang sub-watershed has a drainage density classified as good (Figure 3). The good class ranges from 2–5 mi/mi^2, indicating that the developed drainage network is adequate to convey surface runoff. The drainage density of the Way Urang sub-watershed is 3.5 mi/mi^2.

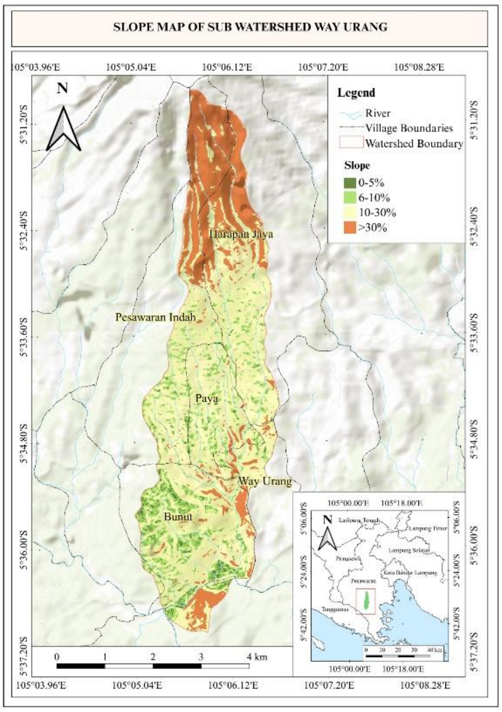

Figure 2. Slope Map

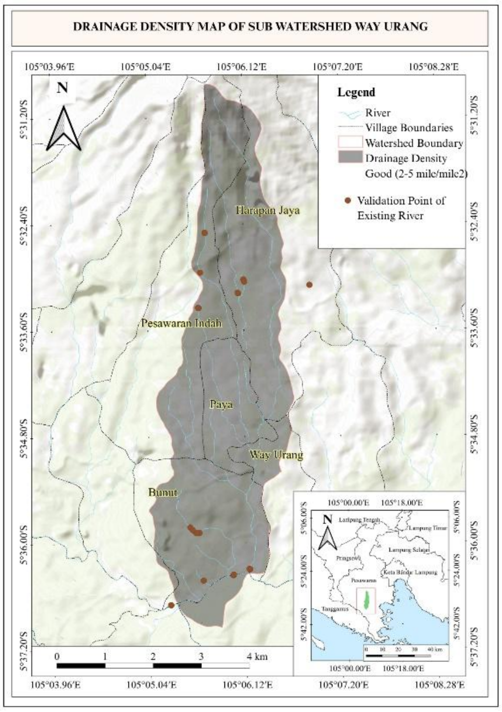

Figure 3. Drainage Density Map

The NDVI transformation in the Way Urang sub-watershed yielded values ranging from −0.1 to 0.9. These NDVI values were subsequently analyzed using statistical methods, including correlation analysis and regression, to identify the relationship between NDVI and field observations, enabling a more accurate assessment of vegetation density. The regression equation derived from field measurements was $y = 135.74x - 24.256$, with a coefficient of determination (R^2) = 0.8196. This regression was then used to convert NDVI values into vegetation density on a new image. The resulting map classifies vegetation density into four classes following the Cook method: low (<10%), moderate (10–50%), high (50–90%), and very high (>90%) (Figure 4).

The model's accuracy test, using the Standard Error of Estimate (SEE), produced a value of 8.66, indicating a typical difference of 8.66 units between the modeled density and field measurements. High-density vegetation predominates in the Way Urang sub-watershed, covering 18.058 km² or 89% of the total area. After field validation, the high-density class primarily corresponds to plantation areas dominated by crops such as cocoa, clove, coffee, nutmeg, durian, and coconut. The moderate-density class includes land with minimal or sparse canopy, such as shrubs and rice fields, which have lower and more discontinuous canopy cover than forests or large trees. The low-density class occupies the smallest area and consists of open land lacking adequate cover, such as exposed soil, which is more susceptible to surface runoff due to limited rainfall infiltration.

Based on the Hydrologic Soil Group (HSG) classification, the headwater area of the Way Urang sub-watershed falls within HSG C. Soils in Group C have poor drainage and low infiltration rates when saturated. In the middle part of the sub-watershed, soils are classified as HSG D. Group D soils have very low infiltration rates—even under unsaturated conditions—resulting in slow water infiltration, which leads to a high potential for surface runoff. These soils typically contain a high clay content that promotes compaction and inhibits water movement. In the downstream area, soils are classified as HSG D/D. Soils in HSG D/D naturally exhibit very poor infiltration and drainage (as in Group D), but their behavior can be improved through the installation of artificial drainage systems.

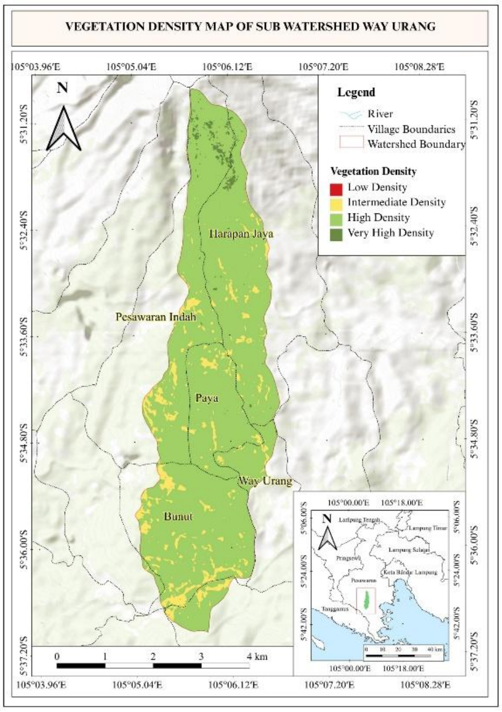

Figure 4. Vegetation Density Map

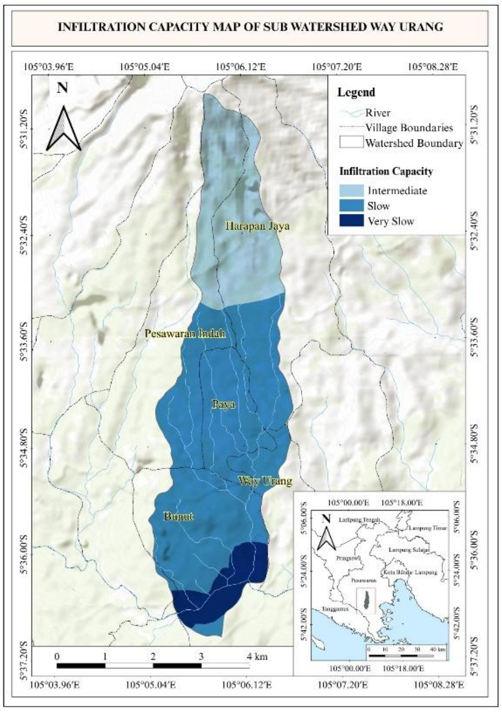

Figure 5. Infiltration Capacity Map

The runoff coefficient is a key parameter for identifying flood potential in a watershed, as it represents the percentage of rainfall that becomes surface runoff. In this study, the runoff coefficient was calculated using the Cook Method, which considers four primary factors: vegetation density, slope gradient, infiltration capacity, and drainage density. Each factor was classified and scored, and the scores were combined via an overlay process to produce a composite score for each mapping unit (Figure 6). The composite scores were then converted to an area-weighted mean—using the ratio of each unit's area to the total watershed area—to obtain the sub-watershed average runoff coefficient (C) (Figure 7). The results indicate that most regions of the Way Urang sub-watershed have runoff coefficients exceeding 50%, implying a substantial potential for surface runoff. Several zones exhibit values above 75% and approaching 100%, reflecting extreme runoff conditions and indicating high vulnerability to flooding.

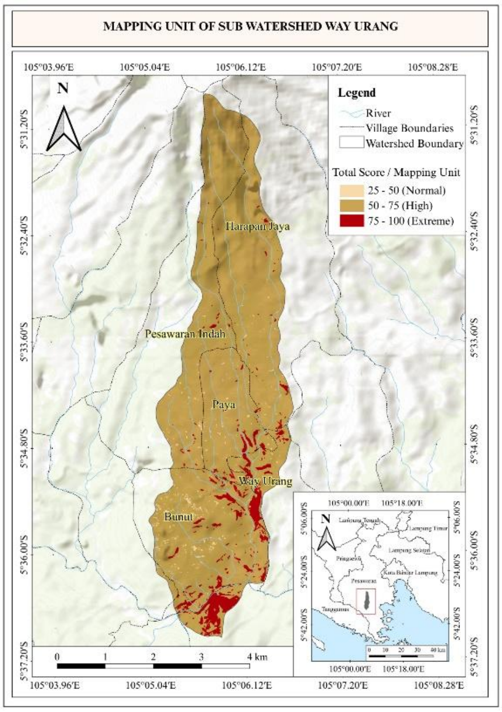

Figure 6. Mapping Units

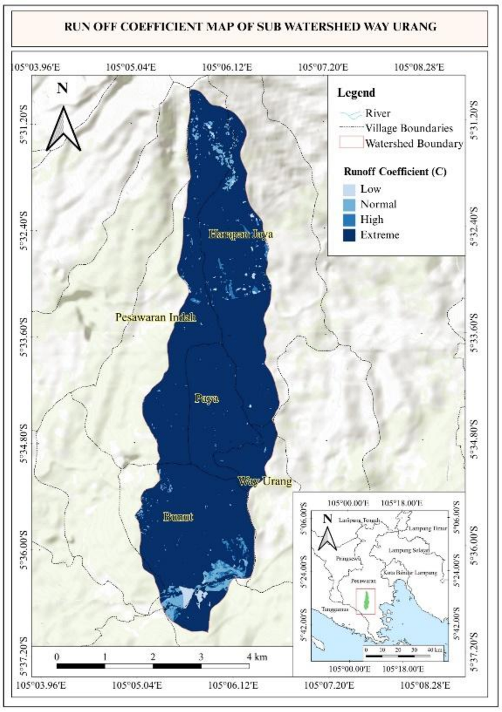

Figure 7. Runoff coefficient (C)

Peak discharge in the Way Urang sub-watershed was estimated using the Rational Method, which is appropriate for small basins. The method combines three primary parameters: runoff coefficient (C), rainfall intensity (I), and drainage area (A), which jointly determine the magnitude of peak flow. The runoff coefficient of 69.20% indicates that most rainfall is converted directly to surface runoff, reflecting biophysical conditions that limit infiltration, such as steep slopes and low-infiltration soils. Using a rainfall intensity of 55.89 mm/h and a drainage area of 20.20 km², the resulting peak discharge is 217.19 m³/s

The analysis in the Way Urang sub-watershed shows that slope gradient is the most dominant factor controlling the runoff coefficient. Hilly headwater areas with slopes ranging from 10–30% to greater than 30% accelerate flow toward the downstream reaches, thereby increasing the volume of surface runoff. This effect is compounded by low soil infiltration capacity, particularly in clay-textured soils classified as HSG C, D, and D/D. These soils exhibit limited water absorption, resulting in a higher proportion of rainfall being converted to runoff. Although vegetation density and drainage density also contribute, their effects are less pronounced than those of the two primary factors. Dense vegetation can enhance infiltration, but it does not fully counterbalance the influence of steep topography and poorly infiltrating soils. The combination of extreme slopes and low infiltration renders the area highly susceptible to elevated peak discharges and heightened flood risk in downstream zones.

Measurements were conducted at the downstream river site at coordinates 105° 6′ 9.280″ E and 5° 36′ 17.443″ S (Figure 8). River depth was measured at each change in channel curvature, yielding a total of 14 observation segments (Figure 9). Measurements indicate a total cross-sectional area of 27.91 m², with a width of 17.28 m. Using the Manning equation, the flow velocity was calculated to be 0.34 m/s. Accordingly, the bankfull discharge under full-section conditions is estimated at 9,53 m³/s.

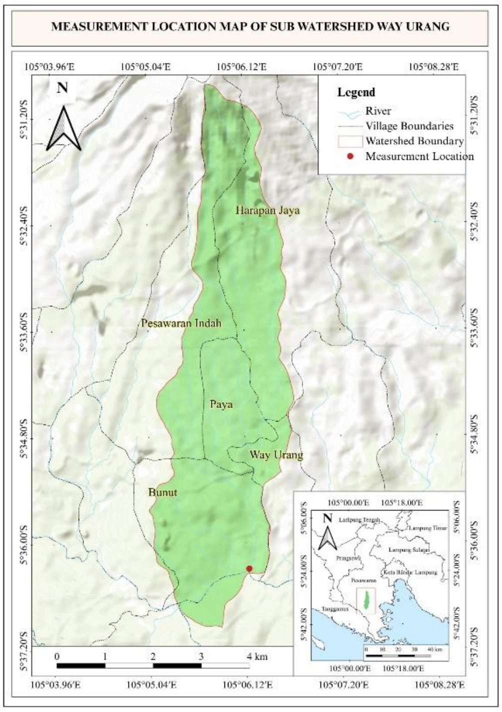

Figure 8. Measurement Location

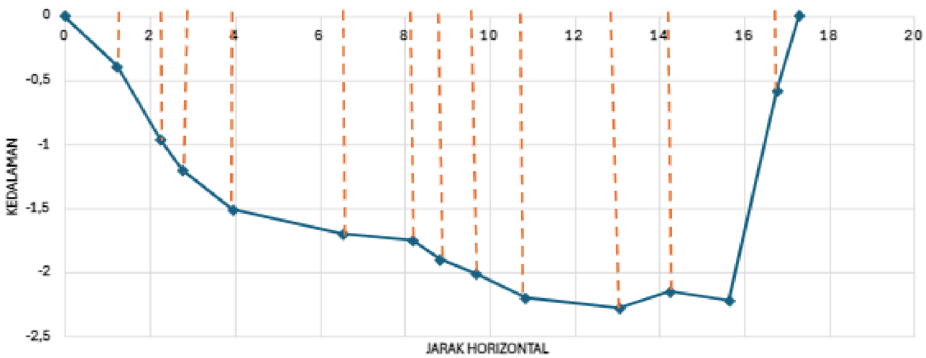

Figure 9. River Cross-Section Profile

The Way Urang sub-watershed has an estimated peak discharge of 217.19 m³/s based on the Rational Method. This value is significantly larger than the estimated bankfull discharge of only 9.53 m^3/s. The pronounced disparity indicates a significant imbalance between the magnitude of rainfall-generated surface flow and the river's conveyance capacity. Peak discharge represents the potential flow volume produced by a high rainfall intensity of 55.89 mm/h over an area of 20.20 km^2, whereas bankfull discharge reflects the maximum capacity of the main channel to carry water before spilling onto the floodplain. Consequently, the river can accommodate only a small fraction of the estimated peak discharge. The excess flow far exceeding bankfull capacity is the principal cause of overbanking onto the floodplain and recurrent flooding in downstream areas, particularly in Bunut Village.

Based on interviews with residents (July 11, 2024), flooding in the Way Urang sub-watershed, especially in Bunut Village (105° 5′ 54.276″ E; 5° 36′ 16.204″ S), occurs almost annually, with an average inundation depth of approximately 50 cm. These events are typically triggered by intense rainfall, for example, two hours of heavy rain. The basin-like topography of Bunut facilitates water accumulation, while its lower elevation relative to the surrounding, predominantly mountainous terrain further exacerbates ponding and flood occurrence.

D. CONCLUSION

This study reveals that the Way Urang sub-watershed has a high flood potential due to its significant runoff coefficient, which is driven by the basin's physical conditions, including steep slopes, low-infiltration soils, and high annual rainfall. These conditions yield an estimated peak discharge of 217.19 m^3/s. Morphometric measurements indicate a total channel cross-sectional area of 27.91 m^2 with an estimated bankfull discharge of only 9.53 m^3/s. This capacity is clearly far smaller than the peak discharge, indicating that the river cannot adequately convey flow during high-intensity rainfall events. The imbalance between peak discharge and bankfull capacity is the primary indicator of the elevated flood potential in the Way Urang sub-watershed. Therefore, integrating spatial data, field surveys, and remote sensing is essential to support planning and targeted flood-mitigation measures tailored to the watershed's physical characteristics.

E. ACKNOWLEDGEMENT

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F. REFERENCES

Asdak, C. (2023). Hidrologi dan pengelolaan daerah aliran sungai. UGM Press.

Dandawate, Y. H., & Kinlekar, S. (2013). Rivers and coastlines detection in multispectral satellite images using level set method and modified Chan–Vese algorithm. In Proceedings of the 2nd International Conference on Advanced Computing, Networking and Security (ADCONS) (pp. 41–46).

Direktorat Sumber Daya Air. (2009). Prosedur dan instruksi kerja pengukuran debit sungai dan saluran terbuka (No. 20).

Gunawan, T., & Sudaryatno. (2020). Penginderaan jauh untuk terapan hidrologi. Ragam Pustaka.

Hadisusanto, N. (2010). Aplikasi hidrologi. Jogja Mediautama.

Kebede, M. G., Wang, L., Li, X. P., & Hu, Z. D. (2020). Remote sensing-based river discharge estimation for a small river flowing over the high mountain regions of the Tibetan Plateau. International Journal of Remote Sensing, 41, 3322–3345.

Raja Shekar, P., & Mathew, A. (2024). Morphometric analysis of watersheds: A comprehensive review of data sources, quality, and geospatial techniques. Watershed Ecology and the Environment, 6, 13–25.

Risky, A. P., Utomo, D. M., & Hapsari, L. D. (2018). Watershed characteristic analysis using remote sensing and GIS techniques for Rational Method application. IOP Conference Series: Earth and Environmental Science, 165(1), 012032.

Saidi, A., & Berd, I. (2013). Karakteristika daerah aliran sungai tropika dan pengelolaannya. LeutikaPrio.

Wu, T., Li, J., Li, T., Sivakumar, B., Zhang, G., & Wang, G. (2019). High-efficient extraction of drainage networks from digital elevation models constrained by enhanced flow enforcement from known river maps. Geomorphology, 340, 184–201.