Geographic Information System for Flood Control: Cilember River, Cimahi City, West Java Province

Yackob Astor, Iin Karnisah, Bambang Setio Budianto and H. Dandi Aprillian

Abstract Urban floods, such as those that occurred in Cimahi City in the last 10 years, have quite extensive economic impacts and are difficult to manage. To develop a comprehensive flood control plan, a complete, integrated and well-structured database is needed. This study will build a Geographic Information System (GIS) to control water damage by conducting flood simulations on the Cilember River in Cimahi using parameters such as hydrological data, river crossings, DEM data, and flood models that are processed using 2-Dimensional flood simulation HEC-RAS Software. The simulation was run based on 2 and 5 years return period of rainfall. The results are presented as a Geographic Information System for Flood Control that visualizes a flood map model, which can identify the location of floods, flood depth, area of flood. Validation of models shows that despite the differences in flood depth between simulation result (max depth 200 cm) and actual condition (max depth 100 cm), there is a suitability of the flood location between the model with the actual conditions. Simulation result also shows that by normalization and widening of the river, the flood conditions which initially had a depth of 10–200 cm, was reduced to 10–140 cm.

Keywords Flood control · Geographic Information System · HEC-RAS

1 Introduction

Flood is the most frequent natural disaster occurred in Indonesia. According to Indonesian National Board for Disaster Management (BNPB 2016), 31.1% of the disasters that occurred in Indonesia were flood [7]. Urban floods give a quite extensive economic impact and more difficult to be manage, especially in denser...
populations area. This makes the damage bigger and more expensive to recover, such as damage to buildings, traffic congestion, and various water borne diseases that often occurs during flood.

The Indonesian government through the Directorate of Water Resources, Ministry of Public Works issued a policy on Water Damage Control to minimize the destructive impacts caused by flood. Water damage control is carried out on rivers, lakes, and/or dams, swamps, groundwater basins, irrigation systems.

Geographically, Cimahi City is a basin with sloping from North to the South. In the North are Mount Burangrang and Mount Tangkuban Perahu, with an altitude of 1040 m above sea level, while in the South is Citarum river with an altitude of 685 m above sea level. This topographic condition causes the southern part of Cimahi more frequently affected by flood compared to northern Cimahi.

This research was built a Geographic Information System (GIS) for Flood Control to minimize water damage in Cimahi City, West Java Province. The system was built based on a comprehensive study of flood in Cimahi City using meteorology, hydrology and geographical data on the condition of the Cimahi City and the surrounding area. Indonesia is located in a tropical climate area which allows high rainfall every year. Climate change and erratic weather cause many disasters, such as flood. The unavailability of information about the map of disaster vulnerability and the losses that can be caused by flood the creation of a flood hazard map is needed as a step to minimize the impact of the disaster. Geographical Information Systems (GIS) can make determination of flood-prone areas easier. The Analytical Hierarchy Procedure (AHP) method was used to determine the weight and score, so the flood vulnerability class is obtained such as very vulnerable, vulnerable, quite vulnerable and not vulnerable [2]. For certain location, flood is an annual routine. The location of the incident can be urban or rural, even emerging countries or developed countries (Suherlan 2001 in [6]).

Geographical Information System (GIS) was successfully used to visualize flood levels and also to analyze flood maps to produce flood damage estimation maps and flood risk maps [5]. The GIS and HEC-RAS model were successfully used to obtain flood maps of the Waller River in Texas, the Ohio Swan River Basin, the Atrato River in Colombia, the Vistula River in Warsaw, Poland, the Gordon River in France, northwest Colombia, Middle East Dhaka in Bangladesh, and also Onaville in Haiti. Çelik et al. analyze the 2004 flood of the Kozdere Stream in Istanbul using HEC-RAS and GIS [1].

The flood in Adamawa Nigeria year 2012 is believed to be the result of a combination of the Lagdo dam effects and the intensity of rainfall. According to the Adamawa State Government (2012), this excessive water due to heavy rain forced the Cameroon government to open the Lagdo dam water channel after sending a warning to Nigeria for the release of water. In addition, through the Flood Early Warning Center, the Nigerian Ministry of Environment (2012) issued heavy rainfall estimates in mid-September and warned of potential flooding in parts of the country including Adamawa State [4].
2 Methodology

The research methodology used to build a flood prevention Geographic Information System in Cimahi City, West Java Province shown in Fig. 1.
An initial survey was carried out to see the condition of the Cilember River cross-sectional in Cimahi City. Measurement of river cross-sectional was done in the upstream, middle and downstream of the river as shown in Fig. 2. Qualitative data was collected trough interviews with local residents regarding the condition of the river during rain and not rain.

3 Data

This research used several secondary data which include:

1. Digital Elevation Model (DEM)

The DEM used is obtained from National DEM (DEMNAS) produce by Indonesian Geospatial Information Agency. DEMNAS with 8 m resolution, as shown in Fig. 3, was used as an elevation for flood overflow.

2. Cimahi City Watersheds

Data is used to see the flow of each river and calculation of the planned flood discharge. Data used in 2014 were obtained from the Public Works Agency (Fig. 4).

3. Daily Rainfall

Daily rainfall data for period of 2007–2017 was collected from West Java Water Resources Agency starting in 2017 is used to calculate the planned flood discharge.

Fig. 2 Measurement of river cross-sections
Fig. 3  DEMNAS 8 m
(DEMNAS 2018)

Fig. 4  Cimahi City
Watersheds (Public Works Agency 2014)
4. River Cross Section Drawing

River cross section from Detail Engineering Design Drawings were used as river condition in flood simulation after river rehabilitation/normalization (Fig. 5).

5. Land Cover of Cimahi City

Land cover data (Fig. 6) was obtained from the Geospatial Information Agency, used to see land used around the Cilember River.

6. SPOT Satellite Imagery 7

Image data of SPOT 7 satellite (Fig. 7) with spatial resolution of 1.5 m in 2017 was used to update land cover data and land use to see the impact of river overflows in Cimahi City.

7. Measurement of River Cross-sectional

Measurements of river cross-sectional in upstream, middle and downstream were carried out as a comparison of river cross-sectional in 2018 with 2014 data obtained from the Cimahi City Government.

4 Result

There are 7 outputs produced from this research, such as:

4.1 Cross Section and Long Section of Cilember River

The river long-sectional used in this modeling is the 2014 river long-sectional data (Figs. 8 and 9) obtained from the Cimahi City Government and the results of field
measurement survey in 2018 in the Upstream, Middle and Downstream of the Cilember River (Fig. 10).

4.2 Flood Discharge

The flood discharge was calculated using the Nakayasu HSS method, the flood simulation was run for 2 and 5 years return periods (Table 1).

4.3 1-Dimensional Flood Simulation

The output of flood simulation of Cilember River, the existing conditions are displayed in 1 dimension and 2 dimensions with the return periods of 2 and 5 years.
The 1-dimension simulation result shows that the Cilember River cannot accommodate a flood discharge for both 2 and 5-year return period, it can be seen in Figs. 11 and 12.

4.4 2-Dimensional Flood Simulation

The 2-dimensional flood simulation were carried out using flood discharge for the return period of 2 and 5 years. From the simulation result (Fig. 13), it can be concluded that for the 2-year return period, water overflows occurred almost along the river segment. Flood depth that occurred can reach 1–3 m from the riverbank.

4.5 Flood-Prone Map of Cimahi City

In Figs. 14 and 15, the flood depth is shown by different colors, the darker the color displayed in line with the higher the flood, and vice versa. Based on the Flood-Prone Map, the estimated flood depth and area of the flood can be calculated (Table 2).
Fig. 8  Cilember River long-sections

Fig. 9  Condition of Cilember River long section
Fig. 10  Cilember River cross section

4.6  River Normalization and Widening

Based on the simulation result in Table 2, flood control is needed to overcome the overflow by normalizing and widening the Cilember River.

Based on the condition of the Cilember River which has an average depth of 3–4 m and an average width of 4 m, the normalization of 2 m and widening of the 0.5 m left and right in several river cross sections was carried out. Based on the result obtained from the normalizing and widening of the river, there is a decrease in water overflow (Table 3). Visualization is also shown the results of 1-dimensional and 2-dimensional flood simulation in Figs. 16 and 17.

The water damage control map of Cilember River for a 5-year return period can be seen in Fig. 18, from the result can be seen the difference in overflow and depth of the flood.
Table 1  Cileember River planned flood discharge of 2-year and 5-year return period

<table>
<thead>
<tr>
<th>Station (km)</th>
<th>Ordinate (m)</th>
<th>Discharge (m³/s)</th>
<th>Ordinate (m)</th>
<th>Discharge (m³/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>0.000</td>
<td>2.100</td>
<td>9</td>
<td>0.000</td>
</tr>
<tr>
<td>1</td>
<td>1.440</td>
<td>4.128</td>
<td>10</td>
<td>1.193</td>
</tr>
<tr>
<td>2</td>
<td>2.885</td>
<td>2.885</td>
<td>11</td>
<td>1.193</td>
</tr>
<tr>
<td>3</td>
<td>4.330</td>
<td>4.330</td>
<td>12</td>
<td>1.193</td>
</tr>
<tr>
<td>4</td>
<td>5.775</td>
<td>5.775</td>
<td>13</td>
<td>1.193</td>
</tr>
<tr>
<td>5</td>
<td>7.220</td>
<td>7.220</td>
<td>14</td>
<td>1.193</td>
</tr>
<tr>
<td>6</td>
<td>8.665</td>
<td>8.665</td>
<td>15</td>
<td>1.193</td>
</tr>
<tr>
<td>7</td>
<td>10.100</td>
<td>10.100</td>
<td>16</td>
<td>1.193</td>
</tr>
<tr>
<td>8</td>
<td>11.535</td>
<td>11.535</td>
<td>17</td>
<td>1.193</td>
</tr>
<tr>
<td>9</td>
<td>12.970</td>
<td>12.970</td>
<td>18</td>
<td>1.193</td>
</tr>
<tr>
<td>10</td>
<td>14.405</td>
<td>14.405</td>
<td>19</td>
<td>1.193</td>
</tr>
<tr>
<td>11</td>
<td>15.840</td>
<td>15.840</td>
<td>20</td>
<td>1.193</td>
</tr>
</tbody>
</table>

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Fig. 11  Long section Water Level Based on HEC-RAS Simulation

4.7 GIS of Flood Control

Geographical Information System of flood control as the final product of this research was made to provide related information about locations affected by flood,
Fig. 12 Typical Water Level Cross Section Based on HEC-RAS Simulation

depth of flood and the impact of overflowing river water in Cimahi City. Geographical Information System visualization shows the location of flood, causes of flooding, the impact of flood, river condition during flood, results of running 1-Dimensional flood simulation and flood control solutions through normalizing and widening activities in the Cilember River.

Furthermore, 3 analyzes are carried out as follows:

1. Depth Data Quality Analysis for the Flood Model produced
2. Comparison of Flood Depth before and after being controlled
3. Comparison of Flood Area before and after being controlled.
Fig. 13 Result of Cilember River flood simulation

Fig. 14 Flood-Prone Map of Cimahi City for 2-year period
Fig. 15 Flood-Prone Map of Cimahi City for 5-year period

Table 2 Depth and area of flood

<table>
<thead>
<tr>
<th>No</th>
<th>River</th>
<th>Depth (m)</th>
<th>Area (ha)</th>
<th>Total area (ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Cilember 2nd</td>
<td>0.5–1</td>
<td>18.02</td>
<td>28.1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1–2</td>
<td>7.07</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>2–3</td>
<td>2.18</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>3–4</td>
<td>0.63</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Cilember 5th</td>
<td>0.5–1</td>
<td>33.32</td>
<td>56.1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1–2</td>
<td>15.93</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>2–3</td>
<td>6.27</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>3–4</td>
<td>0.58</td>
<td></td>
</tr>
</tbody>
</table>

Table 3 Depth and area of flood before and after flood control engineering

<table>
<thead>
<tr>
<th>Depth before being controlled</th>
<th>Depth after being controlled</th>
<th>Area before being controlled</th>
<th>Area after being controlled</th>
</tr>
</thead>
<tbody>
<tr>
<td>10–400 cm</td>
<td>10–140 cm</td>
<td>56.1 ha</td>
<td>26.86 ha</td>
</tr>
</tbody>
</table>
4.8 Depth Data Quality Analysis for the Flood Model Produced

Analysis of secondary data is divided into DEM and River Cross Section Data.

a. DEM data

The DEM data used in this research has a spatial resolution of 8 m, while the Cilember River has an average width of 4 m. The use of DEM lower spatial resolution (8 m) compared to the dimensions of existing object (4 m), causing the interpolation process of high points to be incompatible with the actual conditions in the field. So, in Fig. 19, there are some locations that are not flooded, even though they are located side by side.

Based on the result of the site survey, the location shown in Fig. 19 should have been flooded, but in the model, it was shown that the site was not flooded.

b. River Cross-Sectional

There is a change in the river cross-sectional that has been measured directly in several locations, compared to the 2014 river cross-sectional secondary data obtained from the Cimahi City Government [3]. It is shown in the shape of the river cross-sectional that changes in Figs. 20 and 21.
In Figs. 20 and 21, it can be seen that the elevation of the river cross-sectional in 2018 has decreased, because of the activity of dredging the riverbed and leveling of the land around the river for the construction of warehouse-houses and plans for making reservoir to accommodate the overflow of river water.

4.9 Comparison of Flood Depth Before and After Controlling

Comparison of flood depth in the model towards secondary data in 2017 and primary data in 2018 was carried out in several locations in the Cilember River, as shown in Fig. 22 and Table 4.

Technically, the difference in water depth between each location in Table 4 is due to the influence of 8 m DEM resolution which has not represented the actual conditions in the field. Another reason is that the field survey is conducted 1–2 h after the rain has subsided, so the flood depth is not optimal. Furthermore, there are changes in condition around the river at each point in 2017 and 2018 as follows:
**Fig. 18** Normalization and widening result map of Cilember River

**Fig. 19** Distance of flood runoff on DEM (left) and on Satellite Imagery (right)

**Fig. 20** River cross-sectional
in 2014 (Cimahi City Government 2014)
Fig. 21  River cross-sectional in 2018 (Site Survey 2018)

Fig. 22  Flood point of Cilember River in 2017
Table 4 Comparison of model flood depth and actual condition in 2017 and 2018

<table>
<thead>
<tr>
<th>No</th>
<th>Flood depth</th>
<th>Flood data in 2017</th>
<th>Site survey in 2018</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>50–200 cm</td>
<td>30–60 cm</td>
<td>30–100 cm</td>
</tr>
<tr>
<td>2</td>
<td>30–100 cm</td>
<td>30–60 cm</td>
<td>20 cm</td>
</tr>
<tr>
<td>3</td>
<td>100–170 cm</td>
<td>60–100 cm</td>
<td>Not flooded</td>
</tr>
<tr>
<td>4</td>
<td>50–150 cm</td>
<td>30–100 cm</td>
<td>250 cm</td>
</tr>
<tr>
<td>5</td>
<td>30–100 cm</td>
<td>10–40 cm</td>
<td>100 cm</td>
</tr>
<tr>
<td>6</td>
<td>50–100 cm</td>
<td>30–60 cm</td>
<td>30–100 cm</td>
</tr>
</tbody>
</table>

1. Cigugur Tengah, Cimahi Tengah Subdistrict, the flood depth in the model reached 200 cm, while the results of 2017 survey reached 60 cm and the 2018 survey result reached 100 cm. The difference in flood depth from the results of 2017 and 2018 surveys was due to the river siltation caused by waste and sedimentation of the soil.

2. Melong, South Cimahi Subdistrict, Cibaligo Street, flood depth in the model reached 100 cm, while the result of the 2017 survey reached 60 cm and the result of the 2018 survey reached 20 cm. The difference in flood depth from the result of 2017 and 2018 surveys was due to river widening.

3. Melong, South Cimahi Subdistrict, the flood depth in the model reached 170 cm, while the result of 2017 survey reached 100 cm and the 2018 survey flood did not occur. The difference in flood depth from the results of 2017 and 2018 surveys was due to the widening and construction of embankment in 2018 to prevent flood from overflowing into the toll road.

4. Cigugur Tengah, Central Cimahi Subdistrict, H. Amir Mahmud Street, flood depth in the model reached 150 cm, while the result of the survey in 2017 flood depth reached 100 cm and the result of the 2018 survey the flood depth reached 250 cm. The difference in flood depth from the results of 2017 and 2018 surveys was due to the condition of the river culverts having only a width of 1 m and a height of 1 m so the frequent occurrence of blockages caused by waste and causing overflow of river water into the residential area.

5. Central Cigugur, Central Cimahi Subdistrict, Martaneagara Street, flood depth in the model reaches 100 cm, while the result of the survey in 2017 reached 40 cm and the results of 2018 survey reached 100 cm. The difference in flood depth from the result of 2017 and 2018 surveys was due to the condition of the river siltation and sedimentation and also the position of Martaneagara Street was lower than the banks of Cilember River.

6. Melong, South Cimahi Subdistrict, Sukahaji Street, flood depth in the model reached 100 cm, while the result of the 2017 survey have reached 60 cm and the 2018 reached 100 cm. The difference in flood depth from the results of 2017 and 2018 surveys was due to the narrowing of the Cilember River due to the existence of factory buildings and siltation of the river and the dredging of Cilember River to plan the construction of warehouse-houses.
5 Conclusion

1. The system was built based on hydrological data, river cross-sectional and DEM data of 8 m resolution with flood models that are processed using HEC-RAS Software.
2. With the normalization and widening of Cilember River for a period of 5 years, the depth of the flood decreases, namely before normalization and widening of the flood depth reached 10–400 cm and after normalization reached 10–140 cm.
3. The area of flood overflow before normalization and widening reached 56.1 ha, and after normalization in several cross-sectional of Cilember River for the 5 year return period, the overflow flood area was reduced to 26.86 ha.
4. Based on the comparison of flood depth existing data to the model, there is a significant difference where the depth of flood in the model is 400 cm and the lowest is 20 cm while the field data is 100 and 10 cm.

6 Recommendation

1. It is necessary to input cross section and longitudinal section in the longer riverbank area, to make it more accurate of the actual river conditions.
2. It is better to use high resolution DEM data or use Lidar data so the river geometry results obtained are in accordance with the existing.
3. The Cimahi City Government should update the river cross-sectional data, due to the narrowing of the river caused by factory buildings and houses, and siltation of rivers due to sedimentation and garbage.

References

1. Demir V, Kisi O (2015) Flood hazard mapping by using Geographic Information System and hydraulic model: Mert River, Samsun, Turkey