Flash Flood Characteristics of Ciberang River, Its Impact and Mitigation

V Say¹, D Legono¹*, A P Rahardjo¹, R A Yuniawan²

¹Civil and Environmental Engineering Department, Universitas Gadjah Mada, Indonesia
²Sabo Technical Center, Yogyakarta, Indonesia

*Corresponding author: djokolegono@ugm.ac.id

Abstract. Flash flood is a deadly natural disaster that develops at space and time scales caused by high rainfall intensities and frequently occurs. It occurs in mountainous regions with steep slope relief and often causes a loss of economy, society, and environment and threatens human lives. The Ciberang river is located at Lebak district, Banten Province, and has been experiencing a significant flash flood from December 31, 2019 to January 01, 2020, which contributed to various damages, including households nearby the river. In this study, the impact areas were identified with the HEC-RAS model and satellite image data. The impact area was damage on eight sub-districts, including agriculture (77.86 Ha), buildings (0.80 Ha), roads (2.5 km), and nine bridges. In addition, this study tried to build Sabo Dam upstream of Banjar Irigasi sub-districts to respond to the flash flood occurrence. The results have reduced the discharge to around 40 m³/s, and the travel time was delayed about 53 min. The results of this study help the community and decision-makers be ready for further flash flood disasters.

Keywords: flash flood, model, warning Information

1. Introduction
Flash flood is a deadly natural disaster that develops at space and time scales. Flash flood frequently occurs when there are high rainfall intensities. The main problem causing flash floods is extreme storm rainfall upstream of the catchment [1]. Another flash flood phenomenon typically occurs in steep slope mountainous regions, material sediments, and small catchment areas [2]. It has been a significant concern for decades, costing billions of dollars in losses along with thousands of human deaths and injuries every year around the world [3]. It can destroy buildings, infrastructures, destruct businesses, agricultural properties, ecosystems along the river [4]. Flash flood mitigation strategies are emphasized to reduce the severity of flash flood damage when it occurs. The mitigation in a very community may include planning and zoning, managing flash flood plain, discouraging development within the high risk of flash flood area, providing outreach education, and operating flash flood warning systems. Flash flood warning systems help protect people's lives and prevent property damages by giving sufficient time intervals for evacuations [5]. For efficient flash flood management, two critical factors should consider flash flood travel time and possible mapping inundation areas. Flash flood travel time is essential for the timely evacuation of people from probable flash flood prone areas. Likewise, flash flood inundation maps are imperative tools that represent the spatial variability of flash flood hazards and provide a clear...
visualizing picture and robust understanding of flood patterns [6][7]. According to Indonesia’s National Disaster Management Authority (BNPB), flash floods have massively occurred due to several factors, including the high rainfall intensities and river sedimentation.

The Ciberang river has had heavy rains since December 31, 2019, which also caused several localized landslides in Bogor, West Java Province, Tangerang, and Lebal, Banten Province. The flash flood has severely damaged 1,060 houses, and around eight people died in six sub-districts of Lebak Gedong, Cipanas, Curugbitung, Cimarga, Maja, and Sajira [8]. The research study has three objectives to responding to this flash flood occurrence are:

1. to simulate the flash flood occurrence,
2. to identify impacted areas due to flash flood occurrence,
3. to develop a mitigation plan to respond to flash flood events.

2. Materials and Methods

2.1 Description of the study area

The Ciberang River is located in Banten Province, Indonesia. Figure 1 shows the main study area of this research, the map of reach and sub-districts affected by the flash flood occurrence. There are eight sub-districts including Banjar Irigasi, Cipanas, Bintang Sari, Sipayung, Bintangresmi, Talagahiang, Sukasari and Haurga Jurug that will to identify impacted areas due to flash flood occurrence. According to the topography, the eight sub-districts have inflow from four sub-catchments that have areas 120.70 Km², 31.33 Km², 13.71 Km², and 23.75 Km², respectively. The Sabo Dam provided from Sabo Technical Center has code “A1 to A3” and the code B provided by itself.
2.2. Description of the Study
The research started from comparison rainfall that selects satellite rainfall that satellite uses in this study and then average rainfall using the Isoyet method. The spatial data were used to calculate the GAMA I Unit hydrograph and SCS curve number. The flood hydrograph of each catchment was calculated with average rainfall, GAMA I, and SCS curve number. The results of the flood hydrograph were input in the HEC-RAS model to output the inundation and velocity map. Finally, the inundation map was comparison with a satellite image. The ending of the first objective is the results of a comparison between hydraulic products and satellite images.

The second objective of this research study is to identify affected areas due to flash flood occurrence from the hydraulic modeling and satellite image data, and the third objective is to develop a mitigation plan to respond to flash flood events.

2.3. Data Acquisition
Data collected from different sources for this research study are present in Table 1. The observed rainfall used for this study provided from SABO Agency was available from 2003 to 2008. However, the flash flood occurrence was from December 31, 2019 to January 01, 2020, so the study used satellite rainfall to calculate flash flood hydrograph. The satellite rainfall has three types that are from Global Satellite Mapping of Precipitation (GSMaP) (https://sharaku.eorc.jaxa.jp/GSMaP/), Global Precipitation Measurement (GPM) (https://disc.gsfc.nasa.gov/), Precipitation Dynamic Infrared Rain Rate (PDIR) (https://chrsdata.eng.uci.edu/). The digital elevation model (Figure 3a) was downloaded from DEM and National Bathymetry (https://tanahair.indonesia.go.id/demmas/#/) with elevation from 100 m to 1900 m with the resolution of 8m x 8m. The soil type (Figure 3c) used in this study has three types there are Ao70-2/3b, Ao83-2/3c, and Th17-2c that was download from Global Soil data by food and agriculture organization (FAO) (www.fao.org/). The Sentinel 2 was download from https://scihub.copernicus.eu/ that was high resolution 10 m x 10 m. Sentinel 2 in this study selected two imageries before the flash flood on December 11, 2019 and after the flash flood on March 15, 2020. The select image based on the cloud in the imagery is less than 10% or clear the imagery and the study area. The image has many clouds that could not be used to study after the flash flood until March 15, 2020. The land use was classification from the Sentinel before the flash flood occurrence (Figure 3b). Figure 2 shows the Sentinel 2 map and impacted area from the comparison satellite image after and before flash flood occurrence.

2.4. Rainfall analysis
2.4.1. Linear Scaling Method
The Linear Scaling (LS) method implements a constant corrected factor estimated by the difference between satellite rainfall and observations for each calendar month [9]. This approach can perfectly adjust for climate factors when monthly mean values are included [10]. A multiplier is used to adjust precipitation. To use Linear Scaling to compute bias rainfall, use the following formula:

\[
p_{\text{sat,m,d}}^{\text{bias}} = p_{\text{sat,m,d}} \times \frac{\mu(p_{\text{obs,m}})}{\mu(P_{\text{sat,m}})}
\]

\(p_{\text{sat,m,d}}^{\text{bias}}\) The corrected precipitation on the day or the month \(P_{\text{sat,m,d}}\) is precipitation original of satellite rainfall data on the day or the month, \(\mu(p_{\text{obs,m}})\) and \(\mu(P_{\text{sat,m}})\) average observed rainfall and satellite rainfall data.
Table 1. List of data used in the research study

| Data Type          | Description      | Spatial Resolution | Temporal Resolution | Data Sources                      |
|--------------------|------------------|--------------------|---------------------|-----------------------------------|
| Topography Map     | DEM              | 8m x 8m            | ~                   | DEMNAS: DEM and National Bathymetry |
| Land use Map       | Land use classification | 10m x 10m       | 2019                | Land use classification from Sentinel 2 |
| Soil type Map      | Soil types       | 250m x 250m        | 2002                | Global Soil data (FAO)            |
| Observed Rainfall  | Rainfall station | 3 Stations         | Daily, 2003-2008    | Bolai SABO                        |
|                    | Gridded rainfall | 0.1°               | Hourly, 2003-present| GSMaP: Global Satellite Mapping of Precipitation |
|                    | Gridded rainfall | 0.1°               | 30 mins, 2003-present| GPM: Global Precipitation Measurement |
|                    | Gridded rainfall | 0.04°              | Hourly, 2003-present| PDIR: Precipitation Dynamic Infrared Rain Rate |
| Satellite Image    | Raster           | 10m x 10m          | Before: December 11 2019 After: March 15, 2020 | Sentinel 2 Level-2A |

Figure 2. The Sentinel 2 satellite image illustrated the impact of the rainfall (a) The Sentinel 2 map before a flash flood. (b) The Sentinel 2 map after a flash flood. (c) The impacted area after flash flood occurrence.
2.4.2. Isohyet method

The precipitation is never uniform over the entire basin or catchment area but varies in intensity and duration from region to region. Therefore, Isohyet is used as a weighted mean rainfall method. Isohyet is a method that depends on the influence area of the catchment rainfall, and it needs to be accurate in determination [11]. The formula to analyze weighted rainfall drops in the catchment is expressed as the following:

$$\overline{P} = \sum_{i=1}^{n} \alpha_i \left( \frac{P_i + P_{i+1}}{2} \right)$$

(2)

Figure 3. Spatial data input in the study at Ciberang River and administration boundary a) The digital elevation model map, b) The land use map, c) The soil type map, (d) The stream order delineates from DEMNAS
Where $\alpha$ is the area between each pair of adjacent isohyets, $A$ is the total area in the catchment, $P$ is the average precipitation for each pair of adjacent isohyets, and $\bar{P}$ the average rainfall drops in the catchment.

### 2.4.3. GAMA I Synthetic Unit Hydrograph

GAMA I Synthetic Unit Hydrograph was developed based on several study areas at Java Island [12]. It has three main parts: rising limb, peak, and recession limb. Its variables also have four mains, which are the peak discharge ($Q_p$), time of rising ($T_R$), base time ($T_B$), and recession side that determined with storage coefficient value ($K$). The equations used are as follows:

**Time to rise:**

$$ T_R = 0.43 \left( \frac{L}{100SF} \right)^3 + 1.0665SIM + 1.2775 $$  

(3)

**Peak discharge:**

$$ Q_p = 0.1836A^{0.585}TR^{0.4008}JA^{0.2381} $$  

(4)

**Time to base:**

$$ T_B = 27.4132TR^{0.1457}SN^{0.00986}RUA^{0.2574} $$  

(5)

**Recession limb,** which determined by a storage coefficient

$$ K = 0.5617A^{0.1708}SF^{0.7344}D^{0.452} $$  

(6)

With the amount of discharge in recession limb is

$$ Q_t = Q_p e^{-\frac{t}{K}} $$  

(7)

### 2.4.4. Flood Hydrograph

A catchment flood hydrograph is a plot graph showing the discharge of a catchment at a given point over a scale of time [13][14]. The hydrograph is the response of input rainfall in a catchment. The flow has three phases: runoff, surface, interflow, and baseflow, and combined complex interaction effects of the various catchment and rainfall parameters. Therefore, different storm events in a catchment produce a hydrograph of varying intensity [15]. Two factors affecting storm hydrograph are physiographic factors and climate factors. The physiographic factors include basin characteristics, infiltration characteristics, and channel characteristics. The climate factors include storm characteristics, initial loss, and evapotranspiration. The equation of flood hydrograph calculation is as below:

$$ Q_t = \sum_{n=1}^{\infty} P_{m,m-1} $$  

(8)

### 3. Results and Discussion

#### 3.1. Rainfall Analysis

The comparison was performed with grid cell average rainfall based on ground rainfall measurements to assess the accuracy of the satellite rainfall products. All three satellite rainfall products have been available in near real-time since 2003, and the ground station was from 2003 to 2008. The satellite rainfall was bias-corrected using linear scaling methods based on three rainfall stations and comparing satellite rainfall after bias with satellite rainfall. Table 2 shows the statistics result in the value of annual precipitation, RMSE, PBIAS, NSE, and R² that was compared with ground stations. According to the
statistic results, the GPM of all stations was good, with RMSE smaller or near zero value. The NSE was more suitable than other satellites than was valued higher than 0, and R² of Banjar Irigasi was GSMaP better than GPM around 0.4. Still, the Sajira and Cimijak were better for GPM.

The Taylor diagrams (Figure 4) showed that the GPM selected the best satellite rainfall to accurately select the best satellite rainfall. The correlation coefficient of GPM was valued higher than other satellite produces. For example, the standard deviation of GPM in Banjar Irigasi and Sajira was a value near 1, with Cimijak values lower than 0.5 for all satellite rainfall.

Table 2. Comparison between ground station with satellite rainfall based on statistical method

| No | Station          | Ground Station | Satellite Rainfall | After Bias | | | | | | |
|----|-----------------|----------------|-------------------|------------| | | | | | |
|    |                 | mm mm          | mm mm | % | - | - | | | | |
| 1  | Banjar Irigasi  | 1991           | GSMaP  | 2465.91 | -105.328 | 23.9 | -0.213 | 0.542 | | | |
|    |                 |                | GPM    | 2335.27 | -88.443  | 17.3 | 0.145 | 0.506 | | | |
|    |                 |                | PDIR   | 2377.91 | -112.093 | 19.4 | -0.374 | 0.353 | | | |
| 2  | Sajira          | 2022.58        | GSMaP  | 2183.69 | -91.808  | -8   | 0.341 | 0.575 | | | |
|    |                 |                | GPM    | 2252.42 | -82.708  | -11.4 | 0.465 | 0.613 | | | |
|    |                 |                | PDIR   | 2194.11 | -107.782 | -8.5  | 0.092 | 0.389 | | | |
| 3  | Cimijak         | 2880           | GSMaP  | 2274.82 | 234.235  | 21   | 0.07  | 0.39  | | | |
|    |                 |                | GPM    | 2302.35 | 217.228  | 20.1 | 0.2   | 0.49  | | | |
|    |                 |                | PDIR   | 2324.37 | 234.697  | 19.3 | 0.066 | 0.381 | | | |

The bold value is the best of comparison values.

![Figure 4. Taylor diagram of comparison satellite rainfall with the ground station](image)

The statistic results in Table 2 and the Taylor diagram in Figure 4 were compared between ground rainfall with satellite rainfall show the GPM is a satellite rainfall used in this research study and used to calculate the average rainfall on each catchment in this research study.
3.2. Flood Hydrograph
Figure 5 shows the flash flood hydrograph occurrence of each sub-catchment. The flash flood occurred around 44 hours. The discharge from catchment C1 was a flow that impacted the Ciberang River, as seen in the graphic.

![Flash Flood Hydrograph](image)

Figure 5. Flash flood occurrence from sub-catchment

3.3. Hydraulic Simulation of Flash Flood Occurrence

3.3.1. Calibration of Hydraulic Model
For an accuracy assessment, the Sentinel-2 classification results from March 15, 2020, were compared with the flood inundation mapping from the HEC-RAS model. The overall accuracy of the flash flood events occurrence was found to be 68.00 %. The error shows that 20.37 % was the impact area identified from Sentinel 2 data. The HEC-RAS did not impact real conditions because this study worked without DEM before the flash flood, landslide, and sediment transport in the flash flood event. Thus, the HEC-RAS model was acceptable with flash floods occurring from Dec 31, 2019, to Jan 01, 2020.

| Satellite Image Sentinel 2 | HEC-RAS |
|-----------------------------|---------|
| Flood                       | 68.00 % |
| Non-Flood                   | 20.37 % |
| Non-Flood                   | 11.63 % |
|                             | 0 %     |

3.3.2. Hazard Map
After the HEC-RAS model was acceptable, the output of the 2D simulation HEC-RAS model includes inundation flash flood depth and flood velocity. Figure 6 shows the maximum depth and velocity of a flash flood occurring in eight sub-districts.

The inundation depth and velocity maps merged to create the hazard classification map. Figure 6c shows the hazard map in this research study. From the upstream to downstream, the river was a hazard at number 6 (H6), or all building types considered vulnerable to failure because the depth has a value higher than 4 m, and the velocity along this river is also higher than 4 m/s. After the flash flood, the hazard map and satellite image show that the building or agriculture was damaged along the river.
3.3.3. The Flow of the Flash Flood Occurrence

The inundation depth and output velocity from the HEC-RAS model gave the flow using the river’s cross from the DEMNAS. The discharge of CS1 was an original discharge from catchment C1; the discharge of CS2 was an addition flow catchment 3, that the peak flow was increasing around 30 m³/s. The discharge curve of CS3 was an additional flow from catchment C2 that made the peak flow increase more than 50 m³/s. The last cross-section was CS4 that was the outlet of this study that the peak flow was a value around 400 m³/s. The discharge of flash flood occurrence increased from upstream to downstream with a value of 264 m³/s to 406 m³/s.
3.4. Impact of Flash Flood Occurrence

The flash flood can impact the economic, social, and environmental damage of buildings, roads, agriculture, or bridge along the river. This affected area from the flash flood occurrence was identified on seven sub-districts along Ciberang River, based on the satellite image on March 15, 2020. The inundation map from the HEC-RAS model was damaged on agriculture, building, roads, and bridge along the river. Table 4 shows the value of damaged from flash flood occurrence. The flash flood damaged agriculture around 107.69 Ha, building (1.29 Ha), 2.5 Km of road, and nine bridges. The Banjar Irigasi sub-district was the most affected area.

Table 4. List of effects of Flash Flood in Ciberang River between Sentinel and HEC-RAS simulation

| No | Sub-Districts   | Agriculture | Building | Road | Bridge |
|----|-----------------|-------------|----------|------|--------|
|    | HEC-RAS Satellite | HEC-RAS Satellite | HEC-RAS Satellite | HEC-RAS Satellite |
|    | Ha              | m           | Ha       | m    |        |
| 1  | Banjar Irigasi  | 10.04       | 0.46     | 1.02 | 271.11 | 243.84 | 1 |
| 2  | Ciputai         | 7.46        | 0.12     | 0.10 | 198.20 | 186.91 | 2 |
| 3  | Bintang Sari    | 12.10       | 0.01     | 0.01 | 200.61 | 302.56 | 1 |
| 4  | Sipayung        | 10.76       | 0.01     | 0.01 | 669.92 | 733.31 | 1 |
| 5  | Talangnang      | 3.68        | 0.02     | 0.01 | 456.26 | 75.99  | 1 |
| 6  | Bintangresmi    | 6.90        | 0.03     | 0.00 | 27.32  | 0.00   | 0 |
| 7  | Sitasinga       | 12.30       | 0.07     | 0.07 | 483.58 | 75.99  | 2 |
| 8  | Hauzajirg       | 14.63       | 0.08     | 0.09 | 152.57 | 133.96 | 1 |
|    | Total           | 77.86       | 107.69   | 1.29 | 2,459.57 | 1,752.57 | 9 |

3.5. Mitigation

3.5.1. Sabo Dam

The Sabo dams are a standard measure to limit debris flows. The primary function of a sabo dam is to reduce erosion of the river bed and bank, trap sediment discharge, control sediment discharge, grade the effect of sediment, and reduce the energy of debris flows. To mitigation of flash flood events, this study selected four dams to reduce the flash flood events. In this study, the four Sabo Dam was input in the HEC-RAS model and located upstream of the Banjar Irigasi around 3.5 Km.

Figure 8. The comparison of the graph of Flash flood occurrence under the Sabo Dam commission
Figure 8 shows the comparison of discharge before and after of the sabo dams upstream. The results show the sabo dam could reduce flow by around 40 m³/s, and the time peak of discharge was changed after sabo dam around an hour.

3.5.2. Warning Information
This study presented flash flood travel time between flash flood before and after build sabo dam at the upstream and reaching essential objects, including police academy building, structure, local communities, road, and agriculture in different scenarios for the downstream.

Table 5 shows flash flood travel time between the flash flood before and after the flash flood. The travel time was compared between the peak of discharge on January 01, 2020, at 04:44:20 of cross-section CS1. Before the Sabo Dam, the travel time lasted around 44 mins from the cross-section CS1 to CS4.

| No | Cross Section | Before Sabo Dam | After Sabo Dam | Change |
|----|---------------|----------------|---------------|--------|
|    |               | Peak Discharge  | Time          | Peak Discharge | Time     | Discharge | Time     |
|    |               | m³/s           | -             | m³/s          | -        | %         | -        |
| 1  | CS1           | 264.17         | 0:00:00       | 253.74        | 0:49:30  | 3.95      | 51 mins  |
| 2  | CS2           | 291.63         | 0:10:40       | 278.20        | 1:04:00  | 4.61      | 54 mins  |
| 3  | CS3           | 368.57         | 0:23:40       | 348.13        | 1:13:20  | 5.55      | 50 mins  |
| 4  | CS4           | 406.35         | 0:44:30       | 381.13        | 1:44:00  | 6.21      | 60 mins  |

After the Sabo Dam was built in the HEC-RAS model, the flash flood’s travel time changed to around an hour. As a result, the cross-section at C1 was delayed the travel time around 53 mins from the original flash flood occurrence.

4. Conclusions
This study used GPM satellite rainfall to calculate the flash flood occurrence related to ground rainfall. The duration of flash flood occurrence has 44 hours and started drop on December 31, 2019, at 02:30. The discharge from catchment C1 was damage along the river that has peak discharge at 264 m³/s. The HEC-RAS model was applied to identify the inundation map, velocity map, and hazard map. The impact area identified from the inundation map and satellite image data damaged agriculture (108 Ha), buildings (1.3 Ha), roads (2.5 Km), and nine bridges. The Sabo Dam was applied to respond to the flash flood occurrence. The four Sabo Dams were input in the HEC-RAS model and located upstream of the Banjar Irigasi sub-district. The warning information provided the travel time of flash flood occurrence. As a result, the Sabo Dam reduced the discharge of flash floods by around 40 m³/s and delayed the travel time of discharge to around 53 mins.

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