



Flood Hazard Mapping in a Data-Scarce Basin: Case Study of the Lakitan River, Indonesia

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Abstract

Flood hazard maps are a basic instrument of disaster risk management, yet their preparation normally assumes that streamflow, water level and inundation records are available for model calibration. This study therefore aims to establish a flood hazard mapping framework for data-scarce basins, and to examine how far the resulting classification depends on the assessment framework adopted. GPM satellite rainfall, DEMNAS topography, HWSO soil and MoEF land cover were combined with hydrological (HEC-HMS) and two-dimensional hydraulic (HEC-RAS) modeling to simulate the 2-, 5-, 10-, 25- and 50-year return periods. The GPM rainfall was bias-corrected against the BMKG Tugumulyo station and two hydrological configurations were run in parallel in place of calibration, with the simulated inundation verified against observed flood extents. Hazard was then classified under the BNPB, DEFRA and Australian Government frameworks. For the 25-year return period DEFRA produced the largest extreme hazard zone (467.74 ha), followed by BNPB (384.39 ha) and the Australian Government model (323.87 ha). All three-concentrate extreme hazard along the riverbanks, but their areas are not directly comparable because of differences in parameters and thresholds. Credible flood hazard mapping is therefore attainable without in-situ calibration data, while the BNPB framework still requires clearer definitions of the inundation threshold and of how the flood area and frequency indices are applied spatially.

Keywords: *Flood hazard assessment, data-scarce region, hydrological-hydrodynamic modelling*

Abstrak

Peta bahaya banjir merupakan instrumen dasar dalam pengelolaan risiko bencana, namun penyusunannya umumnya mensyaratkan ketersediaan data debit, tinggi muka air, dan genangan untuk kalibrasi model. Penelitian ini bertujuan menyusun kerangka pemetaan bahaya banjir untuk DAS dengan keterbatasan data, sekaligus menelaah sejauh mana hasil klasifikasi bahaya bergantung pada kerangka penilaian yang digunakan. Curah hujan satelit GPM, topografi DEMNAS, tanah HWSO, dan tutupan lahan KLHK dipadukan dengan model hidrologi (HEC-HMS) dan model hidraulika dua dimensi (HEC-RAS) untuk mensimulasikan banjir periode ulang 2, 5, 10, 25, dan 50 tahun. Data GPM dikoreksi bias terhadap stasiun BMKG Tugumulyo dan sebagai pengganti kalibrasi dua konfigurasi model hidrologi dijalankan berdampingan dengan hasil genangan diverifikasi terhadap data banjir pengamatan. Klasifikasi bahaya kemudian dilakukan menggunakan kerangka BNPB, DEFRA, dan Pemerintah Australia. Untuk periode ulang 25 tahun, model DEFRA menghasilkan zona bahaya ekstrem terluas (467,74 ha), diikuti BNPB (384,39 ha) dan model Australia (323,87 ha). Ketiga model menunjukkan pola serupa di sepanjang tepi sungai, tetapi luasannya tidak sepenuhnya sebanding karena perbedaan parameter dan ambang klasifikasi. Pemetaan bahaya banjir yang memadai dengan demikian tetap dapat dilakukan tanpa data kalibrasi lapangan, sementara kerangka BNPB masih memerlukan kejelasan definisi ambang genangan serta cara penerapan indeks luas dan frekuensi banjir secara spasial.

Kata kunci: *Asesmen bahaya banjir, daerah minim data, pemodelan hidrologi-hidrodinamika*

Introduction

Floods represent one of the most destructive natural hazards, producing cascading effects that extend beyond immediate physical damage to long-term economic and social disruption. Globally, the average annual economic loss attributed to flooding is estimated at around USD 96 billion in terms of Gross Domestic Product (GDP) (Bhuiyan et al., 2022; Tanoue et al., 2020). At the same time, nearly 21 million people are directly affected by flood events every year, whether through displacement, damage to housing and infrastructure, or disruption of livelihoods. Flood hazards are therefore not merely local phenomena, and reducing their impact depends on structural and non-structural measures that are planned from a reliable spatial picture of where the hazard actually falls.

In response to this pressing need, governments, institutions, and researchers worldwide have increasingly focused on the development of flood hazard mapping as a fundamental tool for disaster risk management (Handyastono et al., 2025; Isma et al., 2024; Maranzoni et al., 2023; Supratman et al., 2024). Numerous methodologies have been proposed and tested across different hydrological and geographical contexts. Despite the variety of approaches, a common element is the reliance on hydrodynamic models tailored to specific catchments (Maranzoni et al., 2023).

These models, however, cannot function in isolation; they must undergo proper calibration to ensure their capacity to replicate observed flood behavior. Equally important is the provision of accurate boundary conditions, most notably flood discharge, which is generally obtained through hydrological modeling. Hydrological models themselves require rigorous calibration and validation, as any uncertainty at this stage propagates into subsequent hydrodynamic simulations. Thus, the workflow of flood hazard mapping is inherently sequential and interdependent, demanding careful integration of hydrological and hydraulic components to produce reliable spatial assessments of flood risk.

The villages of Taba Gindo and Batu Gane, located within the Lakitan River Basin, South Sumatra, have been repeatedly identified by the National Disaster Management Authority (BNPB) as areas with high flood susceptibility (Figure 1). Historical records and community accounts describe these villages as chronically flood-prone, where inundation has become a regular occurrence rather than an isolated event. Their geographical setting low lying terrain adjacent to the river channel renders them highly vulnerable to overflow

whenever rainfall intensity exceeds the limited storage capacity of the catchment. This persistent exposure frequently disrupts transportation, damages agricultural land, and affects housing and public facilities. Nevertheless, detailed hydrological and hydraulic data to support systematic flood analysis remain scarce.

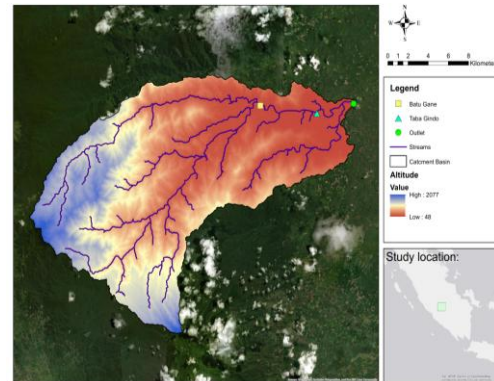


Figure 1. Lakitan River Basin

The absence of essential calibration data poses a major constraint in assessing flood risk for Taba Gindo and Batu Gane. Streamflow, water level, and inundation records are unavailable, while rainfall data from ground stations are sparse and discontinuous, so model calibration and validation through conventional methods cannot be performed. The analysis must instead rely on indirect sources such as satellite-based rainfall products, digital elevation models, and secondary reports, each of which carries considerable uncertainty.

This condition defines the gap addressed here. Flood hazard studies in Indonesia generally assume the availability of observed discharge or inundation records, while the national hazard classification guideline likewise presumes parameters that can be directly measured. What remains unclear is how flood hazard maps should be produced and classified when such observations are unavailable. This study therefore aims to: (1) develop a flood hazard mapping workflow for an ungauged basin using globally and nationally available datasets; (2) compare the hazard classification under the Indonesian (BNPB), DEFRA, and Australian Government frameworks for the same simulated flood; and (3) identify methodological ambiguities in applying the BNPB framework to raster-based hydrodynamic output. The conclusions are structured around these three objectives.

Material and Methods

The study was carried out in five sequential stages, each designed to compensate for a specific

consequence of the missing local observations. The first stage compiled the global and national datasets that stand in for those observations. The second stage corrected the satellite rainfall against the single available ground station and derived the design rainfall for each return period through frequency analysis. The third stage transformed the design rainfall into flood hydrographs using two independent hydrological configurations, since no observed discharge exists against which a single model could be calibrated. The fourth stage routed those hydrographs through a two-dimensional hydraulic model and verified the simulated inundation against the flood extents recorded in the field, which is the only observational check available in this basin. The fifth stage converted the simulated depth and velocity fields into hazard classes under three assessment frameworks and compared the resulting hazard areas. The subsections below follow this order, and together they form the workflow proposed for basins where calibration data are unavailable.

Description of study area

The Lakitan River Basin, located in Musi Rawas Regency, South Sumatra, Indonesia. The river extends for approximately 1,113 km and drains a catchment area of about 376.47 km². Flooding is a recurrent problem for communities along the Lakitan River. In May 2021, a combination of intense rainfall and land-use changes inundated hundreds of houses in the Selangit and STL Ulu Terawas districts. A similar event occurred in May 2023, submerging residential areas in the East Lakitan District with water depths reaching up to 2 meters. Within this basin lie the villages of Taba Gindo and Batu Gane, both situated in the Selangit District at coordinates 3°09'42.4"S, 102°44'40.5"E and 3°09'16.9"S, 102°41'35.6"E, respectively (Figure 1). Field observations, government records and local testimony agree that the areas around the two villages flood frequently, and residents report inundation even under light to moderate rainfall rather than only under the heavy events associated with long return periods. The affected areas include a mosque, wetlands and residential zones, with inundated areas of roughly 18,919 m² to 42,004 m².

A clearer illustration of the flooded areas is provided in Figure 2.

Data

Given the scarcity of local calibration data, the study relies on globally and nationally available sources: satellite rainfall, a digital elevation model, and soil and land cover databases. Table 1 lists them with their sources.

Table 1. Data sets and sources used in this study

Variable	Data set	Source
DEM	DEMNAS	(Badan Informasi Geospasial, 2025)
Observed Rainfall	BMKG	(BMKG, 2025)
Satellite Rainfall	GPM	(Giovanni, 2025)
Land type	HWSD	(Food and Agriculture Organization, 2025)
Land cover	MoEF	(Kementrian Lingkungan Hidup dan Kehutanan, 2025)
Inundation extent	BNPB	Measurement

The data used in this study include satellite-derived elevation data in the form of the Indonesian Digital Elevation Model (DEM), produced by the Geospatial Information Agency (BIG) with a spatial resolution of 8 m × 8 m. This dataset was utilized to delineate the sub-watershed boundaries of the Lakitan River Basin.

Observed rainfall data were obtained from the Meteorology, Climatology, and Geophysics Agency (BMKG) station located in Tugumulyo Station. The dataset contains daily rainfall records from 2012 to 2024. These rainfall data were subsequently processed and converted into spatial rainfall information for hydrological analysis within the Lakitan River Basin. Annual maximum daily rainfall at Tugumulyo station from 2012-2024 could be seen at Figure 3.



Figure 2. Observed flooded area

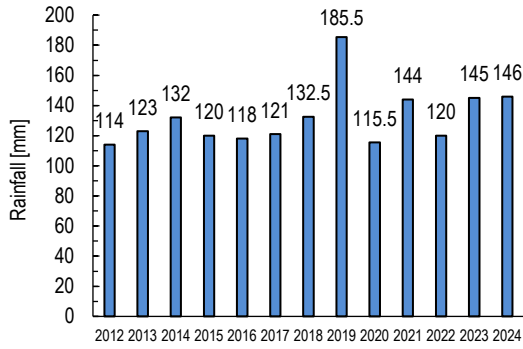


Figure 3. Annual maximum daily rainfall Tugumulyo Station

The Tugumulyo rainfall station, which serves as the nearest observation point, is situated approximately 22.5 km and 28 km from the villages of Taba Gindo and Batu Gane, respectively. In addition, the station lies outside the Lakitan River Basin, making its data less representative of the basin's actual rainfall conditions. To address this limitation, satellite-based rainfall data from the Global Precipitation Measurement (GPM) mission were employed as an alternative source to complement and calibrate the observed rainfall data. GPM was selected because numerous studies have demonstrated its superior performance and reliability compared to other global precipitation products in representing rainfall patterns across Indonesia (Hutagaol et al., 2023; Ramadhan, Muharsyah, et al., 2022; Ramadhan, Yusnaini, et al., 2022).

The GPM dataset provides rainfall estimates at a spatial resolution of $0.1^\circ \times 0.1^\circ$ and a temporal resolution of 30 minutes. Based on this spatial resolution, a grid network was delineated over the study area to represent the Lakitan River Basin. A total of nine GPM grids were identified as covering the basin, with one additional grid located within the Tugumulyo area.

The determination of hydrological parameters for flood discharge analysis requires both soil and land-use data. The Harmonized World Soil Database (HWSD) provides global information on soil properties and morphology at a spatial resolution of 1 km, compiled from national and regional datasets to support large-scale modeling and analysis. In this study, the HWSD was used to identify the soil distribution within the Lakitan River Basin. However, since the HWSD only describes soil characteristics and does not account for areas modified by human activities, land-use data were also incorporated. The land-use database was obtained from the Ministry of Environment and Forestry (MoEF) of Indonesia and subsequently clipped to match the boundaries of each sub-catchment.

Flood Hazard Criteria

$$FHI = a.H + b.T + c.A + d.F \quad (1)$$

Where FHI is Flood Hazard Index, H is Flood Depth Score, T is Flood Duration Score, A is Flood Area Score, F is Flood Frequency Score, a, b, c, d is Weighting coefficient

In the above equation, according to BNPB, flood hazard is evaluated based on four parameters: flood depth, flood duration, flood area, and flood frequency. However, the weighting coefficients and classification criteria for each parameter are not explicitly standardized, resulting in variations among different studies in how these weights and thresholds are applied (Isma et al., 2024; Supratman et al., 2024).

Table 2. Hazard index criterion

Parameter	index criterion	Score
Flood depth (m)		
< 0.76	Low	1
0.76 – 1.50	Moderate	2
> 1.50	High	3
Flood duration (hr)		
< 4	Low	1
4-8	Moderate	2
> 8	High	3
Flood area (m ²)		
< 100	Low	1
100 – 300	Moderate	2
> 300	High	3
Flood frequency - numb. of events		
1-5	Low	1
6-20	Moderate	2
> 20	High	3

Among all parameters, only flood depth shows consistent classification. This depth criterion has been formally established by BNPB, whereas the remaining three parameters exhibit minor variations across studies. The flood hazard criteria employed in this study are summarized in Table 2.

The depth criterion follows the hazard classification issued in the national guideline for disaster risk assessment (BNPB, 2012), while the duration, area, and frequency criteria were adapted from the values applied in earlier Indonesian flood hazard studies (Isma et al., 2024; Supratman et al., 2024) and refined to suit the characteristics of the study area. The weighting coefficients assigned to parameters a, b, c, and d were set to 0.4, 0.2, 0.2, and 0.2, respectively, giving flood depth twice the weight of each remaining parameter in recognition of its status as the only index with a formally established classification.

Flood mapping

Quantifying flood hazard requires a two-dimensional hydrodynamic model to generate inundation maps together with flow velocity and water depth. Hydrological Engineering Center's River Analysis System (HEC-RAS) was used here (Burnama et al., 2023; Karamma et al., 2022). In its 2D mode, HEC-RAS solves the shallow water equations, given as Eq. (2) to (4), where Eq (2) represents the continuity equation, while Eq (3) and (4) correspond to the momentum equations in the x and y directions, respectively. In these equations, u and v denote the flow velocity components in the x and y directions, x and y are the spatial coordinates, h is the mean water depth, n is the Manning's roughness coefficient, and z_b represents the bed elevation.

$$\frac{\partial h}{\partial t} + \frac{\partial(hu)}{\partial x} + \frac{\partial(hv)}{\partial y} = 0 \quad (2)$$

$$\frac{\partial(hu)}{\partial t} + \frac{\partial(hu^2)}{\partial x} + \frac{\partial(huv)}{\partial y} + gh \frac{\partial h}{\partial x} = -gh \frac{\partial z_b}{\partial x} - gn^2 u \frac{\sqrt{u^2 + v^2}}{h^{1/3}} \quad (3)$$

$$\frac{\partial(hv)}{\partial t} + \frac{\partial(huv)}{\partial x} + \frac{\partial(hv^2)}{\partial y} + gh \frac{\partial h}{\partial y} = -gh \frac{\partial z_b}{\partial y} - gn^2 v \frac{\sqrt{u^2 + v^2}}{h^{1/3}} \quad (4)$$

The primary driving force of hydrodynamic model is the inflow hydrograph, representing the flood discharge entering the river system. In this study, the inflow hydrographs were generated using the Hydrological Engineering Center's Hydrology Modeling System (HEC-HMS), which simulates rainfall-runoff processes based on catchment characteristics such as soil type, land use, and precipitation. The resulting discharge data from HEC-HMS serve as boundary conditions for the HEC-RAS model to simulate flood propagation and inundation extent within the Lakitan River Basin.

Hydrological modeling scenarios

Because no observed discharge record exists for the Lakitan River Basin, a single hydrological configuration cannot be calibrated against measured flow. The Indonesian National Standard for design flood estimation requires that at least two different methods or model approaches be applied when observed discharge data are unavailable for calibration and validation (SNI 03-2415-2016).

Two configurations were therefore built in HEC-HMS and are referred to throughout this paper as Scenario 1 and Scenario 2. Scenario 1 combines the SCS Curve Number (SCS-CN) method for the loss process with the SCS Unit Hydrograph (SCS-UH) for the transform process. Scenario 2 combines the Green-Ampt infiltration method for loss with the

Snyder Unit Hydrograph for transform. Both configurations were parameterised from physically derived watershed characteristics such as soil type, land use, flow length, and slope gradient. The single exception is the Snyder peaking coefficient required by Scenario 2, which cannot be obtained from basin properties and has to be assumed. The two scenarios were compared in terms of peak discharge, runoff volume, and time to peak, and the configuration whose parameters are fully traceable to measurable basin attributes was adopted to drive the hydraulic model.

Results and Discussion

Rainfall analysis

A single station cannot represent rainfall variability across the basin, so GPM data were used to provide distributed estimates for each sub-catchment. Global precipitation data (GPD) of this kind require a consistency check and, where necessary, correction against ground observations before they can be used hydrologically (Elsebaie et al., 2025; Lin et al., 2022; Zhu et al., 2023).

Systematic correction of satellite rainfall in Indonesia was introduced by (Mamenun et al., 2014). The GPD are classified into magnitude ranges, and each range is assigned a correction coefficient obtained by regression against observed rainfall (Cristobal et al., 2025; Sanjaya et al., 2024; Senjaya et al., 2023). The corrected rainfall is then obtained by multiplying the GPD data by the respective coefficient, as expressed in Equation (5).

$$Y_i = C \cdot X_i \quad (5)$$

Where Y_i denotes the corrected GPD data, X_i denotes the uncorrected GPD data, and C is the correction coefficient.

The bias correction of GPM data at Grid 10 was performed using the Tugumulyo station as a reference. The rainfall data were classified into ten magnitude intervals, each assigned a correction coefficient derived through an empirical linear regression-based adjustment, see Table 3. The objective function used in determining the optimal correction coefficients was the Mean Absolute Error (MAE), which decreased substantially from 3.25 mm before correction to 0.87 mm after correction, indicating a significant improvement in data accuracy.

Frequency analysis of the annual maximum daily precipitation from each corrected grid was carried out with seven probability distributions: Normal, Lognormal with two and three parameters, Gumbel Type I, Pearson Type III, Log-Pearson Type III and

Generalized Extreme Value, for return periods of 2, 5, 10, 25 and 50 years. The statistical parameters and maximum deviations of each grid were compared to select the best-fitting distribution. Table 4 reports the resulting design rainfall.

Table 3. Coefficient Correction

Rain interval (mm)	Correction coefficient
< 6	0.20
6-11	0.75
11-16	0.90
16-21	1.10
21-26	1.40
31-46	1.25
46-76	1.35
76-106	1.30
106-121	1.20
121-136	1.10

Table 5. Rainfall Distribution SCS-3

Hour	Precipitation (%)
0	0.00
1	0.10
2	0.40
3	1.00
4	2.50
5	6.00
6	13.00
7	22.50
8	25.00
9	20.00
10	9.50

The temporal distribution of the rainfall matters as much as its magnitude. The cumulative distributions of the annual extreme events recorded between 2000 and 2024 were compared with the PSA-007, Huff, SCS-1A, SCS-2 and SCS-3 temporal models. Most extreme events in the basin concentrate 60 to 80 per cent of the total depth within the first four to six hours, a short-duration, high-intensity pattern. Of the models tested only

SCS Type 3 reproduces it, placing the peak intensity early and letting the remainder decline gradually, whereas PSA-007 and Huff spread the depth too evenly and SCS-1A concentrates it earlier than observed. SCS Type 3 was adopted on that basis, with the ordinates listed in Table 5.

Hydrology analysis

The analysis begins with watershed delineation, carried out on the DEMNAS data to obtain flow direction, flow accumulation and catchment boundaries, from which river length, basin area and average slope were extracted for each sub-basin. Figure 4 shows the delineation and Table 6 the resulting characteristics.

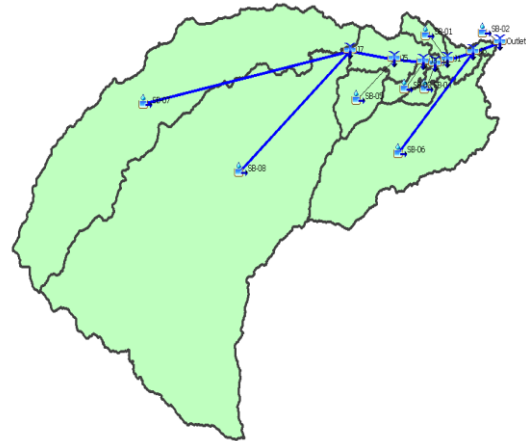


Figure 4. Delineation of the Lakitan River Basin

Table 6. Sub-basin physical characteristics

Sub-catchment	Area (km ²)	Slope (%)	Longest low (km)
SB-01	3.39	0.21	1.47
SB-02	15.51	0.19	12.59
SB-03	2.86	0.17	1.16
SB-04	2.66	0.17	1.52
SB-05	8.22	0.28	3.65
SB-06	50.80	0.29	18.07
SB-07	94.58	0.45	31.53
SB-08	201.45	0.46	31.31

Table 4. Rainfall design

Grid	1	2	3	4	5	6	7	8	9
Distribution	G	P3	GEV	P3	P3	GEV	GEV	P3	G
Return period	Design rainfall (mm)								
2	128.2	131.1	125.5	101.8	130.5	129.6	125.2	110.6	118.7
5	146.9	147.8	140.7	118.2	141.1	154.1	146.0	126.0	139.9
10	159.3	156.1	148.3	127.2	145.6	168.3	158.9	133.7	154.0
25	175.0	164.6	155.7	137.1	149.6	184.1	174.2	141.8	171.7
50	186.6	169.9	159.9	143.7	151.8	194.5	184.9	146.9	184.9

Based on the watershed delineation and sub-catchment characteristics, a hydrological model was developed using HEC-HMS. The model incorporates loss and transform methods, where the loss module estimates effective rainfall after accounting for infiltration and other abstractions, while the transform module converts effective rainfall into runoff hydrographs. The parameters for Scenarios 1 and 2, defined in the Materials and Methods section, were derived from the soil, land-use, and topographic characteristics of each sub-catchment and are summarized in Tables 7–9.

Table 7. Snyder UH parameters

Sub-catchment	Lag time (hr)	Peaking coefficient
SB-01	0.10	0.30
SB-02	0.54	0.30
SB-03	0.10	0.30
SB-04	0.11	0.30
SB-05	0.18	0.30
SB-06	0.60	0.30
SB-07	0.77	0.30
SB-08	0.76	0.30

Table 10 reports the simulated peak discharge, total runoff volume and time to peak for both scenarios across the return periods. Scenario 1 consistently produces higher peaks but smaller runoff volumes than Scenario 2: at the 25-year return period it gives 1,464.18 m³/s and 23.58 × 10⁶ m³ against 1,315.51 m³/s and 28.77 × 10⁶ m³. The results show that both scenarios produce generally consistent results across the return periods, with only minor differences in peak discharge, runoff volume, and time to peak. This indicates that the hydrological model provides a reasonable and consistent representation of the catchment response.

For the subsequent hydraulic and hazard analyses, Scenario 1 was selected because its parameters are derived directly from measurable physical characteristics, including soil type, land use, slope, and flow length. In contrast, Scenario 2 requires several numerical parameters that must be estimated, such as the Snyder peaking coefficient. Therefore, Scenario 1 was considered more

physically defensible for application in this data-scarce watershed.

Hydrodynamic analysis

The key outputs derived from the hydraulic simulation are the water depth and flow velocity, which represent the primary indicators of flood severity and hazard potential. Comprehensive assessments may also draw on duration, inundation extent, or shear stress, but depth and velocity are sufficient for the objectives of this study and provide the basis for classifying hazard levels in the sections that follow. The two-dimensional simulation of the 2-year event produced the inundation depth and velocity fields presented in Figures 5 and 6. Inundation is concentrated mainly in the low-lying areas adjacent to the river, with depths reaching up to 7 m in some depressions. The observed flood areas, indicated in green in Figure 5, show good spatial agreement with the simulated inundation extent, supporting the applicability of the model for the subsequent hazard assessment.

Flood hazard assessment

Using the results of the hydrodynamic simulations, a flood hazard assessment was conducted based on Equation (1) and the flood hazard index criteria presented in Table 2. According to Indonesian water resources management regulations, particularly regarding river flood mitigation, the standard design return period for main river systems is 25 years. Therefore, this study focuses exclusively on the 25-year return period for hazard classification. Figure 7 illustrates the spatial distribution of flood hazard levels in the Lakitan River Basin derived from the two-dimensional hydraulic simulation results. The classification integrates flow depth and velocity parameters to identify varying hazard levels. High-hazard zones (red areas) are predominantly concentrated along the main river channel and meander bends, where both flow velocity and inundation depth are relatively high. Moderate hazard zones (blue areas) extend toward adjacent floodplains, while low-hazard zones (green areas) are found in peripheral areas with shallower depths and lower flow energy.

Table 8. SCS-CN loss and transform parameters

Sub-Catchment	CN	Storage (mm)	Initial abstraction (mm)	Lag time (min)
SB-01	75.81	81.05	16.21	5.83
SB-02	85.92	41.62	8.32	32.13
SB-03	79.71	64.66	12.93	5.30
SB-04	78.11	71.18	14.24	6.49
SB-05	77.87	72.18	14.44	10.58
SB-06	76.03	80.08	16.02	35.79
SB-07	74.73	85.89	17.18	46.10
SB-08	74.90	85.12	17.02	45.79

Table 9. Green-ampt loss parameters

Sub-catchment	Initial content	Saturated content	Suction (mm)	Conductivity (mm/hr)
SB-01	0.31	0.15	208.80	1.50
SB-02	0.31	0.15	208.80	1.50
SB-03	0.31	0.15	208.80	1.50
SB-04	0.31	0.15	208.80	1.50
SB-05	0.31	0.15	208.80	1.50
SB-06	0.32	0.18	148.85	6.45
SB-07	0.32	0.18	148.85	6.45
SB-08	0.32	0.18	148.85	6.45

Table 10. Summarized flood hydrograph results

Return period (years)	Scenario 1			Scenario 2		
	Peak discharge (m ³ /s)	Total volume (10 ⁶ m ³)	Time to peak (h)	Peak discharge (m ³ /s)	Total volume (10 ⁶ m ³)	Time to peak (h)
2	999.67	15.93	9.50	950.69	20.39	9.50
5	1214.08	19.59	9.50	1129.00	24.49	9.50
10	1336.17	21.53	9.00	1220.70	26.59	9.00
25	1464.18	23.58	9.00	1315.51	28.77	9.00
50	1515.97	24.86	9.00	1375.04	30.15	9.00



Figure 5. Simulated Maximum flood depth for the 2 years return period



Figure 6. Simulated Maximum flood velocity for the 2 years return period

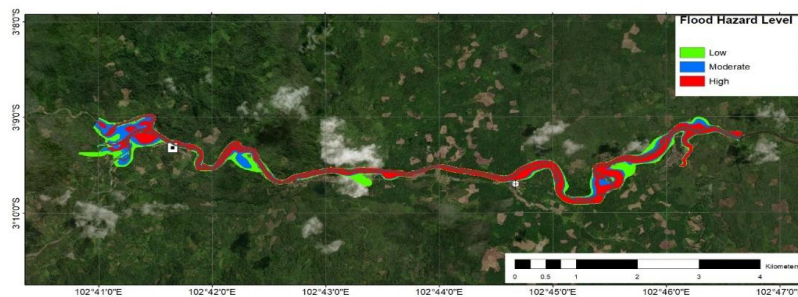


Figure 7. Flood hazard map for 25-years return period using BNPB

Although the flood hazard assessment framework applied in this study follows the general guidelines established by BNPB, several methodological ambiguities remain, particularly in the interpretation and quantification of hazard indicators. Two of these ambiguities proved decisive here, and both stem from the same mismatch: the hydrodynamic output is a raster in which every cell represents an area of 8×8 m (64 m²), whereas the hazard indices are defined in categorical terms. The first issue concerns the definition of what constitutes “flooding.”

Specifically, it remains unclear when a raster cell should be classified as flooded: whether inundation should be recognized only when water depth exceeds 30 cm, or if depths greater than 5 cm should already qualify as flooding. Literature shows that different countries adopt varying thresholds; for instance, in urban areas with underground infrastructure or buildings with basements, even a water depth above 5 cm is often considered flooding, as it can disrupt public activities and traffic (Jamali et al., 2019; Wijaya et al., 2023).

The second issue is the spatial implementation of the flood area index. Because it cannot be obtained by raster aggregation alone, the index has to be localised, and how that should be done is not specified. Of the two settlements analysed here, Batu Gane has an inundated area of about 150 m², giving an index of 2, while Taba Gindo exceeds 300 m² and gives an index of 3. Whether every inundated cell should then carry a uniform index of 3, or the index should vary by settlement, and if so where the boundaries between localised values should fall, is left open. In this study the flood area index was assigned the maximum score of 3, since the total inundated area consistently exceeded 300 m², but the ambiguity points to a need for clearer national standards on flood thresholds and spatial aggregation.

A third difficulty concerns the flood frequency index. In many parts of Indonesia, the Lakitan River Basin among them, records of flood occurrence are unavailable or poorly documented, and what exists is qualitative and spatially discrete, drawn from local testimony or from government reports naming particular flood-prone spots rather than covering areas systematically. That inconsistency makes recurrence impossible to estimate reliably in a raster-based analysis, so the maximum value was assigned here on the strength of community reports and historical accounts of frequent flooding at Taba Gindo and Batu Gane.

Table 11. Flood Hazard Classification by DEFRA

FHI	Class Index
< 0.75	Low
0.75 – 1.25	Moderate
1.25 – 2.5	Significant
>2.5	Extreme

Subsequently, a comparative analysis was conducted by applying alternative flood hazard assessment frameworks that adopt simpler parameterization. In this step, the flood hazard mapping results were evaluated using models developed by the United Kingdom's Department for Environment, Food and Rural Affairs (DEFRA)

(DEFRA Environment Agency, 2006) and the Australian Government (AG) (Cox et al., 2010). Both models rely solely on water depth and flow velocity as key parameters for hazard classification.

Table 12. Flood Hazard Classification by AG

FHI	Class index
<0.3 and H<0.3 and V<2 m/s	H1
<0.6 and H<0.5 and V<2 m/s	H2
<0.6 and H<1.2 and V<2 m/s	H3
<1.0 and H<2.0 and V<2 m/s	H4
<4.0 and H<4.0 and V<4 m/s	H5
>4.0 and H>4.0 and V<4 m/s	H6

The DEFRA model, formulated in Equation (6), and the Australian model, presented in Equation (7). The detailed hazard classification criteria associated with each model are provided in the following tables.

$$\text{FHI} = \text{H} \cdot (\text{V} + 1.5) + \text{DF} \quad (6)$$

$$\text{FHI} = \text{V} \cdot \text{H} \quad (7)$$

Where V denotes the flow velocity (m/s) and DF represents the debris factor. In this study, a DF value of 0.5 was adopted, as the dominant land cover within the study area consists primarily of forested terrain.

Figures 8 and 9 present the hazard maps produced by the AG and the DEFRA models. Both classify hazard from depth and velocity alone, whereas the BNPB framework also brings in inundation area and flood frequency, giving a broader but less parameter-specific characterization. The AG model (Figure 8) grades hazard into six levels (H1 to H6) from progressively increasing combinations of depth and velocity, producing a finer gradation of zones along the meander sections where hydraulic energy concentrates. The DEFRA model (Figure 9) uses four categories, Low, Moderate, Significant and Extreme, from a velocity-depth relationship adjusted by a debris factor and tends to return broader Extreme zones along the main channel.

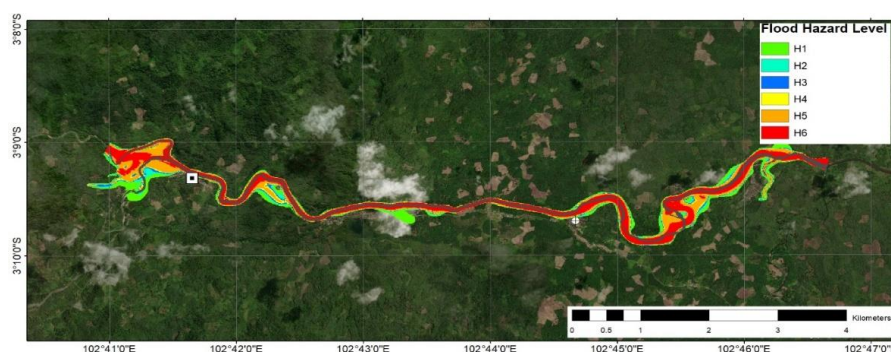


Figure 8. Flood hazard map for 25-years return period using AG

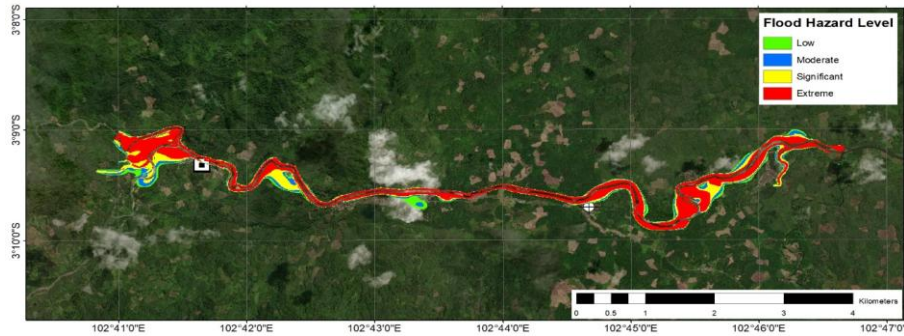


Figure 9. Flood hazard map for 25-years return period using DEFRA

Table 13 represents the total area classified under the highest tier of flood hazard for each flood hazard model across all return periods. These values were obtained by counting the number of grid cells assigned to the highest hazard classification and multiplying that count by the DEM grid cell area. The Extreme area grows consistently with return period under all three models, rising by roughly a third between the 2-year and the 50-year event. The three models nevertheless differ substantially in magnitude at every return period, indicating that classification thresholds and hazard scaling methods strongly influence the resulting hazard zonation.

Table 13. Extreme hazard area resulting from the three classification frameworks

Return period	Extreme level area (ha)		
	DEFRA	AG	BNPB
2	348.82	230.76	300.22
5	412.04	277.98	358.16
10	441.49	300.65	372.22
25	467.73	323.87	384.39
50	480.19	339.26	417.22

Among the three models, the DEFRA model consistently produces the largest extent of Extreme hazard areas, while the AG model yields the smallest. This outcome is expected for several reasons. Firstly, the AG model employs six distinct hazard levels (H1–H6), which distribute the classification more evenly and reduce the total area assigned to the highest category. Secondly, the DEFRA model applies a more conservative threshold in its depth–velocity relationship, including a debris factor that increases the computed hazard value, particularly in high-energy flow zones. The BNPB model generally produces intermediate results, reflecting the influence of its broader parameter set, which incorporates not only flow depth and velocity but also inundation extent and flood frequency. Overall, the three models differ significantly due to their varying methodologies and classification philosophies.

These distinctions reflect the regional priorities of each framework: the DEFRA model focuses on urban safety and pedestrian risk, while the AG model emphasizes hazards to people, vehicles, and buildings.

Conclusions

This study presented a framework for flood hazard mapping in a data-scarce basin, demonstrated through the case of the Lakitan River in South Sumatra, Indonesia. By integrating global and national datasets including GPM satellite rainfall, DEMNAS, HWSO, and MoEF land cover with hydrological and hydrodynamic modeling using HEC-HMS and HEC-RAS 2D, the study successfully generated spatially distributed flood depth and velocity fields for multiple design storms. The approach proved feasible despite the absence of in-situ calibration data, highlighting the applicability of satellite-based rainfall correction and physically derived parameters for ungauged basins.

Flood hazard assessment was conducted using the BNPB framework and further compared with international approaches from DEFRA and the Australian Government. The comparison revealed that the DEFRA model produced the largest extent of “Extreme” hazard zones, while the Australian model yielded the smallest, mainly due to differences in classification thresholds and the inclusion of a debris factor in DEFRA’s formulation. The BNPB model produced intermediate results, reflecting a more balanced influence of multiple parameters depth, velocity, inundation area, and flood frequency. Several methodological ambiguities were identified within the Indonesian flood hazard assessment framework. These include unclear definitions of inundation thresholds (e.g., whether flooding begins at depths of 5 cm or 30 cm) and uncertainty in how the flood area and frequency indices should be applied within a raster-based system. Such ambiguities underscore the need for a standardized national guideline on

hazard classification, particularly in integrating raster-based modeling with categorical indices.

Future work should refine the parameterization of localized hazard indices, improve the representation of flood frequency, and integrate social exposure data to extend the approach in similar ungauged regions.

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