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Hydrographic Analysis of Oyo Hilir River Flood using SCS-CN Method with HEC-HMS and HEC-RAS 6.6 Integrated Modeling

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ABSTRACT

The Oyo Hilir River in Bantul Regency is an area with a high level of flood vulnerability due to rainfall intensity, changes in land use, and river morphological characteristics. Repeated flooding events have an impact on community activities in downstream areas. This study aims to analyze the flood discharge of the Oyo Hilir River design and map the distribution and area of the flood-affected area based on the classification of inundation depth. The research was conducted on the Oyo Watershed (DAS) with a focus on the downstream segment of the river along ±14 km, starting from the confluence of the Oyo–Urang River to the Oyo–Opak River. The data used included rainfall for the period 2004–2023, Digital Elevation Model (DEM), and data on the characteristics of supporting watersheds. Hydrological analysis was carried out through rainfall frequency analysis using AProb and flood hydrographic modeling using the Soil Conservation Service–Curve Number (SCS-CN) method on HEC-HMS, which was then used as an input for two-dimensional hydraulic modeling using HEC-RAS version 6.6. The results showed that the peak discharge of the flood at the 2-year return period was 307.6 m³/second with a peak time at the 16th hour. The largest affected area is in Selopamioro Village, Imogiri District, with an inundation area of 323.62 ha dominated by high flood depth (>3 m). The results of this study are expected to be the basis for flood mitigation planning and sustainable management of the Oyo Hilir River.

INTRODUCTION

Indonesia, as an archipelagic country with tropical climate characteristics, has a high level of vulnerability to hydrometeorological disasters, especially floods. Flooding events often occur during the rainy season and have a significant impact on social, economic, and environmental aspects (Razikin et al., 2017). High-intensity rainfall that is not offset by the capacity of rivers to channel stream discharges is one of the main triggers for overflows, especially in downstream areas, which generally have relatively flat topography and high land use pressure (Sholikha et al., 2022). This condition shows that flooding is a complex hydrological problem and requires an adequate analytical approach.

The complexity of flood problems is increasing along with the dynamics of land use changes and the growth of built-up areas along riverbanks. The conversion of natural land into impermeable areas contributes to a decrease in infiltration capacity and an increase in surface runoff, which ultimately has an impact on increasing peak flood discharge and inundation areas (Hermawan & Ardian, 2025). This phenomenon emphasizes that flood analysis cannot be carried out partially but rather needs to consider the relationship between watershed hydrological characteristics, river morphology, and land-use changes.

Bantul Regency is one of the areas that has a high level of vulnerability to flooding, especially in the Oyo Hilir River segment, which is part of the Opak watershed system. The Oyo River receives accumulated flows from upstream areas with extensive watershed coverage before emptying into the Opak River, so that its downstream part becomes a zone of stream discharge concentration during periods of intense rainfall. This condition is in line with the general characteristics of downstream areas of rivers, which have a higher overflow potential due to the accumulation of flows from upstream and limited channel capacity in channeling flood discharges (AL-Hussein *et al.*, 2022; Shuaibu *et al.*, 2023).

The flooding events that have occurred in the Oyo River in recent years show that the flood problem in this region is not just an incidental event but reflects the condition of vulnerability that takes place repeatedly. The overflow of the river that occurs during the rainy season causes inundation in residential areas along the riverbanks, especially in the downstream segment, which has limited channel capacity. In some instances, inundation not only impacts the residential environment but also triggers damage to access infrastructure as well as erosion of riverbanks, which indicates high flow energy as river discharge increases. The pattern of repeated flooding events shows that the increase in stream discharge due to intense rains in the upstream area has not been fully accommodated by the river system downstream, so that overflows and inundation become a recurring phenomenon from time to time.

In this context, flood hydrographic analysis plays an important role in representing the watershed's response to rainfall events, including the magnitude of peak discharge, the time to the peak, and the characteristics of the river flow (Sory et al., 2025). Flood hydrographic information is the basis for watershed management planning, river capacity evaluation, and the preparation of risk-based flood mitigation strategies. Therefore, reliable hydrological modeling is a crucial first step in flood studies before hydraulic analysis is carried out.

As research progresses, various studies have applied hydrological and hydraulic modeling to analyze flooding in various watersheds. The integration of HEC-HMS and HEC-RAS is widely used to simulate the formation of flood discharge as well as to map the distribution of inundation, with *the Soil Conservation Service–Curve Number* (SCS-CN) method being a common approach in rain-flow analysis (Al-Hussein *et al.*, 2022; El-Bagoury & Gad, 2024). The use of geographic information systems (GIS) has helped improve the accuracy of spatial representations of hydrological and hydraulic parameters in flood modeling (Peker et al., 2024; Yousfi et al., 2023).

Recent studies also emphasize the importance of two-dimensional hydraulic modeling in describing the complexity of flow and distribution of inundation in floodplain areas, especially in the downstream segment of rivers with heterogeneous morphological characteristics (Xafoulis et al., 2023). At the national level, some studies still focus on one-dimensional hydraulic analysis or rain-flow studies without continuing with spatial inundation analysis, as shown in the study (Senjawati et al., 2025). This condition shows that the relationship between the formation of flood hydrographs and inundation patterns in the downstream areas of the river has not been widely studied in an integrated manner.

A review of previous studies shows that flood studies are generally still conducted by separating hydrological and hydraulic analyses. Rainfall modeling is largely focused on the formation of flood discharge, while hydraulic analysis often emphasizes only channel capacity or separate inundation mapping. As a result, the relationship between the characteristics of the flood hydrograph and the distribution and extent of inundation, especially in the downstream areas of the river, has not been fully described comprehensively.

This study applies integrated flood modeling using HEC-HMS with *the Soil Conservation Service–Curve Number* (SCS-CN) method and HEC-RAS version 6.6 to analyze flood hydrographs and map the distribution and extent of inundation due to the overflow of the Oyo Hilir River, Bantul Regency. The approach used connects rain–flow response analysis with two-dimensional hydraulic modeling spatially so that flood discharge characteristics and inundation patterns can be represented more comprehensively. The results of this study are expected to enrich the study of integrated flood modeling and support flood mitigation planning efforts in downstream areas with high levels of vulnerability.

RESEARCH METHODS

Hydrological analysis was carried out on the Oyo watershed, while flood modeling was focused on the Oyo Hilir River in the segment of the Oyo-Urang River to the Oyo-Opak River along the ±14 km, which crosses Kapanewon Dlingo and Imogiri, Bantul Regency. The location and boundaries of the study area are presented in Figure 1.

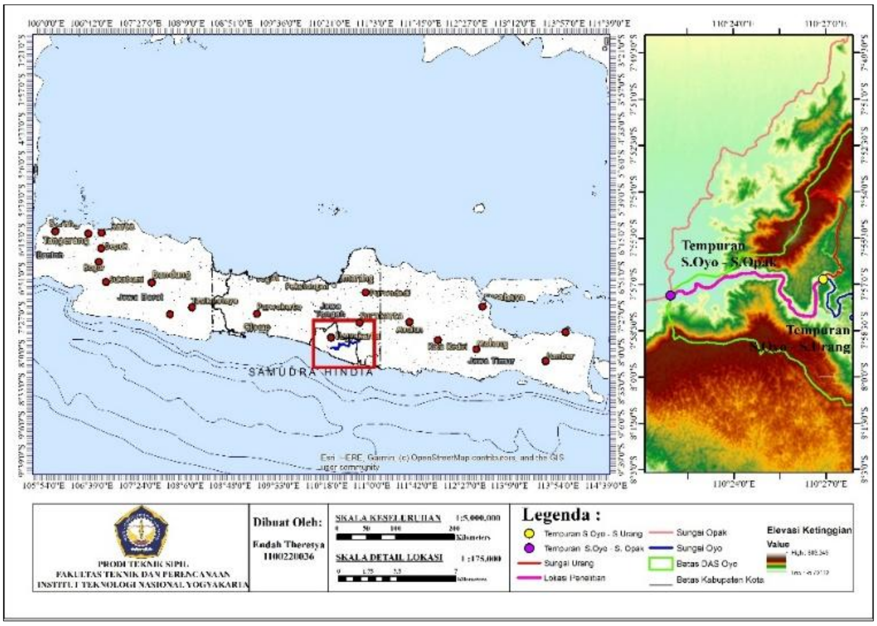

Figure 1. Map of the Research Location

Research Data Collection

This study uses a combination of primary data and secondary data as the basis for flood analysis. Secondary data is obtained from various related agencies and *open-source* sources, while primary data is collected through direct observation in the field to support and validate the secondary data. The types, needs, and data sources used in this study are presented in a concise manner in Table 1. All of this data is used as the main input data in the modeling process.

Tabel 1. Data Needs and Sources

No	Data Name	Data Type	Data Source
1.	Data Digital Elevation Model DEM	Seconds	Geospasial Indonnesia
2.	Land Cover Data	Seconds	Geospasial Indonnesia
3.	Rainfall Data	Seconds	BBWS Serayu Opak, Direktorat Jenderal Sumber Daya Air
4.	Metered Debit Data	Seconds	BBWS Serayu Opak, Direktorat Jenderal Sumber Daya Air
5.	Administrative Limits	Seconds	Geospasial Indonesia

Rain Frequency Analysis

The rainfall data analyzed is the regional rainfall obtained from the processing of point rain data at the rain station representing the Oyo Watershed. Rainfall data in the area is used as a basis for frequency distribution analysis to obtain planned rainfall.

Frequency distribution analysis was carried out to identify the most suitable type of probability distribution in representing rainfall data so that the planned rainfall was obtained, which was used as the basis for calculating flood discharge. Frequency analysis aims to evaluate the relationship between the magnitude of extreme rainfall events and the frequency of their occurrences through a probability distribution approach (Triatmodjo, 2008). The distribution types considered include normal, log-normal, Gumbel, and Pearson log type III distributions, with the determination criteria as presented in Table 2.4. The suitability of the distribution is verified using the chi-squared test and the Smirnov–Kolmogorov test.

Tabel 2. Statistical Parameters for Determination of Distribution Types

No	Parameter Statistics	Requirements
1.	Normal	$(\bar{x} \pm s)$ = 68,27 %
2.	Log Normal	$(\bar{x} \pm 2s)$ = 95,44 %
3.	Gumbel	Cs ≈ 0
4.	Log Pearson Tipe III	Ck ≈ 3

Hourly Rainfall Distribution

The distribution of rainfall during the periods is compiled to form *a hyetograph* as an input for hydrological analysis, considering that the available rainfall data is generally in the form of daily rainfall (Triatmodjo, 2008). In this study, *the hyetograph* plan was compiled using *the Alternating Block Method* (ABM) based on *the Intensity–Duration–Frequency* (IDF) relationship. Rainfall is distributed over n consecutive time intervals with a duration of Δt.

$$Td = n\Delta t \tag{1}$$

The intensity of the rain at each time interval is converted to the depth of the rain and rearranged by placing the maximum intensity in the middle of the duration of the event, while the other blocks are placed alternately on both sides. The resulting rainfall patterns are then used as input in hydrological modeling (Triatmodjo, 2008; Yani et al., 2021).

HEC-HMS Hydrological Modeling

Hydrological modeling was carried out using *Hydrologic Engineering Center–Hydrologic Modeling System* (HEC-HMS) software to simulate the runoff rain response in the Oyo Watershed (DAS) based on the physical characteristics of the study area (Munajad & Suprayogi, 2021). The watershed model was compiled through a delineation process using topographic data and Geographic Information Systems (GIS), which produced sub-watershed elements and river networks to the output point downstream. Hour-to-day rain data from the planned rain distribution is used as input to the meteorological model, while the simulation time specification is determined according to the duration of the analyzed rain event (Sujono, 2023). In runoff rain simulation, *the Soil Conservation Service–Curve Number* (SCS-CN) method was used to calculate rainfall loss, while the effective transformation of rain into runoff was carried out using the SCS *Unit Hydrograph* (Triatmodjo, 2008).

The validation of the HEC-HMS model is carried out as a verification stage by comparing the model output to field observation data without going through a calibration process. Evaluation was carried out through visual and statistical approaches, where the hydrograph pattern of discharge from the simulation was compared with the observation hydrograph, and the model performance was assessed using *the Nash–Sutcliffe Efficiency* (NSE) index, *Root Mean Squared Error–Standard Deviation Ratio* (RSR), and *Correlation Coefficient* (R) (USACE, 2022; Ciptadi et al., 2024; Setiyowati et al., 2025). The interpretation of the performance model refers to the statistical equations used as well as the classification of NSE and RSR values as presented in Table 3 (Moriasi et al., 2007).

$$NSE = 1 - \left[\frac{\sum_{i=1}^{n}(x_i - y_i)^2}{\sum_{i=1}^{n}(x_i - x_i^{average})^2}\right] \tag{2}$$

$$RSR = \frac{RMSE}{STDEV_{obs}} = \left[\left[\frac{\sqrt{\sum_{i=1}^{n}(x_i - y_i)^2}}{\sqrt{\sum_{i=1}^{n}(x_i - x_i^{average})^2}}\right]\right] \quad (3)$$

$$R = \left[\frac{\sum_{i=1}^{n}(x_i - x_i^{average})(y_i - y_i^{average})}{\sqrt{\sum_{i=1}^{n}(x_i - x_i^{average})^2}\sqrt{\sum_{i=1}^{n}(y_i - y_i^{average})^2}}\right] \quad (4)$$

dimana:

x_i = Observation value (field data) at time

y_i = Value of model/simulation results at time i

$x_i^{average}$ = Average observation data during the analysis period

$y_i^{average}$ = Average simulation results over the analysis period

n = Total amount of data

Tabel 3. Reliability Classification of NSE, RSR and R Parameter Models

Classification	NSE	RSR	R
Excellent	0,80 < NSE ≤ 1,00	0,00 < RSR ≤ 0,50	0.85 < R ≤ 1.00
Good	0,70 < NSE ≤ 0,80	0,50 < RSR ≤ 0,60	0.75 < R ≤ 0.85
Satisfying	0,50 < NSE ≤ 0,70	0,60 < RSR ≤ 0,70	0.60 < R ≤ 0.75
Unsatisfactory	NSE ≤ 0,50	RSR > 0,70	R ≤ 0.60

Hidraulika Analysis

Hydraulic analysis was carried out to determine the capacity of the Oyo River channel to withstand flood flows and map the distribution of inundation in the downstream area (Rahmadhani et al., 2024). Hydraulic modeling was carried out using HEC-RAS 2D with peak flood discharge from hydrological modeling as the upstream boundary condition. The results of the two-dimensional simulation are then processed in the Geographic Information System (GIS) to produce a flood inundation map. The area and depth of the resulting inundation are then classified based on the provisions of the Head of BNPB Regulation Number 2 of 2012 as the basis for the analysis of flood-affected areas.

RESULTS AND DISCUSSION

The results of this study include hydrological analysis and integrated flood modeling to describe the flood characteristics of the Oyo Hilir River at the 2-year anniversary. The stages of analysis were arranged sequentially to ensure the relationship between rain-flow response, the formation of flood discharge, and its impact on the downstream area of the river.

Hydrological Analysis

The hydrological analysis begins with the determination of regional rainfall using the Thiessen polygon method to represent the spatial distribution of rainfall in the Oyo Watershed. The resulting regional rainfall was then analyzed by frequency to determine the 2-year re-design rainfall with the help of Aprob 5.1 software, where the selection of probability distributions was based on the best statistical suitability to historical rainfall data.

The designed rain obtained was then distributed into rain hours using the Alternating Block Method with a rain duration of 6 hours. The selection of the duration takes into account the characteristics of rain in Indonesia and is supported by findings (Yani et al., 2021) that show the suitability of the ABM method for a rain duration of 6 hours. The distribution of rainfall overtime analysis results is presented in Table 4 and is used as the main input in hydrological modeling using HEC-HMS to form a hydrograph of the Oyo watershed flood.

Tabel 4. Hourly Rainfall Distribution Values (ABM Method) for a 2-Year Return Period

t (Hour)	I (mm/hour)	P (mm)	ΔP (mm)	Dist ABM (mm)	%	Dist ABM P_2
1	21,49	21,49	21,49	2,63	6,75	4,18
2	13,54	27,08	5,59	3,92	10,03	6,22
3	10,33	31,00	3,92	21,49	55,03	34,12
4	8,53	34,12	3,12	5,59	14,30	8,87
5	7,35	36,75	2,63	3,12	7,99	4,95
6	6,51	39,06	2,30	2,30	5,90	3,66
			∑	**39,1**	**100,0**	**62,00**

HEC-HMS Hydrological Modeling and Validation

Hydrological modeling of the Oyo watershed was carried out using HEC-HMS with the Soil Conservation Service–Curve Number (SCS-CN) approach. The main parameters of modeling include Curve Number (CN), percentage of watertight areas, and lag time, which plays a role in controlling the amount of runoff, watershed response speed, and hydrographic shape of flooding. The values of the modeling parameters are presented in Table 5.

Tabel 5. Oyo Watershed Hydrological Modeling Parameters

Parameter	Value	Units
Curve Number (CN)	77,238	-
Impervious Area	17,229	%
Lag Time	13,503	Hour

A Curve Number (CN) value of 77.238 indicates a relatively high tendency for surface runoff due to limited infiltration capacity and the contribution of built-up areas. This condition has direct implications for the formation of the peak discharge at the 2-year relapse of 307.6 m^3/second, which occurred at the 16th hour, indicating that the increase in rainfall is effectively rapidly converted into surface flow. These findings are in line with Al-Hussein et al. (2022), who stated that high CN values correlate with an increase in peak discharge due to decreased watershed infiltration capacity.

In addition, a lag time of 13,503 hours indicates that the flow concentration process from upstream to downstream takes place in a limited time span, so that the combination of high CN and relatively short lag time accelerates the accumulation of discharge in the downstream segment. This pattern is consistent with the study of Fadila and Purboseo (2022) which recorded the peak discharge of the Oyo watershed at the 2-year anniversary of 437.60 m^3/second and increased to 959.60 m^3/second at the 10-year restore, as well as Saputra et al. (2019) who identified the maximum discharge of the Opak River at 2,185.4 m^3/second with the dominant contribution of the Oyo River of 1,576.5 m^3/second which triggered an overflow along 7.6 km. Although the discharge in this study was lower due to differences in regional scale and re-periods, the rapid response tendency and significant contribution of the Oyo stream showed comparable hydrological characteristics and emphasized the importance of runoff control in the upstream region to reduce flood risk in the downstream segment.

Model validation was carried out through visual comparison between simulated hydrographs and observation discharges of the Kedung Miri Air Suspect Post for the period 5–17 March 2020, as well as quantitative evaluation using *Nash–Sutcliffe Efficiency* (NSE), *Root Mean Square Error Ratio* (RSR), and *Correlation Coefficient* (R) parameters. The results of the hydrograph comparison are shown in Figure 2, while a summary of the model performance is presented in Table 6, which shows that the HEC-HMS model can represent the flow response of the Oyo watershed well.

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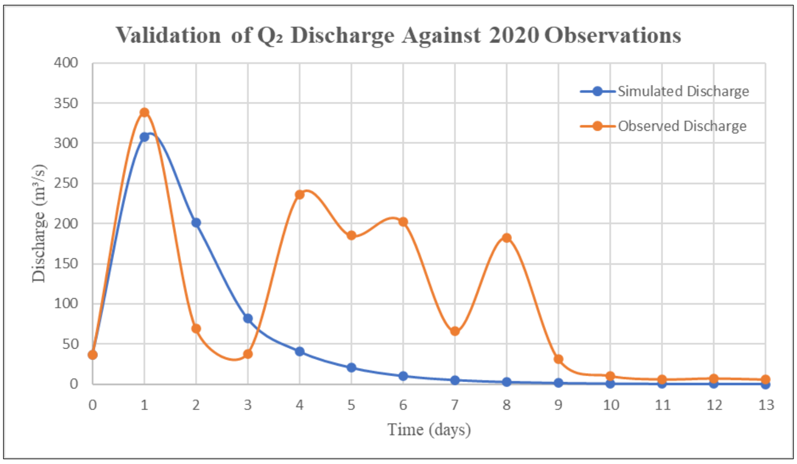

Figure 2. Validation of Simulation Discharge for 2 Years on Observation Discharge on March 5 – 17, 2020

Tabel 6. Statistical Parameter Values of HEC-HMS Model Validation

Parameters Statistics	Value	Category
NSE	0,692	Satisfying
RSR	0,555	Good
R	1	Excellent

Hydraulic Modeling and Flood Inundation Distribution

Hydraulic analysis was carried out using HEC-RAS version 6.6 with a two-dimensional modeling approach to simulate the flow and distribution of flood inundation in the Oyo Hilir River. Modeling was carried out on a ±14 km long river segment using flood discharge during a 2-year repetition of the results of HEC-HMS hydrological modeling as a boundary condition. This modeling process produces flow profile information and the distribution of flood inundation, which is used as the basis for vulnerability analysis of downstream areas.

Based on the modeling results carried out, two-dimensional hydraulic simulations showed the occurrence of overflows in several parts of the Oyo Hilir River, which triggered inundation in the surrounding floodplain area. The visualization of the distribution of flood inundation at the 2-year anniversary is presented in the form of an inundation map in Figure 3, which illustrates the spatial distribution of flood-affected areas along the downstream segment of the river.

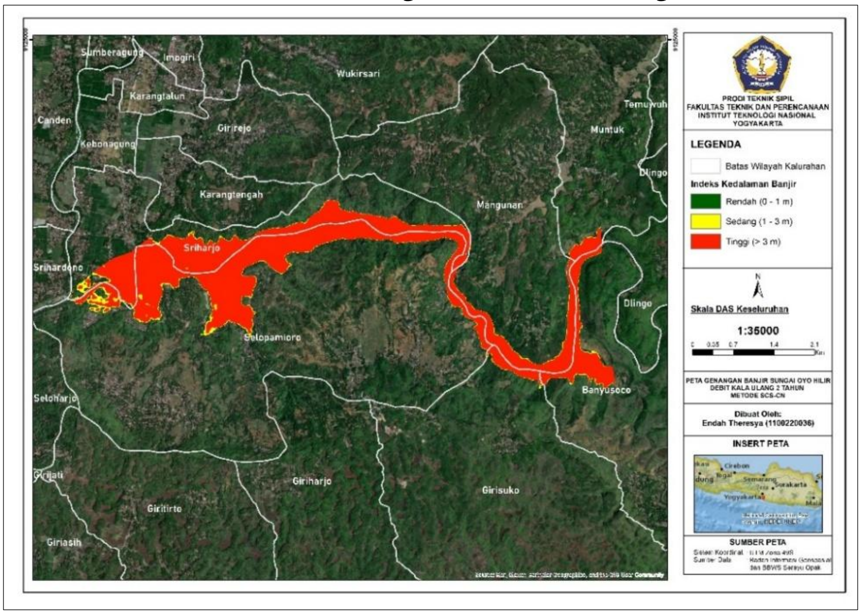

Figure 3. Map of Oyo River Flood Inundation Downstream Q2 Year

Information on the area affected by floods from hydraulic modeling is then analyzed based on the division of administrative areas and presented in Table 7. This analysis provides a quantitative overview of the distribution of flood inundation in each area in the Oyo Hilir River, thus allowing the identification of areas with relatively higher levels of flood exposure.

Tabel 6. Urban Area Affected by Floods Q2 Year

Village	Sub-distric	Districts	Depth (m)	Flood Prone Index Class	Wide (m^2)	Wide (ha)
Selopamioro	Imogiri	Bantul	0-1	Rendah	71.038,23	7,10
			1-3	Sedang	185.337,82	18,53
			>3	Tinggi	2.979.982,63	298,00
			Total		**3.236.358,68**	**323,62**

Based on the results of the analysis of the area of flood inundation, it shows that the overflow of the Oyo Hilir River produced inundation covering an area of 323.62 ha in Selopamioro Village, with 298.00 ha, or about 92%, included in the category of depth of >3 m. Significant inundation depth represents the accumulation of discharge from the upstream region concentrated in the downstream segment with limited channel capacity, thereby increasing the potential for damage and safety risks. This finding is in line with Shuaibu et al. (2023), who stated that the concentration of flows in the downstream area is the main factor in the formation of deep inundation when the flow capacity is unable to accommodate flows from upstream.

These conditions show a direct relationship between the hydrological parameters and the characteristics of the inundation that is formed. Relatively high CN values and watershed responses that take place over a limited time span contribute to the formation of peak discharges that exceed the capacity of the groove, resulting in the dominance of high-depth inundation. These results strengthen the two-dimensional integrative approach of HEC-HMS and HEC-RAS as stated by Peker et al. (2024), while emphasizing that mitigation strategies should be directed at runoff control in upstream areas through increasing watershed infiltration capacity and regulating land use to reduce the risk of deep inundation in a sustainable manner.

The findings of the modeling results are reinforced by the actual flooding events documented in the Oyo River. The overflow of the river in 2017 in Bantul Regency reportedly caused residents' houses to collapse and damage to road infrastructure due to high water levels and flow energy during the intense rainy period (DetikNews, 2017). In addition, the overflow of the Oya River in 2024 will result in the collapse of the river talut and the submersion of agricultural land in the Semin area (DetikJogja, 2024). This empirical fact shows that the capacity of the river channel under certain conditions cannot accommodate flood discharge, so it is in line with the results of two-dimensional hydraulic simulations that show the dominance of high-depth inundation (>3 m) in the downstream segment.

CONCLUSION

This study succeeded in analyzing the flood characteristics of the Oyo Hilir River through integrated hydrological and hydraulic modeling. Hydrological modeling using HEC-HMS using *the Soil Conservation Service–Curve Number* (SCS-CN) method resulted in a 2-year (Q2) peak flood discharge of 307.6 m^3/second with a peak time at the 16th hour, which shows the important role of *the Curve Number* (CN) value in controlling the magnitude of surface runoff and the flood discharge formed.

The validation results showed a match between the discharge of the simulation results and the observation data, both based on visual comparison of hydrographs and quantitative evaluation using *the parameters of Nash–Sutcliffe Efficiency* (NSE), *Root Mean Square Error Ratio* (RSR), and *Correlation Coefficient* (R). These findings suggest that the HEC-HMS application can be used for the analysis of the planned flood discharge in the Oyo Hilir River, although there are still limitations in the availability of hydrological data.

The integration of hydrological modeling results with two-dimensional hydraulic modeling using HEC-RAS version 6.6 can describe the spatial distribution of flood inundation. On the 2-year anniversary, the area with the widest inundation was in Selopamioro Village, with a total affected area of 323.62 ha, consisting of 7.10 ha of low-depth inundation, 18.53 ha of medium depth, and 298.00 ha of high depth. The dominance of high-depth inundation around the main river channel indicates the limited capacity of the Oyo Hilir River in draining the planned flood discharge, with the classification of inundation depth referring to the Regulation of the Head of BNPB Number 2 of 2012.

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