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The Impact of Land Use on Flood Management: A Case Study of the Banjir Kanal Barat River in Semarang with HEC-RAS

Shevananda Arifianto[1*], Ussy Andawayanti[2], Sumiadi[2]

[1] Master Program in Water Resources Engineering, Faculty of Engineering, Universitas Brawijaya, Malang, Indonesia.
[2] Department of Water Resources Engineering, Faculty of Engineering, Universitas Brawijaya, Malang, Indonesia.

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Corresponding Author:
Shevananda Arifianto
shevananda.arifianto@gmail.com

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Abstract: Urban flooding is influenced by land use change, rainfall characteristics, river conveyance capacity, and downstream tidal conditions. This study evaluates the effect of land use conditions on hydrological response, flood inundation, and structural flood control performance using hydrological analysis and HEC-RAS modeling. The 2025 observed land use condition was classified using Landsat 9 imagery and supervised classification, while the 2031 scenario was based on the Semarang City Spatial Plan 2011–2031. The classification produced an overall accuracy of 85.42% with a Kappa coefficient of 0.83. The runoff coefficient increased from 0.41 in 2025 to 0.46 in 2031. The Nakayasu Synthetic Unit Hydrograph method estimated that the 25-year design flood discharge increased from 111.52 m^3/s to 139.09 m^3/s. HEC-RAS 1D/2D coupled unsteady flow simulation under the HWL condition showed that inundation increased from 12.21 ha to 17.24 ha. River normalization and levee construction improved channel conveyance capacity and reduced overflow potential in critical segments. These results indicate that integrating land use control and structural flood mitigation can support sustainable urban flood management.

Keywords: Flood control; HEC-RAS; Land use change; Urban river

Introduction

Urban flooding has become an increasing concern in many cities because rainfall extremes, rapid urban development, and land conversion occur simultaneously. The conversion of vegetated and open areas into built-up surfaces reduces infiltration capacity and increases surface runoff. As a result, flood peak discharge may increase, while drainage and river systems may no longer be able to convey excess runoff effectively (Shrestha et al., 2021; Wu et al., 2024). This condition is particularly critical in dense urban areas where drainage capacity is limited and floodwater has fewer natural storage and infiltration areas; therefore, flood risk reduction also requires adaptation strategies in addition to structural measures (Ongaga et al., 2024; Sari & Hermon, 2025).

Semarang City is one of the coastal urban areas in Indonesia that frequently experiences flooding due to the combined influence of upstream runoff, downstream tidal effects, and rapid urban development. The expansion of built-up areas has altered the hydrological response of the catchment and contributed to higher flood risk in the urban area (Khoirunisa, 2023; Kusumawardani, 2024). In the downstream and coastal zones, sea level fluctuation can also worsen flood duration and limit the ability of river flow to discharge freely into the sea. Therefore, flood problems in Semarang cannot be understood only from rainfall characteristics, but must also be analyzed through the interaction between land use change, watershed runoff response, river conveyance capacity, and downstream boundary conditions.

The Banjir Kanal Barat River is part of the Garang Watershed and functions as one of the main flood control channels in Semarang City. The river receives flow from the upstream catchment and conveys it toward the downstream coastal area. However, land use change within the watershed, sedimentation, and tidal influence have reduced the effectiveness of the river

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system in conveying flood discharge (Ain et al., 2020). Repeated flood events around the Banjir Kanal Barat River indicate that several river segments are still unable to accommodate flood flow under certain rainfall and tidal conditions. One of the critical areas is the Madukoro segment, which is located in a low-lying downstream urban area and is susceptible to overflow from the river as well as backwater effects from tidal fluctuations.

Previous studies have discussed urban flooding, land use change, and hydrological response in Semarang and other urban watersheds. However, studies that integrate observed land use conditions, future spatial planning scenarios, hydrological analysis, and coupled 1D/2D hydraulic modeling for evaluating flood control performance in the Banjir Kanal Barat River remain limited. Most previous studies have focused either on land use change, flood risk mapping, or hydraulic simulation separately, without explicitly linking future land use scenarios with flood discharge response and structural flood mitigation performance (Bena and Khadiyanta, 2020).

Therefore, this study aims to evaluate the influence of land use conditions on flood discharge and inundation patterns in the Banjir Kanal Barat River using integrated hydrological and hydraulic modeling. The novelty of this study lies in the integration of observed land use conditions, future spatial planning scenarios, design flood estimation, and HEC-RAS 1D/2D coupled unsteady flow simulation to assess flood control performance in an urban river system affected by upstream runoff and downstream tidal influence. The 2025 land use condition was used to represent the observed existing condition, while the 2031 land use scenario was developed based on the Semarang City Spatial Plan 2011–2031. The proposed structural measures consist of river normalization and levee construction, which are intended to increase channel conveyance capacity and reduce overflow potential in critical river segments.

Method

Research Area

The study area is shown in Figure 1. Figure 1(a) presents the location of the Garang Watershed, which covers an area of 212.76 km² and includes parts of Semarang City and Semarang Regency, an area known for its high population density. The watershed is drained by several main rivers, including the Kripik River, Garang River, Kreo River, and BKB River (Banjir Kanal Barat), all of which flow toward the downstream area through the BKB River. The Banjir Kanal Barat River functions as the main drainage channel located near the center of Semarang City and receives flow from the Kaligarang, Kreo, and Kripik Rivers. Figure 1(b) shows the Banjir Kanal Barat River area in Semarang, which covers approximately 11,946.26 ha, with a river length of about 9.30 km.

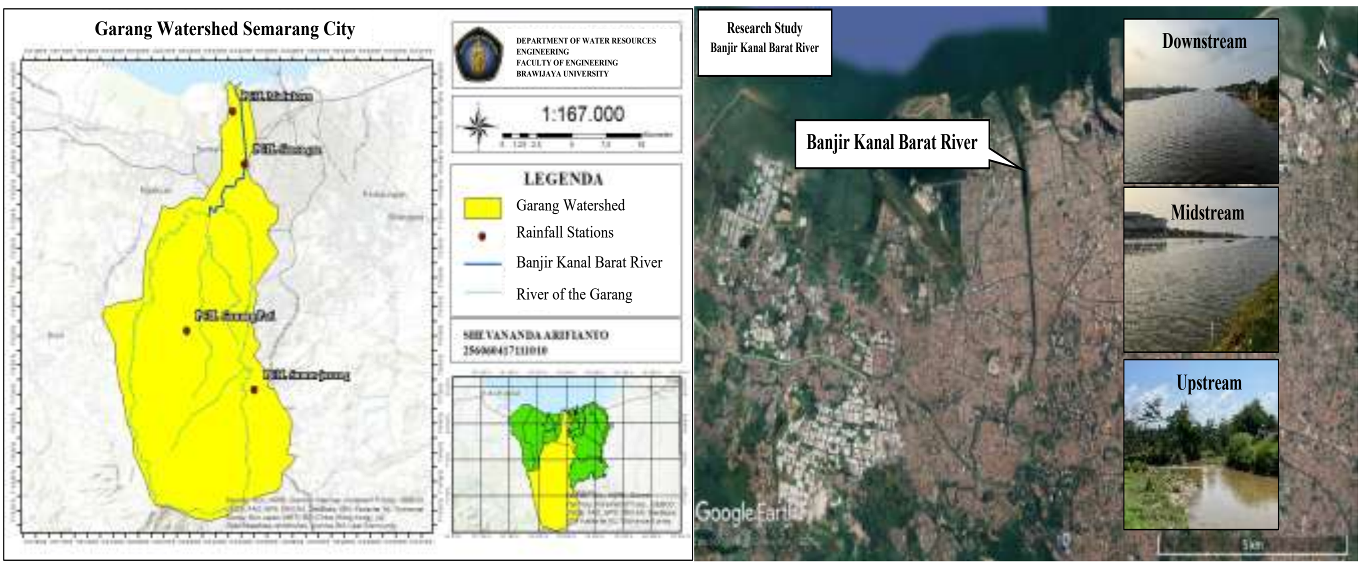

Figure 1. Study area. (a) Garang Watershed boundary and rainfall stations; (b) Banjir Kanal Barat River and field observation points

Data

Several datasets were used to support the hydrological and hydraulic analyses in this study. The Garang Watershed boundary was used to define the spatial extent and physical characteristics of the watershed. Rainfall data were collected from four rainfall stations, namely BPSDA Jratun Madukoro, Sumurjurang, Simongan, and Gunung Pati, for a 10-year period from 2015 to 2024. These rainfall data were used for consistency testing, areal rainfall calculation, frequency analysis, and design flood discharge estimation.

Land use data for the existing condition were obtained from Landsat 9 OLI-2/TIRS-2 Collection 2 Level-2 imagery provided by the United States Geological Survey (USGS). The image used in this study was acquired on September 5, 2025, with Path 120 and Row 065. The acquisition date was selected to represent the observed land use condition in 2025 and to distinguish it from the 2031 land use scenario derived from the Semarang City Spatial Plan 2011–2031. The satellite image was processed in ArcGIS using a supervised classification method with spectral bands 1–7 to classify the main land use categories in the watershed.

Topographic data were obtained from Digital Elevation Model (DEM) data and processed to prepare the terrain input for HEC-RAS. River geometry data, including cross-section and longitudinal-section data of the Banjir Kanal Barat River, were used to build the hydraulic model. In addition, discharge data of the Banjir Kanal Barat River were used as reference data to evaluate the design flood discharge and to assess the suitability of the hydrological analysis results. Tidal water level data were used as the downstream boundary condition to represent the influence of sea level fluctuation on river flow. The hydraulic simulation was conducted under unsteady flow conditions because the downstream segment of the river is affected by tidal fluctuation.

Research Method

As shown in Figure 2, this study was conducted through a sequential analysis consisting of data collection, land use analysis, hydrological analysis, hydraulic modeling using HEC-RAS, flood control simulation, and results interpretation. The method was designed to link land use conditions, watershed runoff response, river hydraulic behavior, and the effectiveness of structural flood control measures.

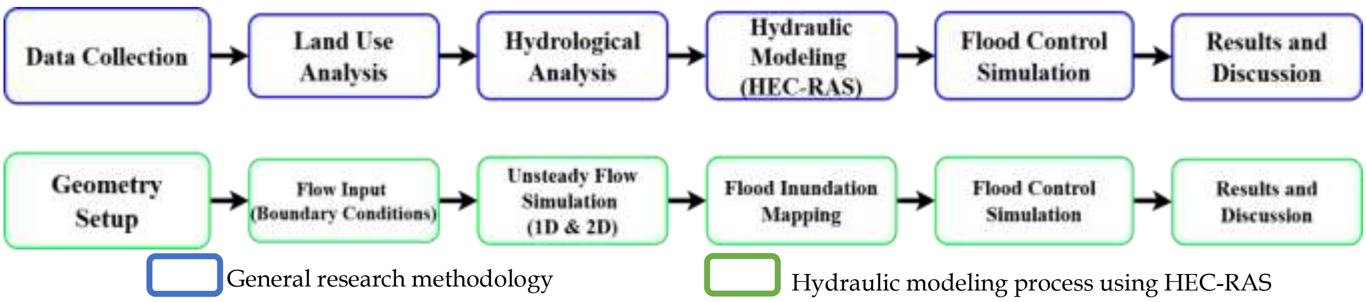

Figure 2. Research methodology framework

The first stage was data collection. The data used in this study included rainfall data, watershed boundary data, Landsat 9 satellite imagery, topographic data, river geometry data, river discharge data, and tidal water level data. Rainfall data from 2015 to 2024 were used for hydrological analysis, while Landsat 9 imagery acquired on September 5, 2025, was used to represent the observed existing land use condition. The 2031 land use scenario was developed based on the Semarang City Spatial Plan 2011–2031 to represent future land use conditions.

The second stage was land use analysis. The 2025 land use map was generated using a supervised classification method in ArcGIS. The classification results were used to determine the runoff coefficient for the existing condition. In addition, the 2031 land use scenario was analyzed to evaluate the effect of planned land use change on runoff coefficient and flood discharge response. The classification accuracy was assessed using a confusion matrix, overall accuracy, and Kappa coefficient.

The third stage was hydrological analysis. Rainfall data were first evaluated using the Double Mass Curve method to ensure data consistency. The mean areal rainfall was then calculated using the Thiessen Polygon method. Frequency analysis was conducted to determine the design rainfall for the selected return period, and the design rainfall was distributed into hourly rainfall using the Mononobe method. Effective rainfall was calculated based on the runoff coefficient derived from land use analysis. The Nakayasu Synthetic Unit Hydrograph method was then applied to estimate the design flood hydrograph. The resulting flood hydrograph was used as the upstream boundary condition in the hydraulic model.

The fourth stage was hydraulic modeling using HEC-RAS. The model was developed using a coupled 1D/2D unsteady flow approach, in which the main river channel was represented as a 1D model and the surrounding floodplain was represented as a 2D flow area. The upstream boundary condition was defined using the design flood hydrograph, while the downstream boundary condition was defined using tidal water level data.

The fifth stage was flood control simulation. Structural flood control measures were evaluated through river normalization and levee construction. River normalization was simulated to increase the conveyance capacity of critical river segments, while levee construction was simulated to reduce overflow potential in low-lying areas along the river. The flood control scenarios were simulated under the same hydrological and tidal boundary conditions as the existing condition to allow comparison between before- and after-mitigation results.

The final stage was results and discussion. The modeling results were evaluated based on changes in water surface elevation, overflow locations, inundation extent, inundation depth, and river conveyance capacity. The comparison between existing and flood control scenarios was used to assess the effectiveness of river normalization and levee construction in reducing flood inundation in the Banjir Kanal Barat River.

Land Use Analysis and Classification Accuracy

Land use analysis was conducted using satellite imagery with a Geographic Information System (GIS)-based supervised classification method (Mi et al., 2019). The land use classification consisted of several main categories, including forest, settlement, industrial area, agricultural land, and water bodies, which influence the hydrological characteristics of the watershed (Susanti et al., 2020). Classification accuracy was assessed using a confusion matrix based on random sampling points. The overall accuracy and Kappa coefficient were calculated to evaluate the agreement between the classified image and reference data, as commonly applied in remote sensing-based land use classification studies (Kurniawan & Sutikno, 2026). An accuracy value above 80% is considered good for land use classification results.

$$Overall\ accuracy = \frac{\text{Number of correctly classified pixels}}{Total\ number\ of\ samples} \times 100 \quad (1)$$

$$Kappa\ Coeffcient = \frac{\mathrm{N} \sum \mathrm{X}_{ii} - \sum(\mathrm{X}_i + \times \mathrm{X+i})}{\mathrm{N}^2 - \Sigma(\mathrm{X}_i \times \mathrm{X+i})} \quad (2)$$

where N is the total number of samples, X_{ii} is the number of correctly classified samples in each class, X_i is the row total, and $X+_i$ is the column total.

Consistency Data Test

Rainfall consistency was evaluated using the Double Mass Curve method by comparing the cumulative rainfall of each tested station with the cumulative mean rainfall of the reference stations. This procedure was applied to identify possible shifts or inconsistencies in the rainfall record before the data were used for frequency analysis (Khalil, 2021; Sriwongsitanon et al., 2023).

Mean Annual Precipitation

The mean areal rainfall was calculated using the Thiessen Polygon method to obtain representative rainfall values based on the area of influence of each rainfall station. This method is commonly applied in watershed hydrological analysis because it considers the spatial distribution of rainfall stations in estimating areal rainfall (Plamonia et al., 2025). However, the accuracy of rainfall estimation using the Thiessen Polygon method is still influenced by the density and distribution of rainfall stations, especially in watersheds with limited or unevenly distributed rainfall networks (Feng et al., 2025).

$$R = \frac{A_1 R_1 + A_2 R_2 + \cdots + A_n R_n}{A_1 + A_2 + \cdots + A_n} \quad (3)$$

Where:
R = mean areal rainfall (mm)
A_1, A_2, A_n = area represented by each rainfall station (m^2)
R_1, R_2, R_n = rainfall at each observation station (mm)

Frequency Analysis and Design Rainfall

Frequency analysis was performed on maximum rainfall data to obtain design rainfall for a specific return period. The Gumbel and Log Pearson Type III distributions were used because both are commonly applied in hydrological analysis to estimate extreme events based on return periods (Pradigta et al., 2024). In flood frequency analysis, these methods are also used to estimate hydrological event magnitudes for various return periods as a basis for flood control planning (Handique et al., 2024). The statistical requirements used to evaluate the suitability of the Gumbel and Log Pearson Type III distributions are presented in Table 1.

Table 1. Distribution Requirements

Distribution method	Requirement
Gumbel	Cs ≈ 1.14; Ck ≈ 5.40
Log Pearson Type III	Cs ≠ 0

Effective Rainfall Analysis

Effective rainfall was determined based on the runoff coefficient (C), which is influenced by land use conditions and watershed characteristics. The comparison of runoff coefficient values was conducted based on different land use conditions to evaluate the effect of land use change on increasing surface runoff and effective rainfall (Azizah et al., 2025). The daily design rainfall was then distributed into hourly rainfall using the Mononobe method as input for hydrological analysis, particularly when hourly rainfall data are unavailable (Pratiwi et al., 2023). This hourly effective rainfall was subsequently used as input for the design flood hydrograph calculation.

Nakayasu Synthetic Unit Hydrograph and NSE Evaluation

The design flood discharge was calculated using the Nakayasu Synthetic Unit Hydrograph (SUH) method based on design rainfall input and watershed characteristics. The Nakayasu SUH method was used to develop flood hydrographs and estimate peak discharge in the watershed, especially when measured discharge data are limited or incomplete (Innocente dos Santos et al., 2023). In this study, the design discharge obtained from the rainfall-based hydrograph was compared with the river design discharge to evaluate the suitability of the calculation results. Model performance was evaluated using the Nash–Sutcliffe Efficiency (NSE) parameter, which is commonly used to assess the agreement between modeled discharge and observed or reference discharge in hydrological analysis (Handique et al., 2024).

Hydraulic Modeling Using HEC-RAS

Hydraulic modeling was carried out using HEC-RAS 6.5 with a coupled 1D/2D unsteady flow approach to simulate river water surface profiles and flood inundation distribution. HEC-RAS was used because it can model flow based on river geometry, discharge, Manning's roughness coefficient, and boundary conditions (Ghaisani et al., 2024). In this study, the main river channel was represented as a 1D model, while the surrounding floodplain was represented as a 2D flow area to describe inundation around the river corridor (Lea et al., 2019; Spor et al., 2025). The model results were evaluated based on river conveyance capacity, water surface profile, inundation extent, and flood depth to assess the effectiveness of river normalization and levee construction (Lake et al., 2026).

Result and Discussion

Land use analysis in the Garang Watershed was conducted using Landsat 9 imagery acquired on September 5, 2025, and processed using a supervised classification method in ArcGIS. The watershed covers an area of 212.76 km² and was classified into six land use classes, namely water body, forest, industrial area, plantation, settlement, and rice field. The classification result shows that forest and plantation areas are mainly distributed in the upstream part of the watershed, while settlement and industrial areas are more concentrated in the middle to downstream urban area. This spatial pattern indicates that runoff generation is spatially varied, as built-up areas generally produce higher surface runoff than vegetated areas.

Table 2. Land Use Classification Accuracy Assessment

Classification	Water body	Forest	Industrial area	Plantation	Settlement	Rice field	User total	User accuracy (%)
Water body	10	0	0	0	0	0	10	100.00
Forest	0	26	0	3	0	0	29	89.66
Industrial area	0	1	9	0	3	0	13	69.23
Plantation	0	0	0	10	0	3	13	76.92
Settlement	0	0	4	0	18	0	22	81.82
Rice field	0	0	0	0	0	9	9	100.00
Total producer	10	27	13	13	21	12	96	
Producer accuracy (%)	100.00	96.30	69.23	76.92	85.71	75.00		

Note: Overall accuracy = 85.42%; Kappa coefficient = 0.83.

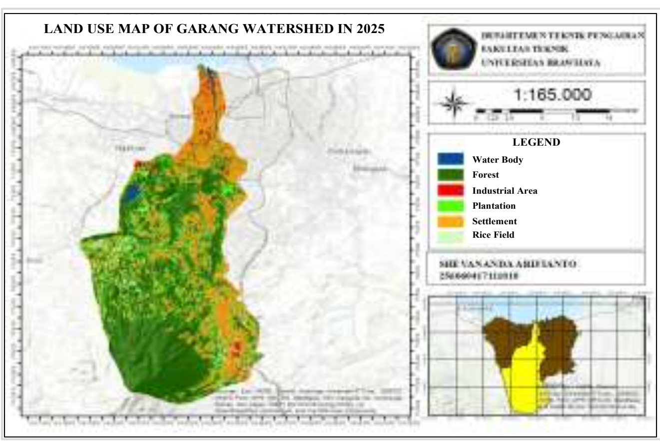

Figure 3. Land use map of Garang Watershed in 2025

The accuracy assessment was conducted using 96 validation points obtained from the supervised classification process and checked using reference data from Google Earth and field observation. The confusion matrix produced an overall accuracy of 85.42% and a Kappa coefficient of 0.83, indicating strong agreement between the classified image and reference data. Therefore, the 2025 land use classification was considered suitable as the basis for determining the runoff coefficient in the hydrological analysis. The detailed accuracy assessment is presented in Table 2.

Although the overall classification result was reliable, the industrial area class showed a lower user accuracy of 69.23%. This result indicates possible misclassification between industrial and settlement areas. Such misclassification may occur because industrial roofs and residential built-up surfaces often have similar spectral characteristics in Landsat imagery. Nevertheless, this limitation does not substantially change the general runoff interpretation because both industrial and settlement areas represent built-up surfaces with relatively high runoff potential.

Based on the 2025 land use condition, the weighted runoff coefficient was 0.41. This value was obtained from the proportion of each land use class and its corresponding runoff coefficient. Although settlement and industrial areas have high runoff coefficients, the average watershed coefficient remains moderate because a large part of the Garang Watershed is still dominated by forest, plantation, and rice field areas. In comparison, the 2031 land use scenario based on the Semarang City Spatial Plan 2011–2031 produced a higher runoff coefficient of 0.46. The increase in runoff coefficient indicates that future land use change may increase effective rainfall and flood discharge response, as land use dynamics are closely related to sustainable watershed management (Zahrani et al., 2026). Therefore, the runoff coefficient values from the 2025 existing condition and the 2031 spatial plan scenario were used as input for the hydrological analysis in the next stage.

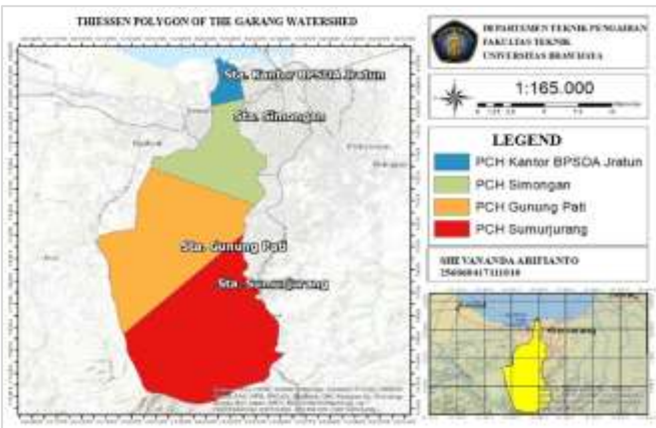

Figure 4. Thiessen polygon of the Garang Watershed

Watershed physical characteristics are important because they influence flood potential and runoff response (Supiyati et al., 2024). The rainfall data used in this study were obtained from four rainfall stations in the Garang Watershed, namely BPSDA Jratun Madukoro, Sumurjurang, Simongan, and Gunung Pati, for the period 2015–2024. Before frequency analysis, rainfall data were evaluated through consistency and statistical tests. The Double Mass Curve method was applied by comparing each tested rainfall station with the cumulative mean rainfall of the other three stations as reference stations. After correction, the rainfall records showed consistent patterns and were considered suitable for further hydrological analysis.

The mean areal rainfall was calculated using the Thiessen Polygon method to represent the spatial influence of each rainfall station. The Thiessen coefficients were 0.03 for BPSDA Jratun Madukoro, 0.38 for Sumurjurang, 0.16 for Simongan, and 0.44 for Gunung Pati. The maximum areal rainfall during the analysis period ranged from 41.74 mm to 104.43 mm, with the highest value occurring in 2024. The Thiessen polygon map is shown in Figure 4, while the annual maximum areal rainfall values are presented in Table 3.

Table 3. Maximum Areal Rainfall

Year	Maximum Areal Rainfall (mm)
2015	57.50
2016	94.82
2017	77.03
2018	60.42
2019	81.83
2020	41.74
2021	76.39
2022	72.13
2023	93.78
2024	104.43

Frequency analysis was then performed using the Gumbel and Log Pearson Type III distributions. The Gumbel distribution produced a skewness coefficient of Cs = -0.30 and a kurtosis coefficient of Ck = 3.62, which did not meet the theoretical requirements of the Gumbel distribution. In contrast, the Log Pearson Type III distribution produced a skewness coefficient of Cs = -0.87 and fulfilled the requirement of Cs ≠ 0. Therefore, the Log Pearson Type III distribution was selected to estimate the design rainfall. The 25-year design rainfall was 108.78 mm and was accepted based on the Smirnov–Kolmogorov test with Δmax = 0.08 and the Chi-Square test with $X^2 = 0.40$.

Table 4. Frequency Distribution Test Results

Distribution method	Analysis result	Requirement	Description
Gumbel	Cs = -0.30 Ck = 3.62	Cs ≈ 1.14 Ck ≈ 5.40	Not accepted
Log Pearson Type III	Cs = -0.87	Cs ≠ 0	Accepted

The 25-year design rainfall was distributed into hourly rainfall using the Mononobe method with a six-hour rainfall duration. Effective rainfall was calculated using the runoff coefficients derived from the land use analysis, namely 0.41 for the 2025 existing land use condition and 0.46 for the 2031 spatial plan scenario. The increase in runoff coefficient indicates that planned land use change may increase runoff generation, effective rainfall, and the flood discharge response of the watershed.

The design flood hydrograph was calculated using the Nakayasu Synthetic Unit Hydrograph method by considering the Garang Watershed area of 212.76 km^2 and the main river length of 40.17 km. The hydrological parameters obtained were a lag time of Tg = 2.73 hours, effective rainfall duration of tr = 2.05 hours, peak time of Tp = 4.37 hours, and recession time to 30% of peak discharge of T0.3 = 5.46 hours. The Q25 design flood discharge increased from 111.52 m^3/s under the 2025 land use condition to 139.09 m^3/s under the 2031 scenario, representing an increase of approximately 24.72%. This result shows that the increase in runoff coefficient due to land use change contributes to higher peak flood discharge. The Nakayasu hydrograph for the 2025 and 2031 conditions is shown in Figure 5.

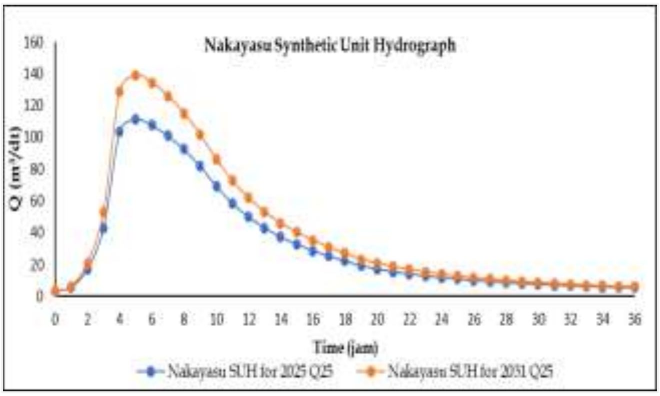

Figure 5. Nakayasu synthetic unit hydrograph for Q25 under 2025 and 2031 land use conditions

The design flood discharge was evaluated by comparing the rainfall-based discharge from the Nakayasu method with the river design discharge of the Banjir Kanal Barat River. For the 25-year return period used as the hydraulic model input, the Nakayasu discharge was 111.52 m^3/s, while the river design discharge was 107.56 m^3/s. The relatively small difference indicates that the rainfall-based design discharge is comparable to the river discharge analysis. The validation also produced a Nash–Sutcliffe Efficiency value of 0.95 and a correlation coefficient of 0.91, indicating that the Nakayasu hydrograph has a good agreement with the reference discharge pattern. Therefore, the Nakayasu-based flood hydrograph was considered suitable as the upstream boundary condition in the hydraulic modeling.

Hydraulic modeling of the Banjir Kanal Barat River was conducted using HEC-RAS 6.5 with a coupled 1D/2D unsteady flow approach. The river geometry was developed using cross-section and longitudinal-section data, while the surrounding floodplain was represented as a 2D flow area. The upstream boundary condition used the Q25 flood hydrograph obtained from the Nakayasu method, whereas the downstream boundary condition used tidal water level data. In this analysis, the High Water Level (HWL) of 1.68 m was selected as the critical downstream boundary condition because it represents the highest tidal condition affecting the downstream segment of the river, where tidal effects can influence flood extent in low-lying coastal river systems (Isma et al., 2024). The river geometry and downstream tidal boundary used in the model are shown in Figure 6 and Figure 7.

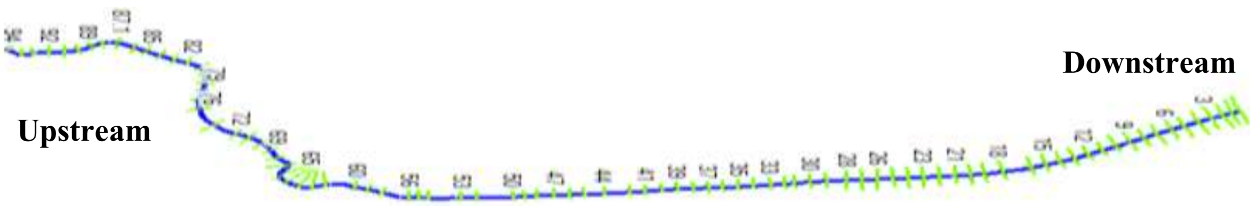

Figure 6. River geometry of the Banjir Kanal Barat River

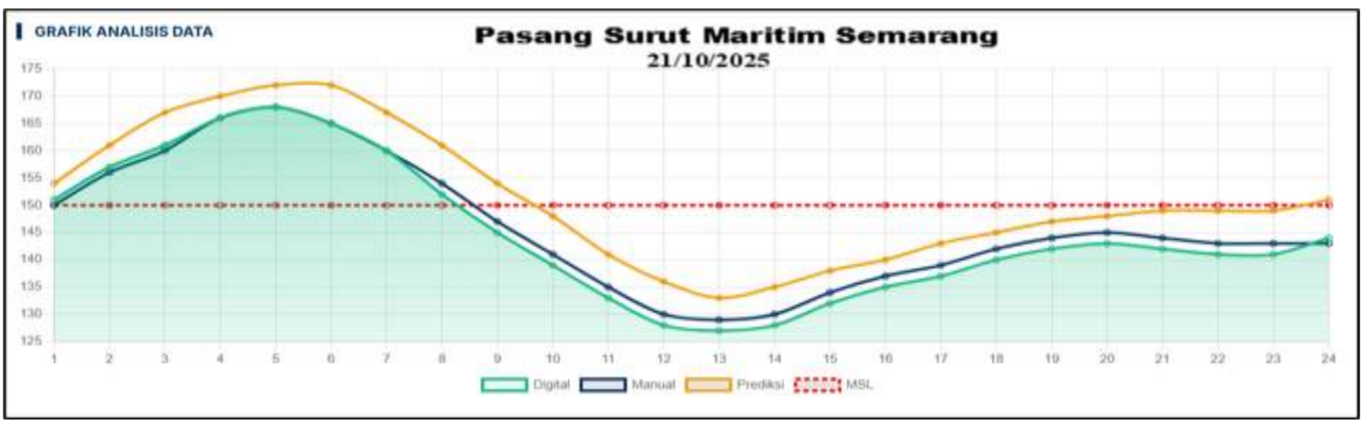

Figure 7. Tidal water level hydrograph at Tanjung Emas, Semarang

The existing 1D simulation was used to evaluate the river conveyance capacity and water surface profile along the main channel. The simulation results show that several river cross-sections were unable to convey the 25-year design flood discharge under the HWL condition. Overflow occurred mainly in the upstream segment around Sta. 78–62 and in the middle to downstream segment around Sta. 28–21. This condition indicates that several river sections have insufficient channel capacity and bank elevation, especially when upstream flood discharge occurs simultaneously with high downstream tidal water level. The longitudinal water surface profile under the existing HWL condition is shown in Figure 8.

Representative cross-section profiles were also evaluated to identify the river sections where overflow occurred. The cross-section results show that overflow was identified around Sta. 74 in the upstream segment and along Sta. 28–24 in the middle-to-downstream segment. These sections are part of the broader critical reach around Sta. 28–20, where inundation was also identified in the 2D simulation. The cross-section results support the longitudinal profile analysis and indicate the locations that require further flood control evaluation. The representative cross-section water surface profiles are shown in Figure 9.

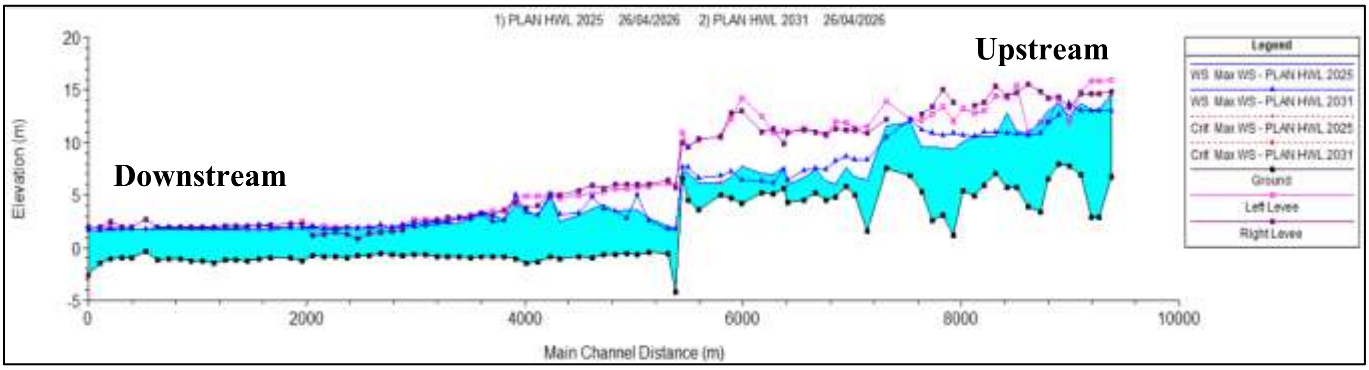

Figure 8. Longitudinal water surface profile under existing HWL condition

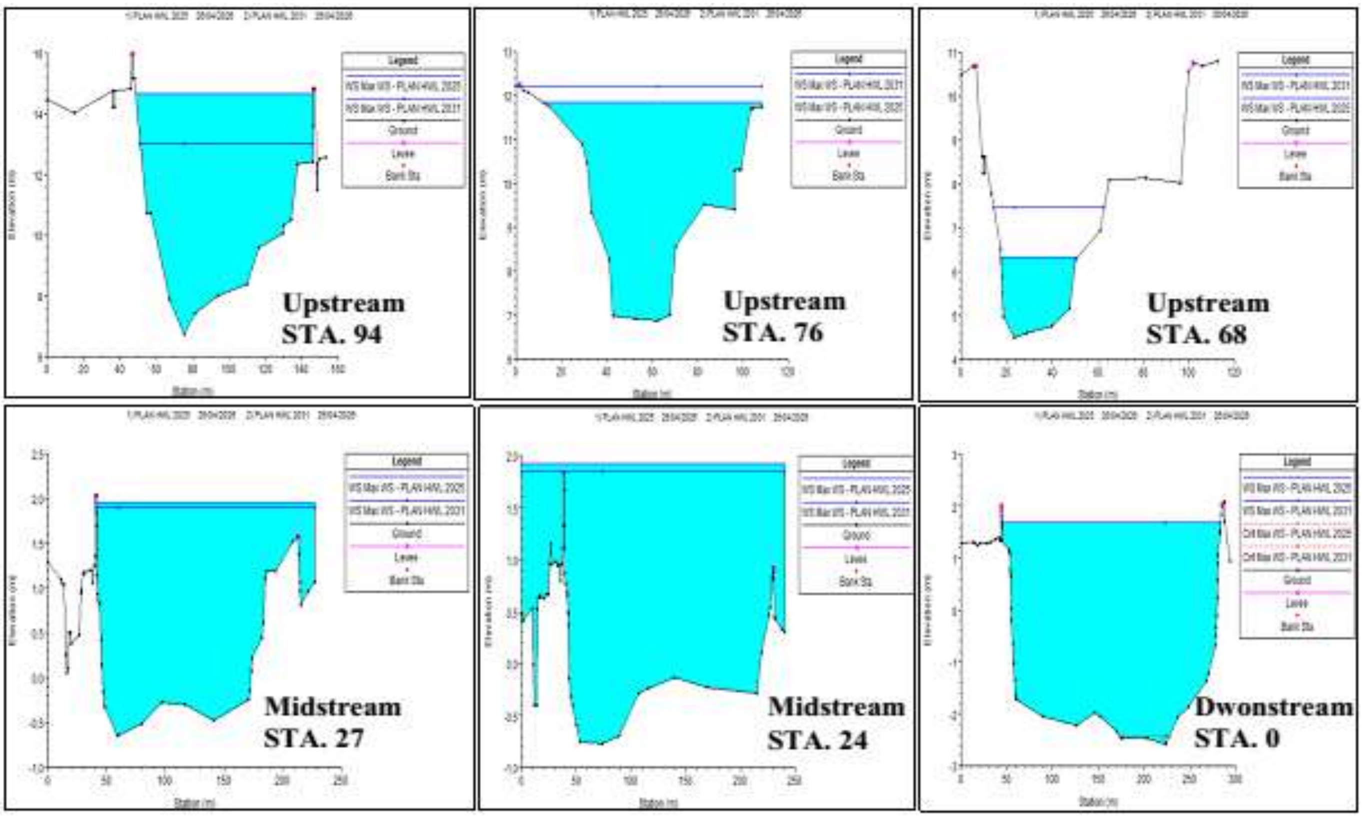

Figure 9. Existing cross-section water surface profiles under HWL condition

The 2D simulation was then used to analyze the spatial distribution of flood inundation around the river corridor. The inundation pattern was generally consistent with the overflow locations identified in the 1D simulation, particularly around Sta. 78–62 and Sta. 28–20. Under the 2025 land use condition, the inundation area reached 12.21 ha with an average inundation depth of approximately 1.20 m. Under the 2031 land use scenario, the inundation area increased to 17.24 ha with an average depth of approximately 1.40 m. This indicates an increase of 5.03 ha, or approximately 41.20%, in inundation area. The increase shows that land use change, which increases design flood discharge, can enlarge flood inundation when it coincides with high downstream tidal water level. The flood inundation maps for the 2025 and 2031 conditions are shown in Figure 10.

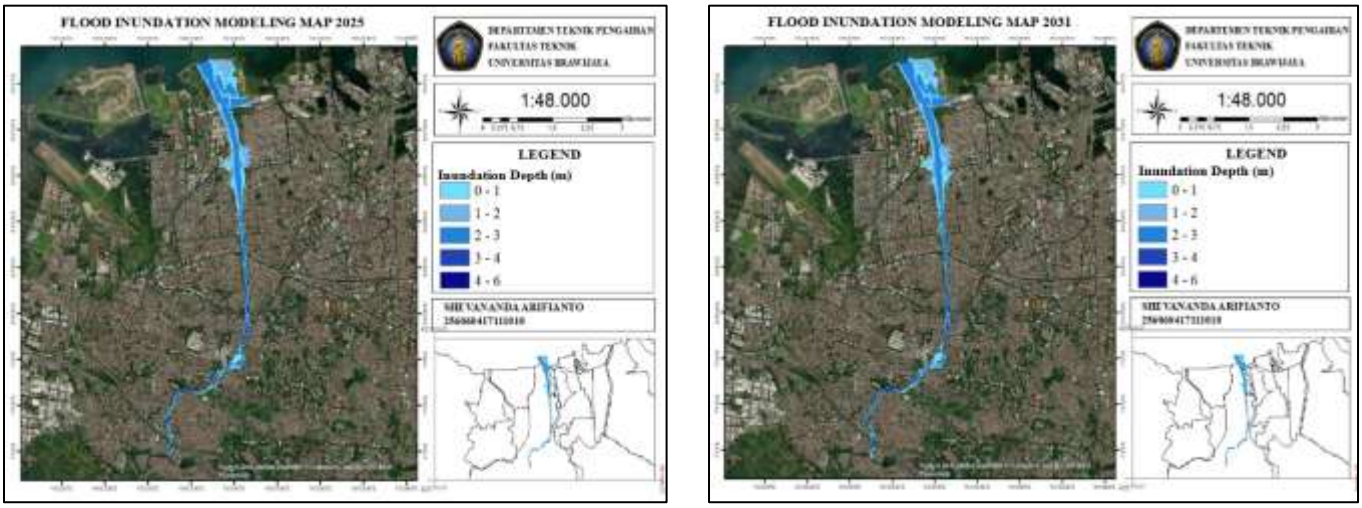

Figure 10. Flood inundation maps under HWL condition for 2025 and 2031 land use scenarios

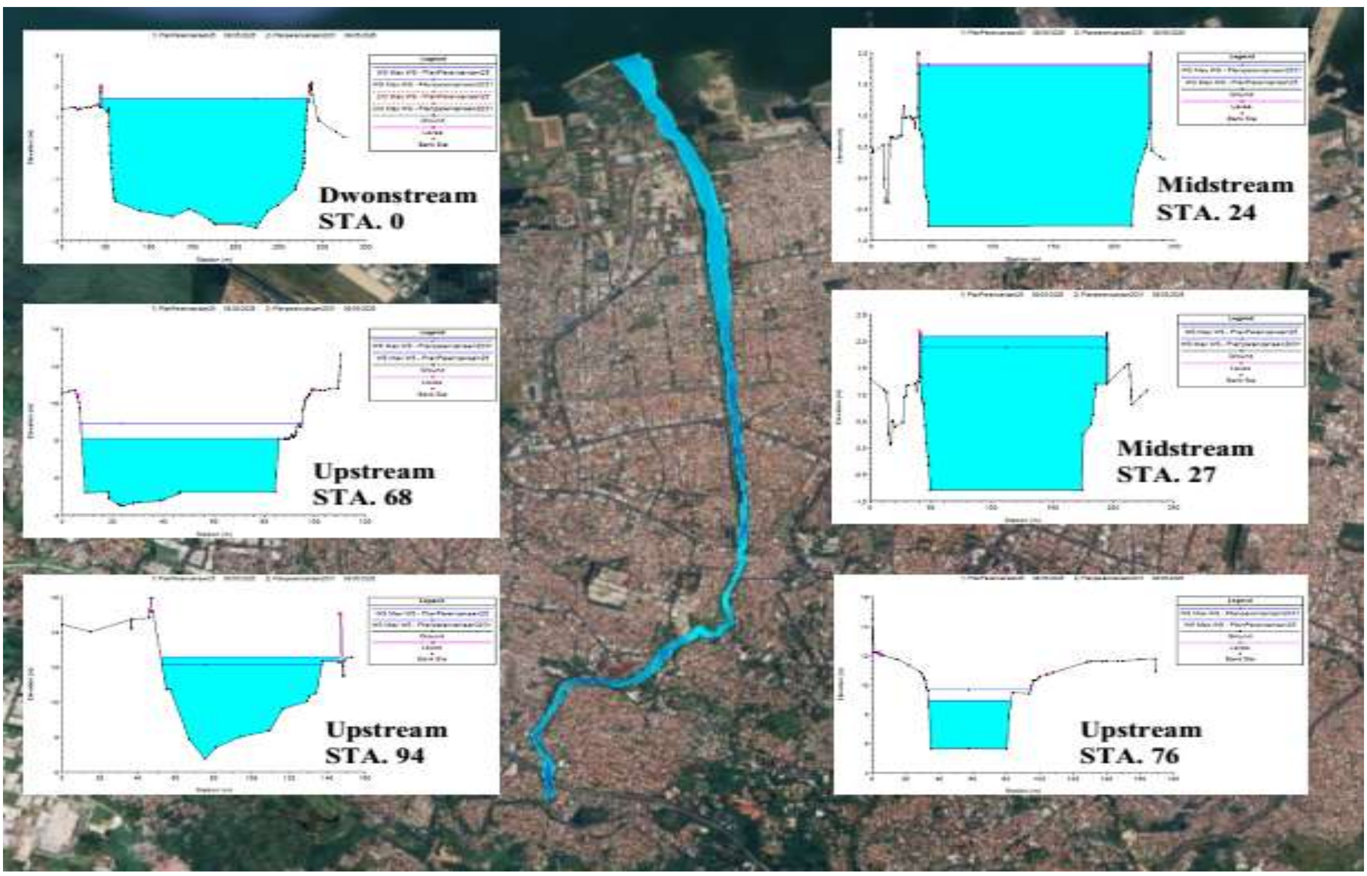

Figure 11. Flood control simulation results under the normalization and levee scenario

The affected areas were mainly located around low-lying built-up areas in the middle-to-downstream segment, including Taman Kampung Jamu, Jalan Madukoro Raya, and Jalan Kokrosono in Panggung Kidul and Panggung Lor. The fishpond area on the downstream right side was not included in the calculated inundation area, so the analysis focused on settlement, infrastructure, and built-up areas along the Banjir Kanal Barat River. Overall, the existing HEC-RAS simulation results indicate that flooding in the study area is influenced by upstream flood discharge, limited river conveyance capacity, and high downstream tidal water level. These results were then used as the basis for evaluating structural flood control measures in the next section.

Based on the existing HEC-RAS simulation results, structural flood control measures were evaluated through river normalization and levee construction. River normalization was planned to increase the channel conveyance capacity at critical segments, particularly in the upstream and middle sections of the Banjir Kanal Barat River. The normalization was applied in six segments, namely Sta. 80–75, Sta. 74–67, Sta. 66–62, Sta. 31–29, Sta. 28–25, and Sta. 24–20, with a total length of approximately 3.24 km. However, the normalization scenario still showed overflow along the right bank in the middle-to-downstream segment. Therefore, levee construction was added along the right side of the river from Sta. 28 to Sta. 20, with a length of approximately 885 m.

The combined normalization and levee scenario improved the hydraulic performance of the river compared with the existing condition. River normalization increased the flow capacity of the channel, while levee construction reduced overflow potential in the low-lying right-bank area. As shown in Figure 11, the planned structural measures were able to reduce overflow at the critical cross-sections under the Q25 design flood and HWL downstream condition. Therefore, the combined normalization and levee scenario can be considered as an effective structural flood control alternative for the Banjir Kanal Barat River.

Conclusion

This study shows that land use change in the Garang Watershed affects runoff response, design flood discharge, and flood inundation in the Banjir Kanal Barat River. The 2025 land use classification produced an overall accuracy of 85.42% and a Kappa coefficient of 0.83, indicating that the classification result was suitable for runoff coefficient estimation. The runoff coefficient increased from 0.41 under the 2025 observed land use condition to 0.46 under the 2031 spatial plan scenario. This increase caused the Q25 design flood discharge to rise from 111.52 m^3/s to 139.09 m^3/s, or approximately 24.72%.

The HEC-RAS 1D/2D coupled unsteady flow simulation showed that several river sections were unable to convey the Q25 design flood discharge under the HWL downstream condition. Overflow occurred mainly around Sta. 78–62 and Sta. 28–20, while the 2D simulation showed that the inundation area increased from 12.21 ha in 2025 to 17.24 ha in the 2031 scenario. The combined river normalization and levee construction scenario improved the hydraulic performance of the river by increasing channel conveyance capacity and reducing overflow potential in critical segments. Therefore, these structural measures can be considered as an effective flood control alternative for the Banjir Kanal Barat River. In addition, spatial planning control is also required to limit the expansion of impervious areas and reduce future flood risk. Further research should consider sedimentation, land subsidence, and more detailed field-based hydraulic validation to improve the reliability of flood modeling.

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Conflicts of Interest
The author declares no conflict of interest.

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