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Flood Study of Sungai Penuh City in the Batang Merao Watershed (Case Study: Hamparan Rawang District)

Ary Firmana[1,✉], Eka Oktariyanto Nugroho[1], Aziz Rizal Prasetiyo[2], Maulya Wijayanthi Sulistiyani[2], Adhyatma Taufik Akbar[2]

[1] Water Resources Engineering Research Group, Faculty of Civil and Environmental Engineering, Institut Teknologi Bandung, INDONESIA.
[2] Master Program of Water Resources Engineering, Faculty of Civil and Environmental Engineering, Institut Teknologi Bandung, INDONESIA.

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Corresponding Author:
✉ aryfirmana@gmail.com
(Ary Firmana)

ABSTRACT

In January 2024, a major flood from Batang Merao River occurred in Sungai Penuh City, submerging residential areas and agricultural land to a depth of 0.5–1.5 m. One of the most severely impacted areas was Hamparan Rawang District with a total of 3985 houses and 866.025 ha of agricultural land inundated. This research aims to identify effective flood management alternatives to reduce inundation area and mitigate flood losses. The research was carried out through hydrological analysis, hydraulic analysis using HEC-RAS, and loss analysis using the ECLAC (Economic Commission for Latin America and the Caribbean) method. The study found that with Q25 discharges of 48.34 m³/s upstream and 720.62 m³/s downstream, an existing inundation area of 968.64 ha occurred, resulting in total losses of IDR 95.239 billion. Therefore, two flood management scenarios were developed, scenario 1 (river normalization) and scenario 2 (combination of river normalization and retention pond). Modeling results showed the inundation area under scenario 1 was 802.78 ha, reduce losses to IDR 43.604 billion (45.78% reduction). Under scenario 2, the inundation area was 780.51 ha, reduce losses to IDR 42,001 billion (44.10% reduction). Scenario 2 is effective for reducing inundation area, but for reducing financial losses, scenario 1 is more effective.

1. INTRODUCTION

Floods are acknowledged as one of the most extensive and destructive natural hazards globally, affecting millions of people and causing significant economic damage each year (Farid *et al*., 2017; Gunawan *et al*., 2025; Kardhana *et al*., 2022; Kuntoro *et al*., 2017). According to the Organization for Economic Cooperation and Development (OECD), the economic damages resulting from flood events have shown a continuous upward trend since 1970 (Awah *et al*., 2024). In Indonesia, flood disasters comprise nearly 32% of the total recorded disaster events (Rahayu *et al*., 2023). Moreover, flooding driven by environmental disturbances has increasingly become a critical concern both nationally and globally (Sugianto *et al*., 2022).

The Batang Merao River is a part of the Batanghari River Basin, flowing through the territories of Sungai Penuh City and Kerinci Regency in Jambi Province, with a total length of approximately 66 km. A major flood struck Sungai Penuh City in January 2024, inundating settlements and agricultural land with water depths ranging from 0.5 to 1.5 meters due to the overflow of the Batang Merao River, resulting in an inundated area of 2945 hectares (Figure 1). This river serves an important role as a water source for domestic needs, agricultural activities, and the local economic sector (Ningsih *et al*., 2020). However, the management of the Batang Merao River currently faces various challenges, including widespread sand and gravel mining activities in the upstream areas, land use conversion from agricultural land to built-up areas, particularly along the riverbanks and riparian buffer zones, as well as the use of the river as a disposal site for domestic and livestock wastewater (Mandasari *et al*., 2020).

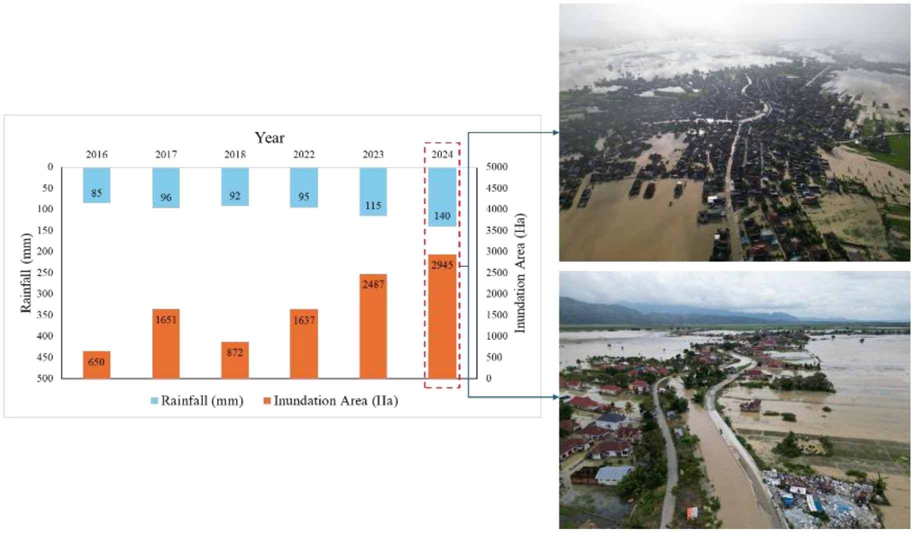

Figure 1. Flooding struck Sungai Penuh City, Jambi Province, in January 2024 due to the overtopping of the Batang Merao River

These activities have led to increased erosion and significant sedimentation within the river channel (Isma *et al*., 2024; Rentier & Cammeraat, 2022). An important measure of watershed deterioration is its hydrological state, reflected in the occurrence of erosion, landslides, sediment accumulation, and uneven flow regimes such as flooding and drought (Rezagama *et al*., 2019). As a result, the river's conveyance capacity has decreased considerably, triggering the occurrence of flood disasters. This condition necessitates a hazards assessment effort to minimize the potential for recurring flood hazards. Disaster hazards assessment is an approach used to identify and evaluate the potential negative impacts that may arise from existing hazard conditions (BNPB, 2023).

This study aims to map flood hazards in the affected areas by integrating technical, economic, and policy-based approaches. The assessment was conducted by developing flood modeling scenarios using the HEC-RAS software to simulate flood inundation under existing hydrological conditions (Sari *et al*., 2025). Flood hazards reduction scenarios were also formulated using a combination of structural measures, including river normalization, and non-structural approaches such as nature-based solutions (NBS), institutional strengthening, and the improvement of early warning systems (Agnes & Naqash, 2025; OECD, 2024; Opperman & Galloway, 2022; Pradoto *et al*., 2025). In the field of flood risk assessment, recent research highlights an increasing emphasis on socioeconomic indicators, including income, education, poverty, and land use (Farid *et al*., 2025).

To determine the optimal flood control measure, alternatives were assessed based on three primary considerations: the capacity to reduce flood inundation, the cost-effectiveness of implementation, and the feasibility of practical execution on site (Saaty, 1987; Sudarmanto, 2017). This alternative is expected to provide solutions that are not only technically and economically viable but also realistic for implementation by policymakers and local communities (Kurniawan & Fusfita, 2025). Furthermore, the disaster threat assessment was conducted in accordance with the guidelines of the Indonesian National Disaster Management Agency (BNPB), which enables the formulation of a comprehensive and measurable disaster management framework. Through this approach, it is expected that an optimal flood mitigation strategy can be formulated, featuring a minimized flood hazard index along with an action plan that is both effectively implementable and sustainable.

2. MATERIALS AND METHODS

Administratively, this study area is located in Hamparan Rawang District, Sungai Penuh City, which is affected by the overflow of the Batang Merao River (Figure 2). This research was conducted between July and August 2025. Hamparan Rawang District consists of 13 villages, namely: Campaka, Dusun Dilir, Kampung Dalam, Kampung Diilir, Koto Beringin, Koto Dian, Koto Teluk, Larik Kemahan, Maliki Air, Paling Serumpun, Simpang Tiga Rawang, Tanjung, and Tanjung Muda.

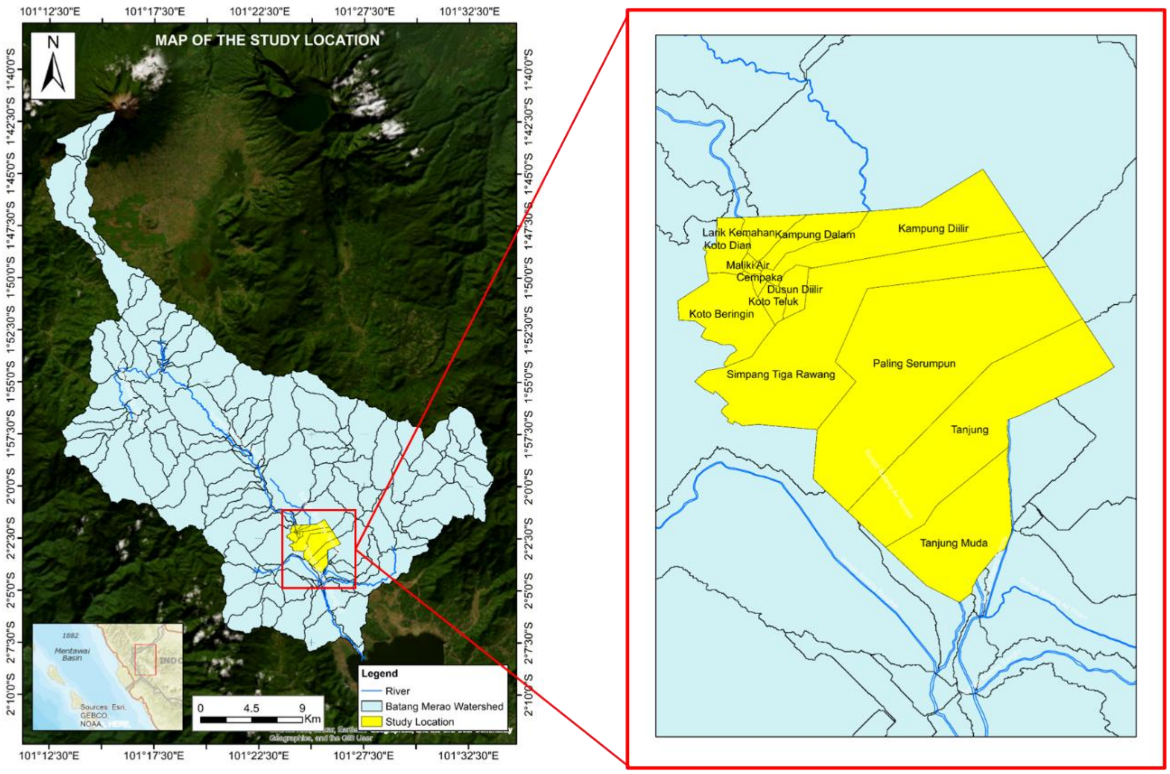

Figure 2. Map of study location in Sungai Penuh City

To complete this study, several stages of analysis are required with the objective of formulating an optimal flood mitigation strategy. The main steps in the methodology of this study are as follows:

a. The compilation of secondary data and literature reviews encompasses a variety of supporting datasets, including topographic data that reveals details about landforms and elevation, sourced from DEMNAS and Balai Wilayah Sungai Sumatera VI; and rainfall data collected from ground-station observations managed by Balai Wilayah Sungai Sumatera VI and BMKG. This rainfall dataset include 9 (nine) ground-stations, recording data from 2003 to 2023, with their spatial distribution illustrated in Figure 3. To address the limited availability of rainfall data from ground-stations, GPM satellite-based rainfall data—divided into 12 GPM grid points—were utilized and the data were calibrated using ground-station observations. Meanwhile, land-use information was drawn from the Ministry of Environment and Forestry's 2022 dataset, with the corresponding land-use map depicted in Figure 3.
b. Hydrological analysis was conducted to obtain the design flood discharge and design flood rainfall for the river using HEC-HMS, applying SCS Unit Hydrograph methods. The model was calibrated by comparing the simulated discharge at specific return periods with water level data from the nearest Water Level Observation Station.
c. Hydraulic analysis was carried out to simulate and model the river's hydraulic behavior. This analysis aims to determine whether flooding occurs within the river or water bodies and to identify its causes. One of the hydraulic modeling tools used is HEC-RAS, applying a two-dimensional flow model approach under specific hydrograph discharge boundary conditions. Model calibration was performed using historical flood inundation data to generate corresponding flood inundation extents. The same modeling procedures were applied for each proposed flood management scenario.
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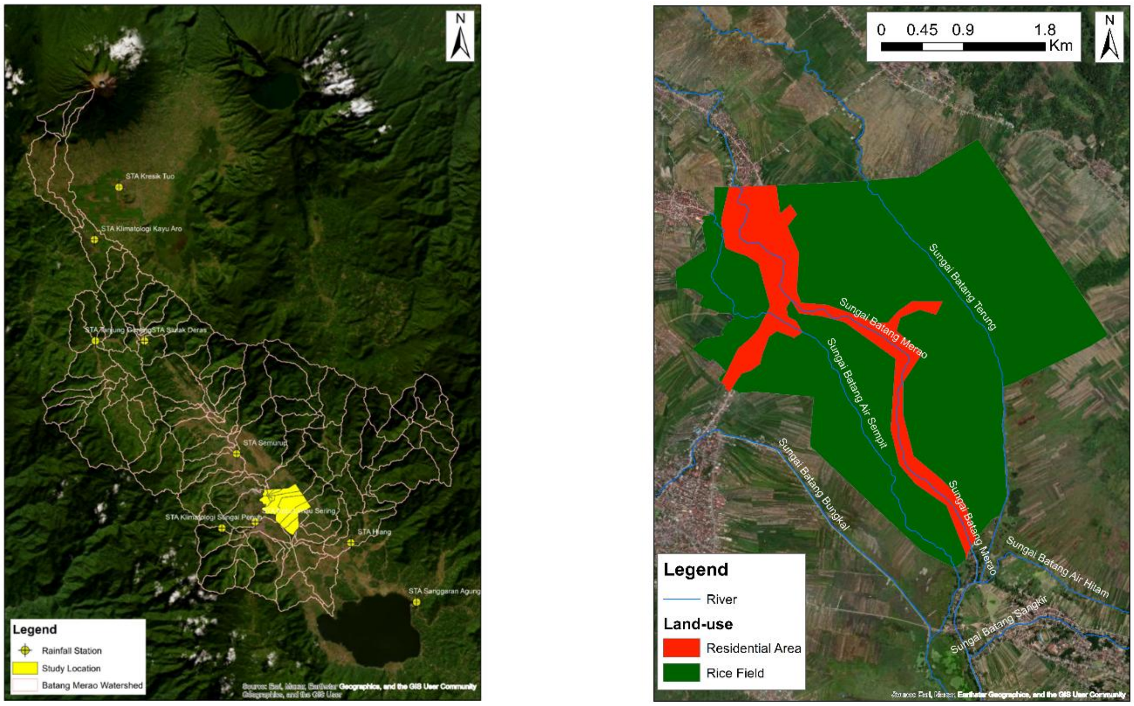


(a) (b)

Figure 3. (a) Map of rainfall stations, and (b) map of land-use in study location

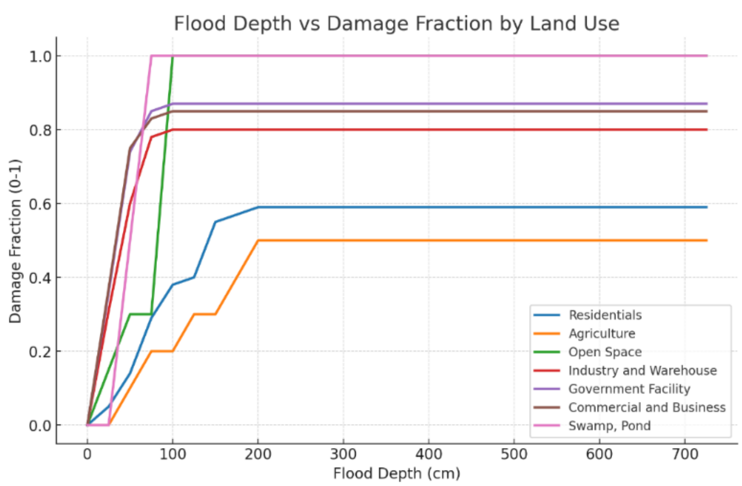


Figure 4. Damage factors based on the flood loss function (Budiyono *et al*., 2016)

e. An estimation of loss impact analysis was conducted using the ECLAC method, a technique developed and applied in Latin America and the Caribbean, also known as DaLA (Damage and Loss Assessment). The loss estimation was performed for each flood management scenario using the following equation (Budiyono *et al*., 2016):

$$\text{Loss} = (\text{Damage Quantity/Area}) \times (\text{Damage Factor}) \times (\text{Unit Value}) \quad (1)$$

where the damage quantity per affected area is obtained from the flood inundation extent resulting from the existing condition and 2 management scenarios. The damage factor is based on the flood loss function illustrated in Figure 4. The replacement unit value is determined based on the unit loss value data for each sector, as presented in Table 1.

Table 1. The replacement unit value per hectare for each land cover type in USD (Budiyono *et al*., 2016)

No	Land use class name	New maximum economic exposure value (1000 USD/ha)
1	Government facility [a]	301.0
2	Forestry	10.4
3	Industry and warehouse	517.9
4	Commercial and business	517.9
5	Residential [b]	150.6
6	Residential with greenery [c]	341.8
7	Agriculture	1.6
8	Swamp river and pond	3.8
9	Agriculture and open space	3.1

Note: [a)] Educational, public facilities, and government facilities land use, [b)] Residential land use with high and low population density, [c)] Planned residential land use.

3. RESULTS AND DISCUSSION

The study area has experienced recurring flood events in 2016, 2017, 2018, 2022, 2023, and 2024, with a progressively increasing trend in both extent and severity. The inundated area, which was initially around 650 ha in 2016, expanded significantly to approximately 2945 ha in 2024, affecting nearly all districts within Sungai Penuh City, with Hamparan Rawang District recorded as the most severely impacted. This situation has been exacerbated by the intensification of extreme rainfall, increasing from 85 mm/24 hours in 2016 to 141 mm/7 hours in 2024, accompanied by a rise in flood depths from 0.1–0.3 meters to 0.5–1.5 meters. The combination of increasing rainfall intensity, broader affected areas and deeper floodwater indicates that the vulnerability of this region has continued to escalate over the years.

3.1. Hydrology Analysis

The analysis of rainfall data was conducted using GPM-based precipitation estimates that were calibrated through ground-station observational datasets to reduce systematic errors. The overlay of the GPM satellite grid showed that the Batang Merao Watershed is covered by 12 grids. The satellite rainfall data were corrected using data from the Siulak Deras Rainfall Observation Station, as it had the highest data availability and a correlation coefficient of 0.7025 with the GPM satellite data and a Root Mean Square Error (RMSE) value of 128.96 mm/month.

The design rainfall calculation for the Batang Merao Watershed was carried out using the General Extreme Value (GEV) method with the Hydrognomon software, followed by distribution goodness-of-fit tests using the Chi-square and Smirnov-Kolmogorov methods. The resulting design rainfall values are presented in Table 2.

Table 2. Design rainfall using the GEV method in the Batang Merao Watershed

Return Period	B1/ Kresik Tuo	C1/Siulak Deras	D2/ Semurup	E3/ Hiang	E3/ BMKG
100	120.84	183.38	146.96	142.83	165.25
50	116.07	156.25	137.66	134.10	143.51
25	110.57	134.04	128.03	124.81	124.68
20	108.62	127.77	124.84	121.69	119.16
10	101.86	110.58	114.63	111.47	103.45
5	93.72	96.16	103.67	100.20	89.47
2	78.94	79.66	86.50	81.89	72.23

The runoff coefficient was analyzed by inputting a Curve Number value of 85.5 and an impervious area percentage of 4.94 as loss parameters in the HEC-HMS software. The design flood discharges using the SCS Unit Hydrograph method was calibrated against recorded discharge data at the Debai Water Level Observation Station under bankfull capacity conditions. The SCS Unit Hydrograph method showed results that more closely approximated the actual discharge, and therefore, the design flood discharge from the SCS Unit Hydrograph method was subsequently used. The flood discharge hydrograph generated by the SCS Unit Hydrograph method is presented in Figure 5.

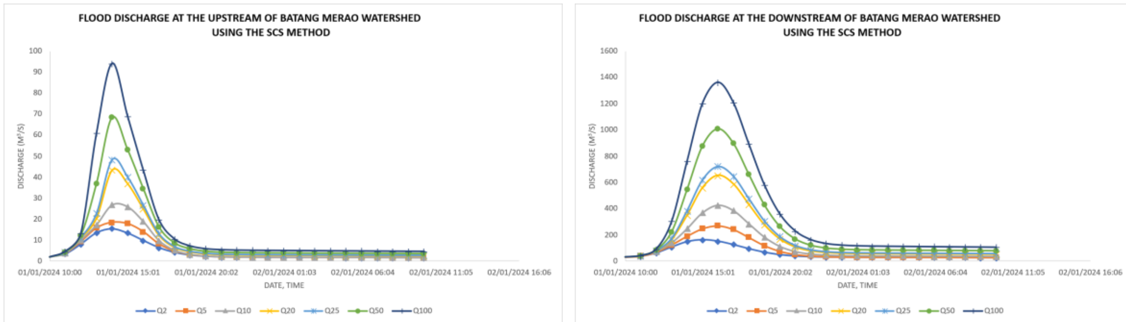


Figure 5. Design flood discharge hydrograph for the Batang Merao Watershed using the SCS unit hydrograph method: (a) Upstream area, (b) Downstream area

The flood discharge modeling results using the SCS Unit Hydrograph method required calibration. Calibration was conducted by comparing the Q2 flood discharge from the SCS Unit Hydrograph method at the Debai Water Level Observation Station (PDA Debai) with the recorded maximum and minimum discharge data. The Q2 flood discharge was 56.77 m³/s, which falls within the range of the recorded maximum discharge of 79.46 m³/s and the minimum discharge of 18.08 m³/s at the PDA Debai.

3.2. Existing Flood Inundation Analysis

Flood modeling was performed using the HEC-RAS 6.0 software with a two-dimensional (2D) flow simulation. The flood simulation was carried out using the 25-year return period flood discharge (Q25). The HEC-RAS modeling results for the flood event (Figure 6) were calibrated using flood discharge data from the Debai Water Level Observation Station.

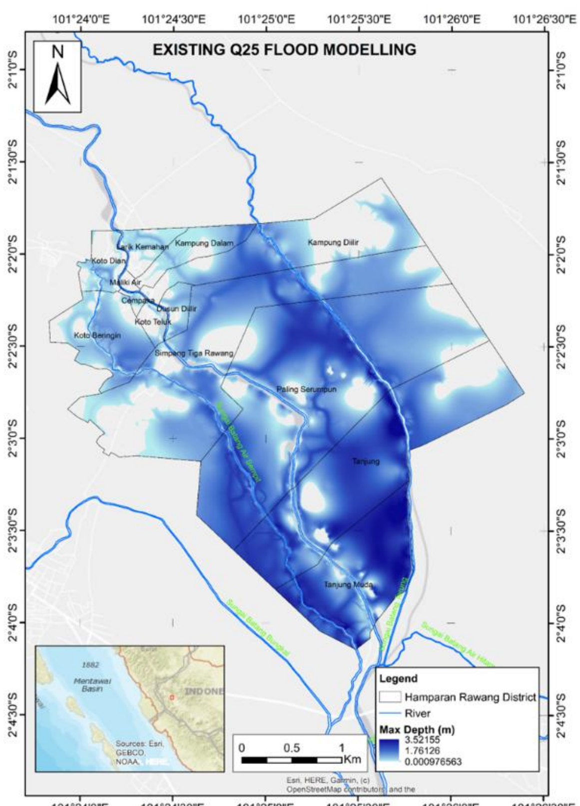


Figure 6. Results of existing Q25 flood modeling

The existing flood modeling without flood control measures in the Batang Merao Watershed, using the Q25 flood discharge, resulted in a total inundation area of 968.64 hectares. Paling Serumpun Village showed the most extensive flooding due to its lowland area. It is submerging 25.88 hectares of residential areas and 290.51 hectares of rice fields. This naturally positions the area as a functional flood retention basin. The distribution of flood inundation area by sub-district is presented in Table 3.

Table 3. Existing flood inundation area (ha) in residential area and rice field by village

Village Name	Residential Area (ha)	Rice Field (ha)	Total (ha)
Cempaka	1.69	0.00	1.69
Dusun Diilir	6.18	3.41	9.59
Kampung Dalam	3.82	17.25	21.07
Kampung Diilir	1.56	65.74	67.3
Koto Beringin	2.43	47.27	49.7
Koto Dian	5.72	4.66	10.38
Koto Teluk	2.80	0.00	2.8
Larik Kemahan	9.36	3.18	12.54
Maliki Air	0.46	0.00	0.46
Paling Serumpun	25.88	290.51	316.39
Simpang Tiga Rawang	15.86	161.26	177.12
Tanjung	10.90	177.65	188.55
Tanjung Muda	15.19	95.85	111.04
Total	**101.86**	**866.78**	**968.64**

3.3. Flood Reduction Analysis

Flood control scenarios were conducted using two approaches: scenario 1 involving river normalization, and scenario 2 combining river normalization with the construction of a retention pond. Flood mitigation through river normalization can reduce flood inundation areas, flood hazard levels, affected populations, potential losses, and overall risk. Therefore, structural flood control measures are highly recommended (Sukmajati *et al*., 2022). The river normalization design was developed by considering the minimum stream power concept for each river reach. For example, the designed river cross section dimensions at Sta +321 to Sta +466 (Figure 7) are as follows:

a. Designed minimum river bed slope is 0.001097.
b. River width is determined to be 20 meters.
c. The planned river depth is 5.1 meters.

The retention pond is planned by utilizing existing wetland areas based on a NBS concept. The wetland area will be cleared of vegetation to increase its water storage capacity while maintaining the natural soil material as the pond embankment. The proposed locations for the retention ponds are along the Batang Terung River and Batang Bungkal River which are tributaries of the Batang Merao River. The planned surface areas of the retention ponds are 201.7 ha and 69.88 ha, with each pond designed to a depth of 3 meters. Retention pond shows in Figure 8.

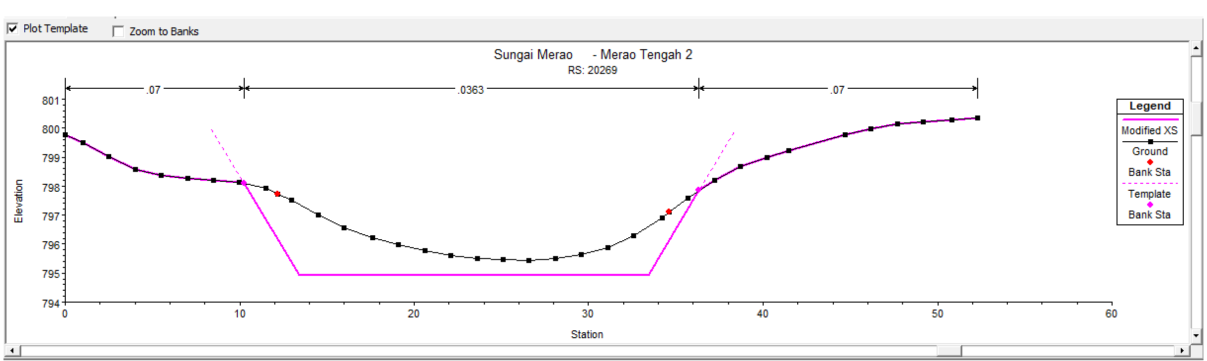


Figure 7. Designed river cross section

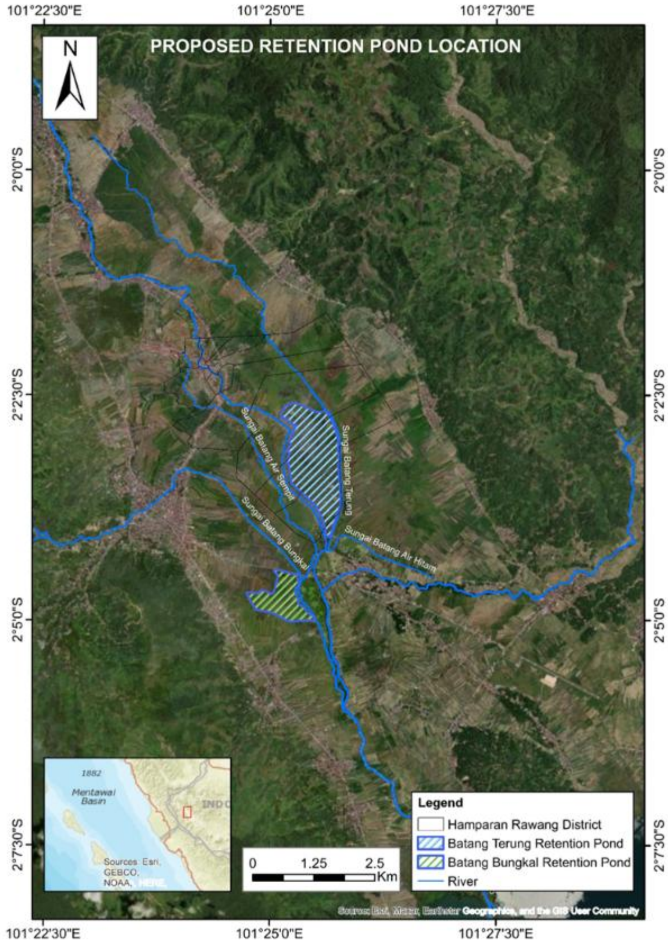
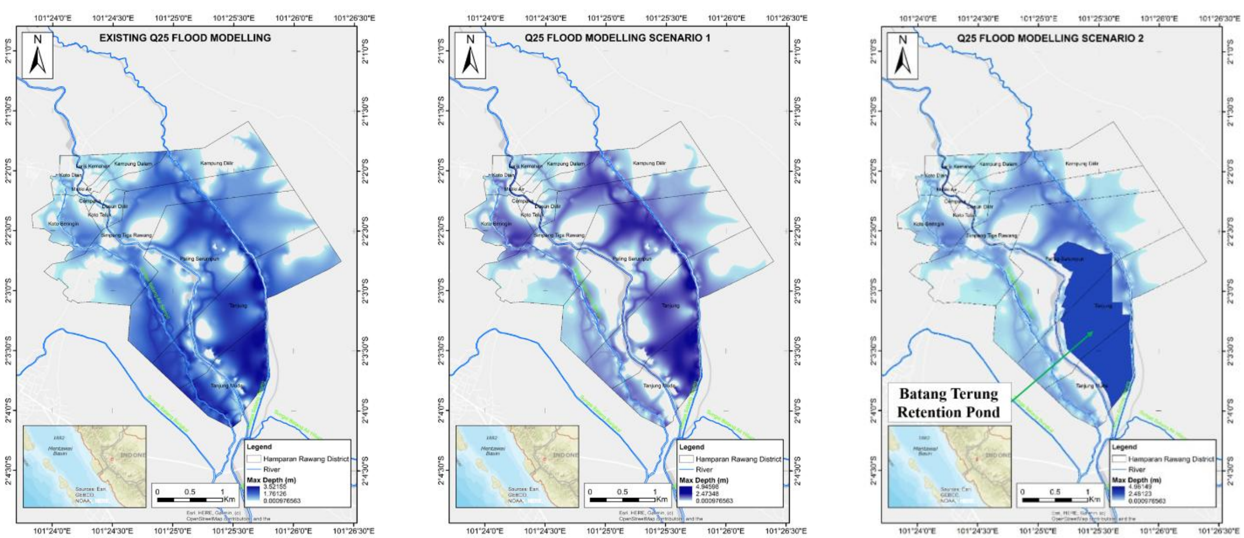


Figure 8. Proposed retention pond location



(a) (b) (c)

Figure 9. Result of flood modeling: (a) existing Q25, (b) scenario 1 Q25, (c) scenario 2 Q25

The flood modeling results for the Q25 scenario under scenario 1 showed a total flood inundation reduction of 17% compared to the existing inundation area. However, flood inundation remained in residential areas covering 79.23 hectares and rice fields covering 723.55 hectares. Meanwhile, flood modeling results for the Q25 in scenario 2 achieved a total flood inundation reduction of 19% from the existing condition. Flood inundation still occurred in 74.85 hectares of residential areas and 705.66 hectares of rice fields.

Flood modeling results for scenarios 1 and 2 indicate a reduction in the total flood inundation area. However, this reduction is inversely proportional to the increase in maximum flood depth, which reached 3.5 meters under existing conditions, 4.95 meters in scenario 1, and 4.96 meters in scenario 2. Comparison of flood inundation reduction for each scenario on village is presented in Table 4 and Figure 9.

Table 4. Comparison of flood inundation area by village for each scenario

Village Name	**Inundation Area (Ha)**					
	Existing Inundation		**Scenario 1**		**Scenario 2**	
	Residential Area	**Rice Field**	**Residential Area**	**Rice Field**	**Residential Area**	**Rice Field**
Cempaka	1.69	0.00	0.47	0.00	0.53	0.00
Dusun Diilir	6.18	3.41	5.67	3.41	5.58	3.41
Kampung Dalam	3.82	17.25	3.60	15.91	3.58	15.81
Kampung Diilir	1.56	65.74	1.54	47.30	1.52	43.14
Koto Beringin	2.43	47.27	1.65	48.96	1.77	49.13
Koto Dian	5.72	4.66	7.14	4.83	7.23	4.84
Koto Teluk	2.80	0.00	1.98	0.00	2.00	0.00
Larik Kemahan	9.36	3.18	9.25	3.18	9.16	3.16
Maliki Air	0.46	0.00	0.64	0.00	0.64	0.00
Paling Serumpun	25.88	290.51	17.82	230.47	16.72	228.40
Simpang Tiga Rawang	15.86	161.26	15.70	140.09	15.70	133.44
Tanjung	10.90	177.65	6.88	145.73	4.89	139.63
Tanjung Muda	15.19	95.85	6.89	83.68	5.52	84.68
Total	101.86	866.78	79.23	723.55	74.85	705.66
Difference			22.63	143.23	27.01	161.12
Reduction			22.22%	16.52%	26.51%	18.58%
Total Reduction			18.74%		45.09%	

Table 5. Damage factors

No	**Depth (m)**	**Damage Factor**	
		Residential Area	**Rice Field**
1	< 0.76	0.12	0.08
2	0.76 – 1.5	0.44	0.27
3	> 1.5	0.59	0.49

Table 6. Flood damage and loss calculation

Scenario	**Depth**	**Damage Factor**		**Inundated Area**		**Loss Value**		**Total Loss (USD)**	**Total Loss (IDR)$**	**Reduction**	
				RA	**RF**	**RA***	**RF†**				
	(m)	**RA**	**RF**	**(Ha)**	**(Ha)**	**(10^3 USD)**	**(10^3 USD)**	**(10^3)**	**(10^6)**	**(10^6 IDR)**	**(%)**
Existing	<0.76	0.12	0.08	41.51	240.99	750.89	29.88	5,856.787	95,238,98		
	0.76-1.5	0.44	0.27	27.99	297.16	1860.59	126.94				
	>1.5	0.59	0.49	32.03	327.87	2832.67	255.82				
Scenario 1	<0.76	0.12	0.08	52.37	407.84	947.42	50.57	3,175.351	51,635,33	43,603,65	45.78
	0.76-1.5	0.44	0.27	16.08	206.21	1068.76	88.08				
	>1.5	0.59	0.49	10.58	109.02	935.46	85.06				
Scenario 2	<0.76	0.12	0.08	47.93	348.83	867.04	43.25	3,273.933	53,238,41	42,000,57	44.10
	0.76-1.5	0.44	0.27	11.27	129.79	748.90	55.44				
	>1.5	0.59	0.49	15.62	227.73	1381.62	177.68				

Note: RA = Residential Area; RF = Rice Field; *) Unit value = 150.6; †) Unif value = 1.6; $) Currency = 16,261.30 IDR/USD

3.4. Damage and Loss Analysis

Flood losses were calculated using the ECLAC (Economic Commission for Latin America and the Caribbean) methodology, based on the affected area, unit value in USD per hectare, and damage factors. The unit value for residential areas was 150.6×10^3 USD/ha, while for rice fields it was 1.6×10^3 USD/ha. Flood depth, classified according to BNPB Regulation No. 2 of 2012, was used as a variable to determine the damage factors (Table 5). Calculation of flood-related losses for each scenario is presented in Table 6.

The results of the flood loss calculation indicate that scenario 1 provides the highest reduction in economic losses. This is because the ECLAC method takes into account flood depth in determining the damage factor, where deeper inundation results in a higher damage factor and consequently greater economic losses. Scenario 1, which involves river normalization, proved to be more effective in reducing flood losses compared to scenario 2 (combination of river normalization and retention pond).

4. CONCLUSIONS

Results of the inundation area analysis showed that the existing inundation area covered 968.64 hectares, equivalent to 80% of the total area of Hamparan Rawang District (1210.39 hectares). Scenario 1, which involves flood control through river normalization, was able to reduce the inundation area by 165.86 hectares, equivalent to 38.74% of the existing inundation area. Meanwhile, scenario 2, involving flood control through river normalization combined with retention ponds, reduced the inundation area by 188.13 hectares, or 45.09% of the existing inundation area.

In terms of reducing flood-related economic losses, scenario 1 proved to be more effective, achieving a reduction of IDR 43.60 billion, equivalent to 45.78% of the existing losses, which amounted to IDR 95.24 billion. Meanwhile, scenario 2 was only able to reduce losses by 44.10% of the existing value. Therefore, scenario 2 was selected as the preferred flood management option for reducing inundation area, while scenario 1 was selected as the preferred option for reducing flood-related economic losses.

AUTHOR CONTRIBUTION STATEMENT

Author	C	M	So	Va	Fo	I	R	D	O	E	Vi	Su	P	Fu
AF	✓		✓								✓		✓	✓
EON		✓		✓						✓		✓		
ARP					✓	✓								
MWS									✓					
ATA							✓	✓						

C: Conceptualization	Fo: Formal Analysis	O: Writing - Original Draft	Fu: Funding Acquisition
M: Methodology	I: Investigation	E: Writing - Review & Editing	P: Project Administration
So: Software	D: Data Curation	Vi: Visualization	
Va: Validation	R: Resources	Su: Supervision	

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