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Utilization of Digital Terrain Model (DTM) from LiDAR data for flood inundation simulation due to Ciujung River overflow in Banten Province

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ABSTRACT

Flood phenomena are natural disasters that are still difficult to predict due to climate change. Climate change has caused rainfall to become extreme, leading to floods as the water discharge exceeds river capacity. The Ciujung River is one of the major rivers in Banten Province. In 2012, the Ciujung River overflowed, cutting off access to the Tangerang-Merak Toll Road. This study utilizes a Digital Terrain Model (DTM) derived from LiDAR data and HEC-RAS software to simulate flood inundation due to the overflow of the Ciujung River in Banten. LiDAR data provides a high-resolution DTM, offering detailed and accurate topographic information. Using HEC-RAS, a hydraulic model was created to simulate water flow and potential flood inundation along the river. The simulation method refers to the Saint-Venant equations with an iterative procedure known as the standard step method. The simulation results show reliable flood depth and inundation spread as a reference for flood disaster mitigation planning. The final result of this study is a flood inundation map that provides a clear picture of flood risk levels along the Ciujung River, which can be used by local governments and other stakeholders for decision-making. From 12 flood inundation sample points, 60% were validated based on respondents' feedback. The area affected by flood hazards along the Ciujung River increased with rising water discharge, with the largest area being 109.06 hectares when the discharge reached 3000 m^3/s.

ABSTRAK

Fenomena banjir merupakan bencana alam yang masih sulit diprediksi akibat perubahan iklim. Perubahan iklim menyebabkan curah hujan menjadi ekstrem sehingga menyebabkan banjir karena debit air melebihi kapasitas sungai. Sungai Ciujung merupakan salah satu sungai besar yang ada di Provinsi Banten. Pada tahun 2012, Sungai Ciujung meluap sehingga memutus akses Tol Tangerang-Merak. Penelitian ini memanfaatkan Digital Terrain Model (DTM) yang berasal dari data LiDAR dan software HEC-RAS untuk melakukan simulasi genangan banjir akibat meluapnya Sungai Ciujung di Banten. Data LiDAR menyediakan DTM resolusi tinggi, menawarkan informasi topografi yang detail dan akurat. Dengan menggunakan HEC-RAS, model hidrolik dibuat untuk mensimulasikan aliran air dan potensi genangan banjir di sepanjang sungai. Metode simulasi mengacu pada persamaan Saint-Venant dengan prosedur iteratif yang dikenal dengan metode langkah standar. Hasil simulasi menunjukkan kedalaman banjir dan sebaran genangan yang dapat diandalkan sebagai acuan perencanaan mitigasi bencana banjir. Hasil akhir dari penelitian ini adalah peta genangan banjir yang memberikan gambaran jelas tingkat risiko banjir di sepanjang Sungai Ciujung, yang dapat digunakan oleh pemerintah daerah dan pemangku kepentingan lainnya dalam pengambilan keputusan. Dari 12 titik sampel genangan banjir, 60% tervalidasi berdasarkan masukan responden. Luas wilayah yang terkena bahaya banjir di sepanjang Sungai Ciujung bertambah seiring dengan meningkatnya debit air, dengan luas terluas 109,06 hektar dengan debit mencapai 3000 m^3/s.

Keywords: *DTM, LiDAR, HEC-RAS, Ciujung River, Banten Province*

INTRODUCTION

Floods is a natural phenomenon that can occur throughout the globe, and it is one of the most frequent natural disasters in Indonesia, have significant impacts on communities and the environment (Istiadi & Priatna, 2021). The complexity of flood events is triggered by a combination of various factors, including hydrometeorological, topographical, geological, soil, and human activities (Nucifera & Putro, 2018; Mahfudz et al., 2022). One hydrometeorological disaster is flooding due to rainfall. Excessive rainfall occurred in most parts of Indonesia throughout 2010, even during the dry season from June to August (Yulihastin, 2011). Flooding is a natural phenomenon that frequently occurs in various regions, especially in areas with high rainfall and inadequate water management systems. Scientifically, floods can be defined through two main concepts: 1) river water overflow caused by river discharge exceeding the river's capacity during high rainfall, 2) inundation in flat lowland areas that are usually not flooded (Ariyora et al., 2015; Mahfudz et al., 2024). Almost every region in Indonesia has experienced floods due to river overflow, such as in the Ciujung River Basin (DAS) in Banten.

The degradation of the Ciujung River Basin, due to increasing population pressure and economic activities, has led to changes in land use. The degradation is indicated by decreasing water discharge during the dry season. In the rainy season, extreme discharge increases along with the runoff coefficient, causing floods. Additionally, river narrowing and sedimentation from uncontrolled deposits harm communities living along the Ciujung River (Chalid et al., 2022). Based on land cover maps, from 2006-2016, forest areas in the Ciujung River Basin decreased from 10,507.89 hectares to 10,209.68 hectares, while residential areas increased (from 6,923.73 hectares to 9,537.65 hectares) and agricultural land (from 149,829.49 hectares to 161,283.69 hectares). From 2013-2018, land use changes occurred in the Upper Ciujung Sub-basin, with secondary dryland forest area percentage decreasing from 3.04% to 1.00% of the total sub-basin area, while dryland farming, mixed dryland farming, and residential areas increased (Naitkakin et al., 2023).

METHODS

Research Location

The study was conducted in the Ciujung River Basin (DAS) in Banten Province, specifically along the river crossing parts of Kibin Sub-district and Kragilan Sub-district in Serang Regency (Figure 1). The Ciujung River Basin is geographically located at 5°57'14"-6°4'20" S and 106°01'00" - 106°29'03" E. The Ciujung River is one of the trans-provincial rivers in West Java and Banten provinces. It originates from Mount Karang and Mount Halimun, flowing northward through Bogor Regency, Lebak Regency, Serang Regency, and ending in the Java Sea estuary.

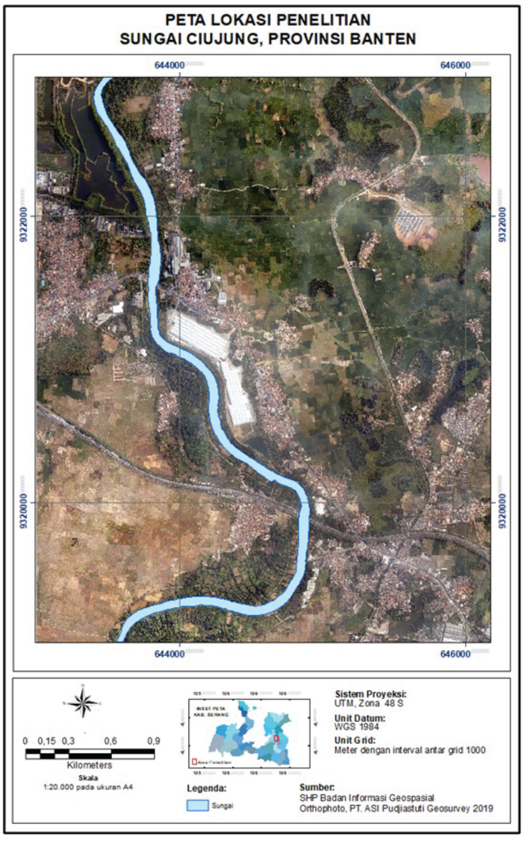

Figure 1. Research Location.

Spatial analysis is highly effective in processing and analyzing data, thereby speeding up the decision-making process in the field under study. In this research, data collection is the first step, followed by data analysis to obtain results and validation processes. For clarity, the data processing steps can be seen in the flow diagram in Figure 2.

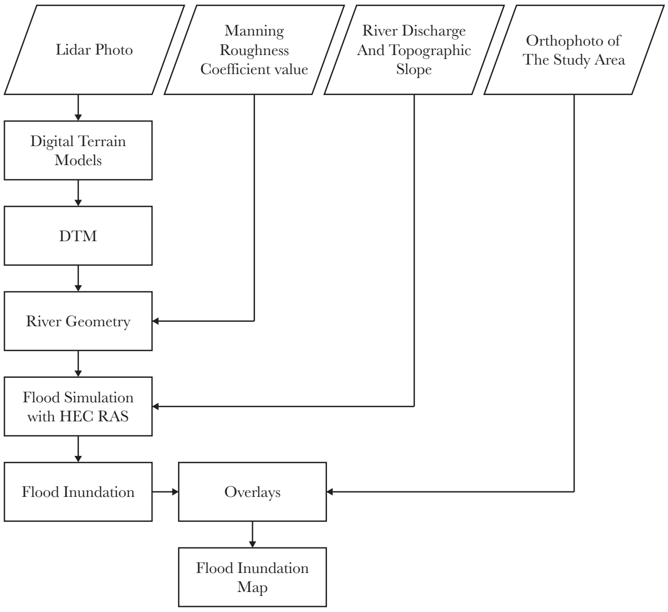

Figure 2. Research flow diagram.

LiDAR and DTM Formation

LiDAR data generates a significant amount of point cloud data, necessitating classification to understand the relationships and correlations among these points. Classification is the process of grouping points into several classes based on physical similarities, distribution areas, and characteristics relative to their needs (Asriyah et al., 2017). The desired result is a Digital Terrain Model (DTM); therefore, the automatic classification results in point cloud data that must distinguish between ground (surface) and non-ground (objects above the surface) classes. However, based on automatic classification results, some point clouds still do not fit their classes. This can be identified by overlaying the classified point cloud with orthophotos of the research area and examining the cross-sectional profile of these points. The overlay results show that brown points indicate ground, while non-brown points indicate non-ground. According to Aisyah (2017), to address the inaccuracies in automatic classification, a manual classification process is necessary. This process is called manual classification.

Inundation Mapping with HEC-RAS

Flood inundation modeling in watersheds using HEC-RAS has been conducted by researchers, including (et al., 2020; Irawan et al., 2021; Nagarajan et al., 2022;

Gunawan et al., 2023). In this study, the creation of a flood inundation map of the Ciujung River overflow involves two stages: river geometry creation and flood inundation simulation using HEC-RAS. The river geometry in this study is done using digitization techniques, with the DTM of the research area serving as the reference data. The process involves removing LiDAR points found in water bodies and converting the LiDAR data to DTM data. Creating river geometry and extracting Manning's roughness values for land cover is done using tools from the HEC-GeoRAS 10.3 application. Flood inundation simulation can then be performed using HEC-RAS 5.0.1. HEC-RAS is one of the most popular models that provides flood elevation or water surface elevation (WSE) dimensions for rivers, river flows, etc. This model solves the energy equation based on the Saint-Venant equations using an iterative procedure known as the standard step method (Kumar et al., 2017). According to Brunner (2016), the energy equation is written as follows (Cahyono & Hak, 2023):

$$Z_2 + Y_2 + \frac{a_2 V_2^2}{2g} = Z_1 + Y_1 + \frac{a_1 V_1^2}{2g} + h_e$$

Where:

Z_1, Z_2 = the elevation of the main channel inverts
Y_1, Y_2 = a depth of water at cross sections
V_1, V_2 = average velocities (total discharge/total flow area)
a_1, a_2 = velocity weighting coefficients
g = gravitational acceleration
h_e = energy head loss

RESULT AND DISCUSSION

Flood Inundation Simulation

The flood inundation simulation stage was conducted using steady flow simulation available in the HEC-RAS software. This process requires topographic slope data along the river channel and flow discharge data to be simulated. According to data from BBWS C3 Banten Province, the average topographic slope of the river used in this study is 0.0002, as the research area is located downstream. The flow discharge simulated in this study includes 1000 m^3/s, 1500 m^3/s, 2000 m^3/s, 2500 m^3/s, and 3000 m^3/s. These discharge values are based on upstream boundary conditions, with the highest recorded discharge at the Pamarayan Water Control Post (PDA) being 2600 m^3/s.

In the classification stage, the point cloud was divided into two classes: ground and non-ground. In Figure 3, brown points indicate the ground class, while gray points indicate the non-ground class. The classification results can be seen in Figure 4, which shows a cross-sectional view of a small part of the research area.

To ensure that the point cloud classification results are divided according to their respective classes, in Figure 4, the brown color representing the ground class depicts the contour lines of the surface area. Meanwhile, the gray color does not resemble the surface contour but rather resembles the shape of a roof, which is higher than the surface and thus falls into the non-ground class. Subsequently, a filtering process is performed to separate and retain only the points in the ground class, as seen in Figure 5. These ground class points will be used for the formation of the Digital Terrain Model (DTM).

The ground class point cloud is further processed to form a Digital Terrain Model (DTM). The DTM generated in this study is in GRID format. In Figure 6, the DTM formation results are displayed in grayscale, where darker shades indicate areas with lower values.

The results of the DTM at this stage involved adjusting with the Digital Elevation Model (DEM) data downloaded from the INA Geoportal. The adjustment was limited to assessing the conformity of topographic features and elevation value ranges between the DTM model and the downloaded DEM model. It was found that the modeling results matched the actual surface of the earth. Figure 7 shows the DTM display.

Figure 3. Point cloud classification results.

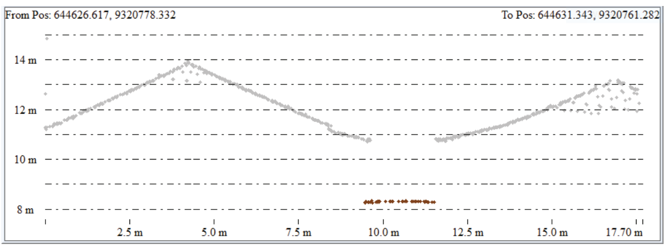

Figure 4. Cross-sectional view.

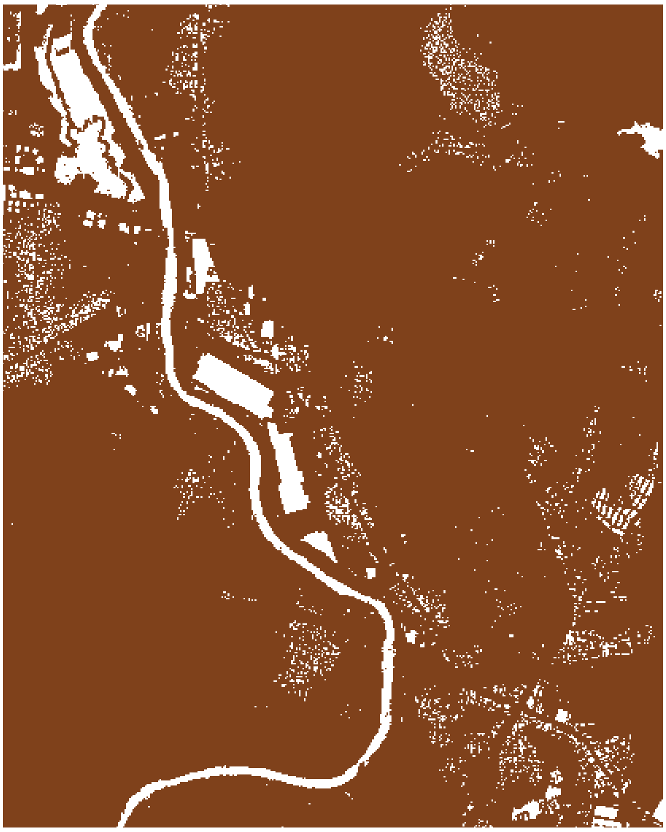

Figure 5. Ground class point cloud.

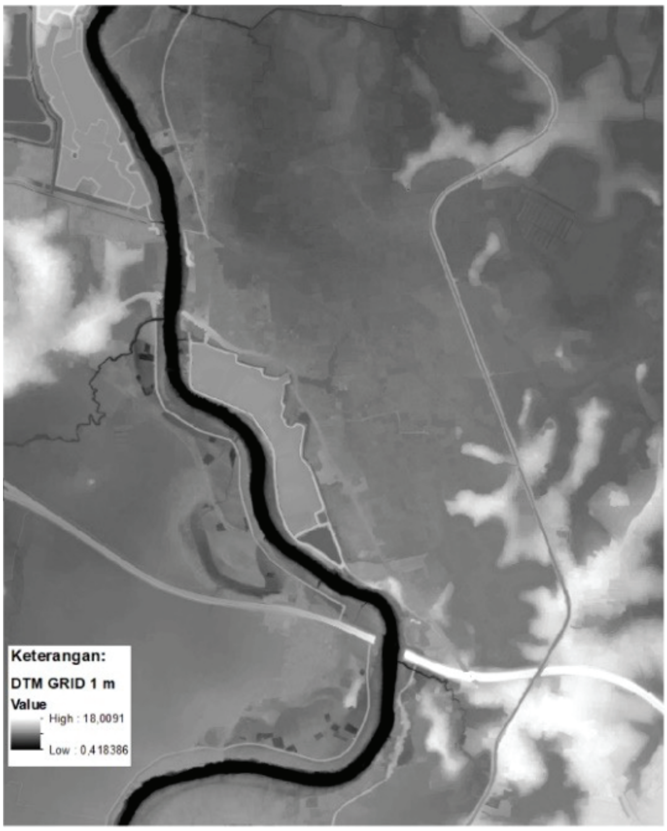

Figure 6. DTM in grid format.

After the DTM is formed for the research area, it is then used in the river geometry creation process. River geometry creation involves digitizing the main river channel, riverbanks, and cross-sectional profiles. This digitization process is carried out using HEC-RAS 5.0.7 software. Below, in Figure 8, you can see the digitization results and the formed river geometry.

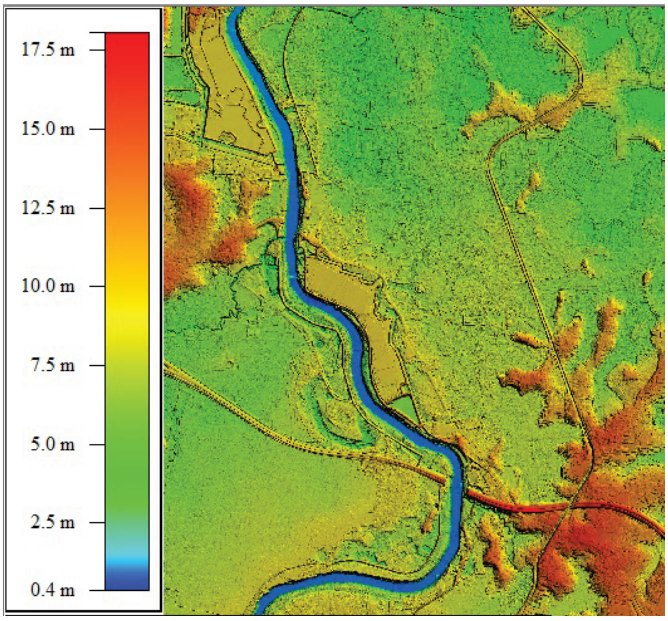

Figure 7. DTM in color display.

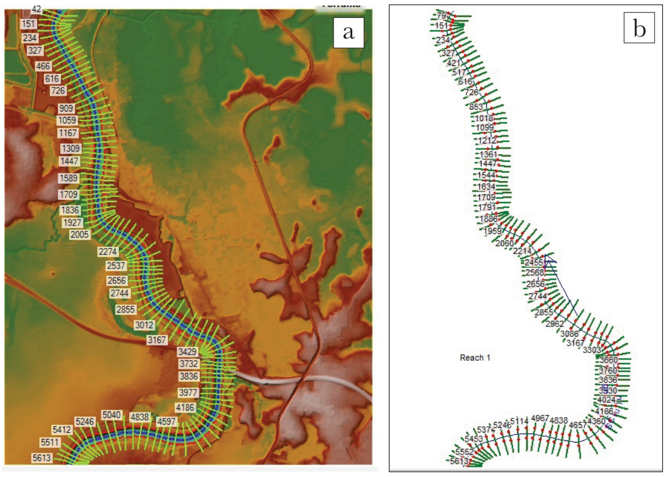

Figure 8. a) River cross-section digitization; b) River geometry.

The green lines in the image represent the cross-sectional profiles of the river, which display the cross-sectional profile of the DTM. These profiles enable the depiction of flood water levels along the cross-section. The river geometry serves as the basis for flood inundation simulation processes. During simulation, discharge data and the slope of the river's topography are used. This simulation is conducted using HEC-RAS 5.0.7 software. The simulation results produce flood depth, as shown in Figure 9, illustrating how high the water reaches at various points in the affected area.

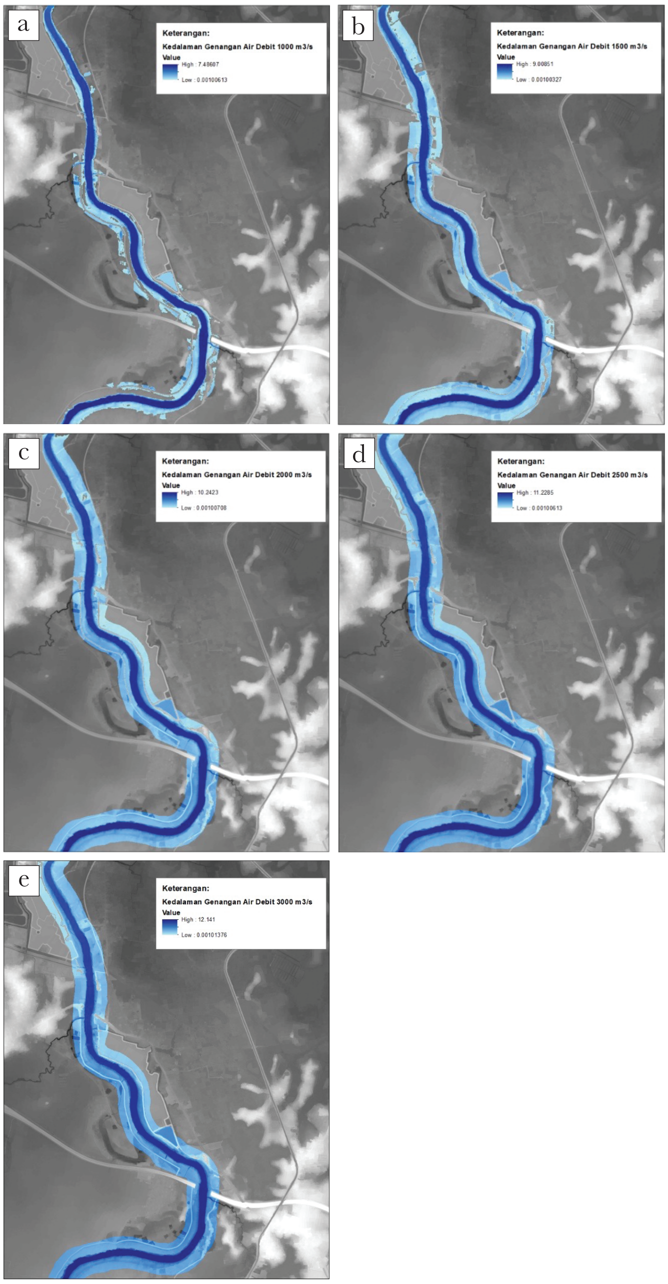

Figure 9. Flood elevation results discharge: (a) 1000 m³/s (b) 1500 m³/s (c) 2000 m³/s (d) 2500 m³/s (e) 3000 m³/s.

Analysis of Flood Depth

The results of the steady flow simulation using HEC-RAS software yielded flood depth profiles. During the simulation process, various discharge inputs were repeatedly used to determine the maximum capacity of the river cross-sections to accommodate water discharge. The findings indicated that the maximum discharge capacity held by the river at each cross-section was 775 m³/s. When the river discharge exceeded 1000 m³/s and beyond, it resulted in overflow beyond the river's boundaries, thus classified as flooding.

The flood depth results show varying water levels for each increase in discharge. At a discharge of 1000 m³/s, the water level ranged from 0.001 to 7.4 m, while at 1500 m³/s, it ranged from 0.001 to 9.0 m. At 2000 m³/s, the water level ranged from 0.001 to 10.2 m, at 2500 m³/s it ranged from 0.001 to 11.2 m, and at 3000 m³/s it ranged from 0.001 to 12.1 m. These results indicate an average increase in flood depth of 1 to 1.5 m for every 500 m³/s increase in discharge.

This trend is illustrated in Figure 10, which depicts the increase in water depth corresponding to each discharge level at one of the river cross-sections. The results highlight how increasing discharge affects the water level profiles along the river, with higher discharges resulting in greater depths.

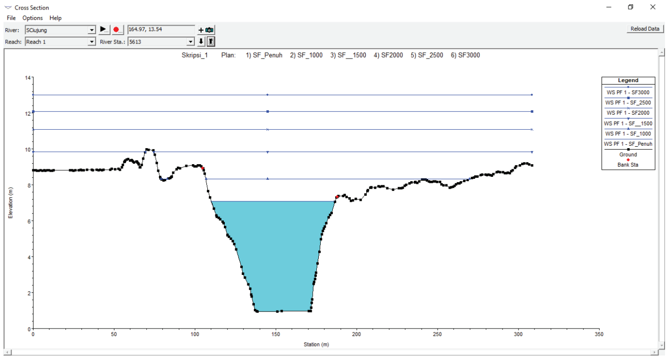

Figure 10. Cross-sectional profile of the river.

Flood inundation mapping shows the areas along the riverbanks that are inundated and prone to flooding. The results of flood inundation mapping also indicate variations in the flooded area along the riverbanks at intervals of 100 m. The flooded area at each discharge can be seen in Table 1.

Figure 1. Flooded area of riverbanks.

Discharge (m³/s)	Flooded Area of Riverbanks (Ha)
1000	32,37
1500	79,47
2000	97,48
2500	105,86
3000	109,06

In the table, you can see that the flooded area along the riverbanks increases with the rising river discharge. This is because higher river discharge means more water flowing into the river. From the results of the steady flow simulation in the research area, a discharge of 775 m³/s was obtained when the flooding reached the river's threshold limit. As the discharge increased to 1000 m³/s and beyond, several areas were identified as potentially prone to flooding, necessitating mitigation efforts for residents living in the Ciujung River buffer zone.

Validation of Simulation Results Based on flood inundation simulation using HEC-RAS, validation was conducted to determine if the flood simulation results were representative. In this study, validation involved simulating flood inundation from the overflow of the Ciujung River based on the discharge data during the flood event on December 7, 2020, which was 1389.50 m^3/s and used as a sample. Subsequently, validation was performed through interview methods, where data was collected by directly asking respondents using questionnaires. The interview questions focused on the flood event on December 7, 2020, as detailed in the appendix. Following this, a comparison was made between the flood inundation simulation results during the event and the field interview results. To determine the percentage of sample validation results from field interviews, the following formula was used:

$$\frac{\text{Number of sample points}}{\text{Total number of sample points}} \text{ X } 100\%$$

The sample points obtained from the interviews totaled 20 points, divided into 12 points affected by flooding and 8 points unaffected by flooding in the flood inundation simulation results. Table 2 shows the field validation results of flood inundation, indicating an 80% validation rate with 16 sample points considered valid and 20% with 4 points considered invalid. Therefore, the validity of the flood inundation simulation results using HEC-RAS software can be considered sufficiently valid based on respondent feedback.

Figure 2. Field validation results.

Analysis	Field Sample Points Affected by Flood	Total Points	Percentage (%)	Valid Points
Results	Floods	12	60	9
	Not Floods	8	40	7
Validation	Valid	16	80	16
	Not Valid	4	20	4
	Total	20	100	20

CONCLUSION

The use of DTM derived from LiDAR data significantly aids in river geometry creation, providing a high-resolution of 1 x 1 meter that facilitates clear visualization and interpretation of river geometries. The mapping results of flood inundation at various discharge levels demonstrate the areas susceptible to flood risks along the riverbanks. This allows for appropriate measures to be taken in flood disaster mitigation. The validation test results from 12 flood sample points in the field showed a 60% validity rate based on respondent feedback. The flood-prone area along the Ciujung River's banks expands with increasing discharge, reaching its largest extent at 3000 m^3/s, covering 109.06 hectares.

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CONFLICT OF INTEREST

The author declares no conflict of interest in the research and preparation of this article.

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