Identification of Flood-prone Areas using HEC-HMS and HEC-RAS, the Case of Ciberang River Basin, Lebak District of Banten Province

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Abstract. It is common practice that flood hydrograph simulations help to provide better flood prediction and flood damage reduction planning. These efforts require information on flood-prone areas identification from the hydrological and hydraulic analysis results. Historically, the Ciberang River Basin has experienced floods. Those floods cause the loss of human life and damage some houses along the river's channels, especially in Lebak District, Banten Province, Indonesia. The main objective of this study is to identify flood-prone areas based on the simulation result of a hydrologic and hydraulic model of catchment response due to several extreme rainfall events using HEC-HMS and HEC-RAS software. Rainfall and discharge data measured at the Ciberang-Sabagi water level gauge on 10 January 2013 were used to calibrate hydrological watershed parameters. The hydraulics channel routing is started from the planned location of the Sabo dam to the downstream control point. The next stage was the simulation of rainfall-runoff transformation and 1D unsteady flow channel routing for the 2, 5, and 10-years floods return periods. The main result of this study is a flood hazards map that shows the spatial distribution of the area and inundation depth for each return period of the flood.

Keywords: Flood hydrograph, hydrologic and hydraulic simulation, flood hazards map, flood inundation

1. Introduction

Flood is also the main subject that arouses to be more and more critical in the field of water sciences [1]. Studying or explored these situations could help for the reducing of severe material losses and human life. The flood risk reduction strategy can be conducted in various actions, e.g., risk quantification. The activity minimizes disaster risk with a non-physical effort needed in flood-prone areas, such as flood warning information at the site [2]. Rainfall data from frequency analysis of a hydrological event, such as floods, is an essential tool to get the event's probability and return periods [1]. Frequency analysis study is significant in the hydrological literature field [3]. Flood modeling for
flood hydrograph simulation requires a model to predict information that the decisions maker will use in deciding the planning [4].

Presently, the assessment of flood hazards maps has improved significantly due to the use of GIS in combination with hydraulic and hydrological modeling. The GIS extracted the hydrological variables from good-quality DEM data, such as watershed shape, path length, slope, flow direction, and watershed delineation. The assessment of flood inundation areas that came from extreme precipitation can develop an appropriate flood hazards map. These efforts have been made to combine the hydraulic and hydrological models with GIS software. The models are the physical-based integrated models, such as ArcGIS, HEC-HMS, HEC-RAS, and extension tools [5].

This study carried out a flood analysis on the Ciberang River Basin. The watershed boundary and river morphology were generated from the DEM data with 8×8 meters resolution. There was a flash flood in the Ciberang river on 5 January 2016. Flood is one of the most devastating natural disasters with socio-economic consequences. Thus, preparing the flood-prone area map is essential for flood disaster management. Furthermore, identifying flood-prone areas for comprehensive flood management strategies is a critical issue to plan development activities.

2. Material and Method

2.1. Study area

Ciberang river is located in Cipanas Village, Cipanas Sub-district, Lebak District of Banten Province, West Java, Indonesia. This research area is located at the geographical coordinates of 6° 21ʹ 40ʺ S and 6° 43ʹ 20ʺ S in latitude and 106° 15ʹ 0ʺ E and 106° 28ʹ 20ʺ E in longitude. The upstream catchment area is around 213.47 km², and the mainstream is 44.873 km in length, with an average river slope of 0.0023. The downstream catchment area is 64.228 km² with 37.295 km length of mainstream and an average river slope of 0.0035, as shown in Figure 1.

In this study, the daily rainfall data were obtained from three rainfall stations, i.e., Banjar Irigasi (BI) and Sajira (SP), and Ciminyak Cilaki (CC). BI rain gauge, which is located at the geographical

![Figure 1](image_url). Location and DEM-based map of the Ciberang catchment.
coordinates of 6° 34' 9.12" S and 106° 24' 39.96" E, and SP rain gauge (6° 29' 58.60" S and 106° 21' 57.38" E), are located in the Ciberang Catchment. The CC is located at 6° 32' 22.92" S and 106° 18' 29.16" E. Sabo dam location is the boundary that separates the upstream and downstream sub-basins, as shown in Figure 1.

The DEM data obtained from the Sabo Technical Center Office was analyzed for the watershed boundary's size, then delineated to get flow direction grid, stream grid, and watershed grid slope data. Land use distribution data was collected from Balai Sabo Office, as shown in Table 1. The catchment has two soil categories: loam and sandy clay loam derived from the Harmonized World Soil Database (HWSD) application. The downstream catchment area is mainly covered by sandy clay loam and soil (Type C), and the upstream of the catchment is covered by loam (Type B). Table 2 shows the upstream catchment soil type distribution.

Table 1. Land use distribution of Ciberang catchment.

| No. | Land use           | Area (km²) | Percentage (%) |
|-----|--------------------|------------|----------------|
| 1   | Pond without water | 4.613      | 2.162          |
| 2   | Village            | 0.337      | 0.158          |
| 3   | Forest             | 82.555     | 38.694         |
| 4   | Crop Land          | 31.198     | 14.623         |
| 5   | Rice fields        | 15.364     | 7.201          |
| 6   | Open field         | 1.905      | 0.893          |
| 7   | Plantation         | 77.380     | 36.269         |
|     | Total              | 213.352    | 100.00         |

Table 2. Upstream catchment soil type distribution.

| No. | Soil type         | Area (km²) | Percentage (%) |
|-----|-------------------|------------|----------------|
| 1   | Sandy Clay Loam   | 201.35     | 94.34          |
| 2   | Loam              | 12.07      | 5.66           |
|     | Total             | 213.42     | 100            |

In this study, a long historical daily rainfall data from 1975 to 2018 collected from Sabo Technical Center Office at three rain gauge stations of Banjar Irigasi, Sajira, and Ciminyak Cilaki have been used to calculate the upper and lower sub-basins rainfall Thiessen polygon method. After evaluating the collected data, the big flood event of 10 January 2013 was chosen to calibrate watershed parameters in hydrology and hydraulic flood modeling. Table 3 shows the observed extreme daily rainfall data from January 2013 to May 2018. The corresponding water level and discharge data at the Ciberang-Sabagi water level gauge can be seen in Table 4.

Table 3. Observed daily rainfall data 2013-2018.

| Date   | Rainfall (mm) |
|--------|---------------|
| 1/10/2013  | Ciminyak Cilaki | 91 | Sajira | 66 | Banjar Irigasi | 20 |
| 1/21/2014  | 76 | 65 | 60 |
| 1/3/2015   | 52 | 6  | 5  |
| 5/3/2016   | 13 | 3  | -  |
| 2/8/2017   | 13 | 3  | 24 |
| 5/19/2018  | 54 | 9  | 102 |
### Table 4. The observed maximum discharge and water level data.

| Date       | Discharge (m³/s) | Water Level (m) |
|------------|------------------|-----------------|
| 1/10/2013  | 232.22           | 5.4             |
| 1/21/2014  | 179.78           | 4.6             |
| 1/3/2015   | 114.43           | 3.46            |
| 5/3/2016   | 54.5             | 2.17            |
| 2/8/2017   | 58.64            | 2.3             |
| 5/19/2018  | 59.72            | 3.23            |

#### 2.2. Thiessen Polygon
Thiessen Polygon is a graphical technique that calculates the rainfall station weighting factor according to the relative areas of individual measurement from rainfall stations in the Thiessen Polygon network. This method is widely used to calculate the average precipitation over a watershed. The weightage is rationally given to the various stations. Each weighting factor is multiplied by the station observation data values that are summed to get the average areal precipitation [6], as follows:

\[
P_a = \sum_{i=1}^{n} \alpha_i P_i
\]

Where \( P_i \) is the rainfall data at station \( i \), \( \alpha_i \) is the station weighting factor \( i \), \( n \) is the number of stations.

#### 2.3. Rainfall Data Frequency Analysis
The frequency analysis calculates the design values based on the magnitude of a hydrological event that has a particular probability of occurrence. It is crucial to estimate the exact maximum rainfall probability for any defining return period. It can be used for flood risk reduction, operating flood control reservoirs, and as the alternative estimation of top water level. Four methods are commonly used to determine frequency rainfall, i.e., Normal distribution, Log-Normal, Log-Pearson type III, and Gumbel distribution [7].

#### 2.4. Hourly Rainfall Distribution
The Alternating Block Method (ABM) is a simple method to derive the hourly distribution of design rainfall, using the empirical formula of intensity-duration-frequency (IDF) curve. In this study, the Mononobe formula has been chosen to determining the IDF as [7].

\[
I_T^t = \frac{R_{24}^T}{24} \left( \frac{24}{t} \right)^{2/3}
\]

\( I_T^t \) is rainfall intensity for \( t \) duration with \( T \) years of the return period (mm/hr), \( t \) is rainfall duration (hr), \( R_{24}^T \) is maximum daily rainfall with \( T \) years return period (mm).

#### 2.5. Loss Method
2.6. The Soil Conservation Service Curve Number (SCS-CN) loss method determined the hydrologic loss rate. The hourly-effective rainfall transformed into a runoff for a flood hydrograph. The CN for a sub-basin can be estimated as a function of land use, soil type, and antecedent soil moisture, as used in the tables published by the SCS of the United States. The CN curve number values ranged from 100 for water bodies to approximately 30 for permeable soils with high infiltration rates [8]. The equations to
calculate the potential maximum retention from a storm by the SCS-CN method is written as follows [7].

\[ S = \frac{254000 - 254}{CN} \]  

(3)

Where \( S \) is potential maximum retention, \( CN \) is the curve number.

\[ CN(III) = \frac{23 \text{ CN(II)}}{10 + 0.13 \text{ CN(II)}} \]  

(4)

\( S \) is the site index defined as the maximum possible difference between discharge and precipitation (mm). \( CN \) or \( CN(II) \) is the curve number in normal antecedent moisture conditions, and \( CN(III) \) is the wet condition.

2.7. Rainfall-runoff Transform Method

Clark's model derives a watershed unit hydrograph by explicitly representing two critical processes transforming excess precipitation to runoff. Rainfall excess is translated from its origin in the drainage to watershed outlet attenuation, or reduction of the discharge magnitude as the quantity is stored throughout the watershed [9]. \( R \) is the basin storage coefficient, and \( R \) is an index of the temporary storage of precipitation excess in the watershed as it drains to the outlet of a watershed. It can be estimated through the calibration process if gaged precipitation and discharge data are available. The rainfall-runoff transform needs a time of concentration as input data. The Clark has developed time of concentration \( (T_c) \) and the Storage coefficient \( (R) \). The concentration-time in this study is calculated by Hatkanir and Sezen (1990) formula as [10].

\[ T_c = 0.7473 \times L^{0.841} \]  

(5)

Where \( L \) is the length of the watercourse (km).

2.8. Baseflow Method

Baseflow can be used to understand a watershed's hydrology. It includes the interaction of surface and subsurface water and urbanization's role on runoff generation. The method applies to a single peak hydrograph resulting from a single storm event [9]. The baseflow was calculated using an empirical formula of GAMA I synthetic unit hydrograph as follows [11].

\[ Q_b = 0.4715 \times A^{0.6444} \times D^{0.9430} \]  

(6)

Where \( Q_b \) is the baseflow (m³/s), and \( A \) is the catchment size (km²). \( D \) is drainage density = \( L/A \), \( L \) is the river network's total length, including tributaries (km).

2.9. HEC-RAS 1D Unsteady Flow Hydrodynamics

Continuity equation describes the conservation of mass for a 1D system. With the addition of storage term (S), the calculation of using continuity equation can be express as follows:

\[ \frac{\partial A}{\partial t} + \frac{\partial S}{\partial t} + \frac{\partial Q}{\partial x} - q_l = 0 \]  

(6)

Where \( A \) is the cross-sectional area, \( t \) is time, \( Q \) is the streamflow, \( x \) is the distance along the channel, \( S \) is the storage from the non-conveying portions of the cross-section, \( q_l \) is the lateral flow per unit river.

The momentum equation indicates that the rate of change in momentum is equal to the external forces acting on the system. The equation can be written as

\[ \frac{\partial Q}{\partial t} + \frac{\partial (QV)}{\partial x} + gA\left(\frac{\partial Z}{\partial x} + S_f\right) = 0 \]  

(7)

Where \( S_f \) is the friction slope, \( g \) is the acceleration gravity, and \( V \) is the average flow velocity.
2.10. Flood Hydrograph

The hydrograph is the response of input rainfall in the catchment. The flow has three phases: runoff, runoff on the surface, interflow, and baseflow; flood hydrograph provides peak discharge, which is vital for studying flood types, including flash floods, short rain floods, long rain floods, and rain-on-snow floods [12]. Figure 2 shows that the base flow indicates the typical day-to-day streamflow of a river and is the consequence of groundwater seeping into the river [13]. The limb AB is rapidly rising due to rainfall duration D, causing surface runoff and a flow. The peak discharge P happens when the river reaches its highest depth.

In this study, the lower basin is divided into four sub-basins. The calculation of the flood hydrograph at the Sabo dam planned location uses HEC-HMS for the upstream boundary condition of 1D unsteady flow hydraulic channel routing to the downstream control point of Ciberang-Sabagi water level gauge. The calculation of flood hydrograph of each sub-basin will be converted to uniform lateral inflow in the hydraulic channel routing simulation. Identification of inundation area distribution and flood depth based on the hydraulic simulation output using HEC-RAS. Furthermore, ArcGIS is used to estimate the area’s size and the depth of inundation in each flood-prone area.
3. Results and Discussion

3.1. Thiessen Polygon
The estimation of rainfall impact over the entire watershed, several points rainfall data was transformed to the areal rainfall using Thiessen Polygon method of equation (1). Figure 3 shows the Thiessen Polygon method map of the upper basin, and Figure 4 for the whole basin. The daily areal rainfall for each sub-basin (SB) can be calculated by using the associated weighting factor of each rainfall station based on the Thiessen polygon method.

3.2. Rainfall Data Frequency Analysis
Determination of the design rainfall requires the maximum daily rainfall of each sub-basin with several return periods. For this purpose, the calculation results of the areal maximum daily rainfall of 1973-2018 were used to conduct the frequency analysis. Table 5 shows the output of the analysis frequency as the design daily rainfall with the corresponding distribution type.

Table 5. The maximum daily rainfall of upper and lower sub-basin.

| T (Year) | Upper basin | Sub-basin 1 | Sub-basin 2 | Sub-basin 3 | Sub-basin 4 |
|----------|-------------|-------------|-------------|-------------|-------------|
|          | Log-Normal  | Log-Pearson III | Log-Pearson III | Log-Pearson III | Gumbel |
| 2        | 79.4        | 77.6        | 80.7        | 77.6        | 79.3        |
| 5        | 100.1       | 106.5       | 108.2       | 106.5       | 104.5       |
| 10       | 113.0       | 125.2       | 125.8       | 125.2       | 121.2       |

3.3. Design Rainfall
The rainfall duration can be estimated by Equation (5), the time of concentration, and Equation (2) of the IDF Mononobe formula. This study found that the concentration-time is ten hours for the upper sub-basin, sub-basin 1 four hours, sub-basin 2 four hours, sub-basin 3 five hours, and sub-basin 4 six hours. The distribution of hourly rainfall for the upper sub-basin and four sub-basins downstream was calculated using the ABM method, as shown in Table 6, Table 7, and Table 8.

Table 6. The design rainfall of upper and lower sub-basins for a 2-years return period.

| Sub-basin       | Hourly rainfall depth (mm) |
|-----------------|-----------------------------|
|                 | 1   | 2   | 3   | 4   | 5   | 6   | 7   | 8   | 9   | 10  |
| Upper sub-basin | 2.95| 3.53| 4.52| 6.72| 36.84| 9.58| 5.35| 3.95| 3.45| 2.74|
| Sub-basin 1     | 8.91| 48.88| 12.70| 7.09 |
| Sub-basin 2     | 9.65| 52.92| 13.75| 7.68 |
| Sub-basin 3     | 5.56| 8.27 | 45.37| 11.79| 6.59 |
| Sub-basin 4     | 5.35| 7.95 | 43.63| 11.34| 6.33 | 4.67|

Table 7. The design rainfall of upper and lower sub-basins for 5-years return period.

| Sub-basin       | Hourly rainfall depth (mm) |
|-----------------|-----------------------------|
|                 | 1   | 2   | 3   | 4   | 5   | 6   | 7   | 8   | 9   | 10  |
| Upper sub-basin | 3.72| 4.45| 5.69| 8.47| 46.45| 12.07| 6.74| 4.98| 4.04| 3.45|
| Sub-basin 1     | 12.24| 67.12| 17.45| 9.74 |
| Sub-basin 2     | 12.62| 69.21| 17.99| 10.05 |
| Sub-basin 3     | 7.64 | 11.36| 62.31| 16.19| 9.04 |
| Sub-basin 4     | 7.05 | 10.49| 57.52| 14.95| 8.35| 6.16 |
Table 8. The design rainfall of upper and lower sub-basins for a 10-years return period.

| Sub-basin       | Hourly rainfall depth (mm) | 1  | 2  | 3  | 4  | 5  | 6  | 7  | 8  | 9  | 10 |
|-----------------|----------------------------|----|----|----|----|----|----|----|----|----|----|
| Upper sub-basin | 4.20                       | 5.02| 6.43| 9.56| 52.44| 13.63| 7.61| 5.62| 4.57| 3.90|
| Sub-basin 1     | 14.38                      | 78.87| 20.50| 11.45|     |     |     |     |     |     |
| Sub-basin 2     | 14.52                      | 79.65| 20.70| 11.56|     |     |     |     |     |     |
| Sub-basin 3     | 8.97                       | 13.35| 73.22| 19.03| 10.63|     |     |     |     |     |
| Sub-basin 4     | 8.18                       | 12.16| 66.71| 17.34| 9.68 | 7.15|     |     |     |     |

3.4 Flood Hydrograph
In the calibration process, the calculated peak discharge of flood hydrograph on 10 January 2013 in Ciberang river at the downstream control point of Ciberang-Sabagi AWLR was 240.8 m³/s, which is close to the observed peak discharge of 232.22 m³/s. Basin parameters from the calibration are used to simulate the flood hydrograph in all sub-basins for 2, 5, 10-years return periods, as shown in Table 9. This study uses the flood hydrographs simulation for the lower sub-basins as uniform lateral inflow hydrographs for 1D unsteady flow channel routing simulation. Figure 5 shows the schematic of the hydraulic channel routing simulation using HEC-RAS.

Table 9. Simulated peak discharge of upper and lower sub-basins.

| Sub-basin       | 2-years return period | 5-years return period | 10-years return period |
|-----------------|------------------------|------------------------|------------------------|
| Upper sub-basin | 233.60                 | 320.40                 | 374.30                 |
| Sub-basin 1     | 30.30                  | 44.80                  | 54.60                  |
| Sub-basin 2     | 28.10                  | 39.20                  | 46.60                  |
| Sub-basin 3     | 28.70                  | 42.40                  | 52.90                  |
| Sub-basin 4     | 26.40                  | 36.70                  | 43.80                  |

Figure 5. Schematic of the hydraulic channel routing simulation.
3.5 Flood Hazard Maps
Flood hazards mapping is a crucial tool for non-structural measures. It can reduce water-related to disaster-damaged and property loss impacted at a prone zone, especially for flood mitigation and the contingency planning sector. The hydraulic channel routing simulation results were used to develop the hazard maps with five inundation depth hazard classes. The flood hazard classes are categorized as low if the value is less than 0.5 meters, low for 0.5 to 1 meter, medium for 1 to 2 meters, high for 2 to 5 meters, and greater than 5 meters for extreme. An example of a longitudinal water level profile along the river channel due to the 5-years return period can be seen in Figure 6.

![Figure 6. Longitudinal profile of water level due to the 5-years return period of the flood.](image)

The actual result of this study is the flood hazard maps for 2, 5, and 10-years flood events. The evaluation results of the flood inundation distribution based on the hydraulic simulation output show that the seven flood-prone areas with varying inundation depths. The flood-prone areas are denoted as A1, A2, A3, A4, A5, A6, and A7, as shown in Figure 7-9. The land use in flood-prone areas is mainly cultivation, except for A7, which is dominated by residential areas.

![Figure 7. Flood hazard map of the 2-years return period of flood.](image)

![Figure 8. Flood hazard map of the 5-years return period of flood.](image)
Figure 9. Flood hazard map of the 10-years return period of flood.

The hazard map must be informative because it will be used to determine the flood mitigation plan. It is related to the spatial distribution of locations and the hazard level of the flood-prone areas. Table 10 describes the distribution of high hazard locations with the name of village and sub-district. More detailed information about hazard classes and flood inundation depths in each flood-prone area is described in Table 11, Table 12, and Table 13. Figure 10 and Figure 11 show more detailed illustrations of inundation covering the left and right banks in the hazard areas A1 and A7 due to the 10-years return period.

Table 10. High hazard location.

| High hazard area | Location (Village) | Sub-district       |
|------------------|--------------------|--------------------|
| Area 1           | Margajaya          | Rangkasbitung      |
| Area 2           | Tambak             | Rangkasbitung      |
| Area 3           | Tambak             | Rangkasbitung      |
| Area 4           | Tambak             | Cimarga            |
| Area 5           | Sanyiang Jaya      | Cimarga            |
| Area 6           | Calungbungur       | Sajira             |
| Area 7           | Calungbungur       | Sajira             |
Table 11. The distribution of hazard class and inundation depth for the 2-years return period of flood.

| Hazard class | Water Depth | Area (ha) | Area 1 | Area 2 | Area 3 | Area 4 | Area 5 | Area 6 | Area 7 |
|--------------|-------------|-----------|--------|--------|--------|--------|--------|--------|--------|
|              |             | Cultivated land | Residential |        |        |        |        |        |        |
| H1           | < 0.5 m     | 0.303       | 0.778  | 0.086  | 0.054  | 0.049  | 0.027  | 0.070  |        |
| H2           | 0.5-1 m     | 0.456       | 0.856  | 0.068  | 0.094  | 0.064  | 0.038  | 0.068  |        |
| H3           | 1-2 m       | 0.762       | 1.474  | 0.136  | 0.173  | 0.081  | 0.158  | 0.119  |        |
| H4           | 2-5 m       | 1.589       | 2.520  | 0.352  | 0.310  | 0.270  | 0.503  | 0.177  |        |
| H5           | > 5 m       | 1.967       | 1.667  | 0.389  | 0.077  | 0.147  | 0.285  | 0.032  |        |
| Total area   |             | 5.076       | 7.296  | 1.031  | 0.708  | 0.612  | 1.011  | 0.466  |        |

Table 12. The distribution of hazard class and inundation depth for the 5-years return period of flood.

| Hazard class | Water Depth | Area (ha) | Area 1 | Area 2 | Area 3 | Area 4 | Area 5 | Area 6 | Area 7 |
|--------------|-------------|-----------|--------|--------|--------|--------|--------|--------|--------|
|              |             | Cultivated land | Residential |        |        |        |        |        |        |
| H1           | < 0.5 m     | 0.367       | 0.684  | 0.081  | 0.080  | 0.045  | 0.072  | 0.062  |        |
| H2           | 0.5-1 m     | 0.466       | 0.927  | 0.096  | 0.094  | 0.045  | 0.083  | 0.051  |        |
| H3           | 1-2 m       | 0.964       | 1.787  | 0.172  | 0.166  | 0.097  | 0.170  | 0.164  |        |
| H4           | 2-5 m       | 1.843       | 3.428  | 0.426  | 0.449  | 0.254  | 0.480  | 0.368  |        |
| H5           | > 5 m       | 2.415       | 2.516  | 0.497  | 0.144  | 0.258  | 0.421  | 0.064  |        |
| Total area   |             | 6.056       | 9.343  | 1.273  | 0.933  | 0.699  | 1.228  | 0.709  |        |

Table 13. The distribution of hazard class and inundation depth for the 10-years return period of flood.

| Hazard class | Water Depth | Area (ha) | Area 1 | Area 2 | Area 3 | Area 4 | Area 5 | Area 6 | Area 7 |
|--------------|-------------|-----------|--------|--------|--------|--------|--------|--------|--------|
|              |             | Cultivated land | Residential |        |        |        |        |        |        |
| H1           | < 0.5 m     | 0.534       | 0.695  | 0.095  | 0.092  | 0.032  | 0.094  | 0.045  |        |
| H2           | 0.5-1 m     | 0.514       | 0.859  | 0.109  | 0.100  | 0.051  | 0.119  | 0.064  |        |
| H3           | 1-2 m       | 1.004       | 1.697  | 0.197  | 0.164  | 0.087  | 0.198  | 0.138  |        |
| H4           | 2-5 m       | 1.828       | 4.090  | 0.452  | 0.462  | 0.269  | 0.499  | 0.379  |        |
| H5           | > 5 m       | 2.905       | 3.076  | 0.578  | 0.238  | 0.412  | 0.487  | 0.122  |        |
| Total area   |             | 6.785       | 10.417 | 1.432  | 1.056  | 0.851  | 1.398  | 0.748  |        |

Figure 10. Illustration of 10-years flood inundation in hazard area 1.

Figure 11. Illustration of 10-years flood inundation in hazard area 7.
4. Conclusion

This study applied hydrological modeling of rainfall-runoff transformation and the hydraulic modeling of unsteady flow channel routing. They were using HEC-HMS and HEC-RAS software in the Ciberang River Basin. The identified flood-prone areas were used to develop hazard maps that provide essential information. The information is primarily for flood disaster mitigation purposes, i.e., the distribution of locations, the scope and depth of inundation, and the hazard level. The hazard map shows several vulnerable areas vulnerable to damage, located along the riverbanks, the cultivated land, and settlements.

The authorities and local communities can use the flood hazard maps in preparing the proper mitigation plan to minimize the disaster risk at any time in the future. Besides, the characteristics of inundation areas are essential information needed by the local authorities to adopt structural and non-structural measures depending on the hazard classes that have been assigned using those hazard maps. Further research needs to be carried out by applying 2D unsteady flow hydraulic modeling to obtain more accurate flood hazards information that can be used to develop flood risk maps.

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