Study of flood characteristic in Cikalumpang River by using 2D flood model

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Abstract. Flood is one of the natural disasters that occur in Indonesia frequently. At least there are 8.498 occurrences since 1980 through Indonesia. In order to prevent and resolve that natural disaster, some actions should be done. To know the best solution to solve flood, we should know the flood characteristic (what causes it, the inundation area, the height, how long it occurs, and etc.). The characteristic of flood will be easily known only when the flood occurs. Thus, it is necessary to build a model with high accuracy. The model was obtained by re-modeling the inundation incident that happened on March 7th, 2018, and validated with observed data from several locations in that period. The result shows a good agreement with the observed data. This is evident from the extent and depth of the puddle from the modeling results similar to the value of field observation data. From the results, it can be concluded that the Cikalumpang River model has been obtained with a good correlation. From field observations, it is known that flooding is caused by quite complex problems, such as decreasing river capacity due to illegal building construction, sedimentation, land cover change, and climate change.

1 Introduction

Flood is a natural disaster that can occur when water from the river flow over the riverbank and inundated an area that shouldn't be inundated by water. Flood can be caused many losses both materially and immaterially. Therefore, to reduce or to minimize the damages the proper solution should be conducted.

On the other side to know the proper solution for Flood problem is not easy. Because to solve the main problem of the flood we should do an investigation into the flood that happened. But obviously, there is a little chance for us to meet the same flood in another event. So another way to investigate the flood is we should make a flood model that can predict the same as the actual flood.

Various studies have been carried out in various parts of the world to find out the causes, effects, and characteristics of floods. In 2012 Ichamo et al. doing flood modelling by using ASTER DEM data in the Tisza River, Hungary. Then flood modelling has also been developed in both 1D and 2D. However, 2D modelling is considered a model that has better accuracy compared to 1D modelling (Gharbi, 2016). In 2016, V. N. Duong conducts a flood map by using MIKE Flood, by coupled 1D and 2D models.

Paudel in 2016 had been comparing three models of hydraulic model Hec-RAS, MIKE 21, and TUFLOW. The results are Hec-RAS give an overestimate result, MIKE 21 give a quite well result and the TUFLOW give an underestimate result. By comparing the performance of those models Mike 21 give a better performance in the calculation process.

1.1 Study area

The floods that occurred in the Cikalumpang watershed in the period March 5th-9th, 2018 caused submerged hundreds of settlements, several hectares of rice fields, and submerged community gardens. This disturbed the search for flood events that had occurred.

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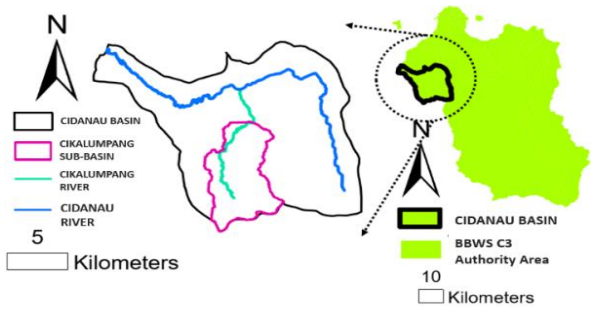

Fig. 1. Study area

Cikalumpang Basin (Fig 1) is one of several Sub-Basin in Cidanau River Basin, which specifically located in Province Banten and Cikalumpang basin is under the authority of BBWS Cidanau Ciujung Cidurian (C3). Cikalumpang watershed has an area of about 41 km2, with land cover dominated by rice fields and forests. Flooding is not a new problem in the Cidanau watershed area. This led to the importance of observation activities related to the characteristics of inundation, affected areas, and the rain mechanism that occurred to determine the causes and the process of flooding that occurred.

Based on information obtained from studies that have been conducted and related data, it can be seen that the Cikalumpang River experienced several recorded flood events. The earliest recorded flood event occurred in 2002 and during the last three years, flood events occurred every year (2016-2018). The main causes of flooding that occur are thought to be due to changes in land use, especially around the banks of the Cikalumpang River itself, while other causes are sedimentation and waste problems.

Based on the results of a search related to previous studies that have been conducted, there are some temporary conclusions that can be used as a reference in the preparation of the study to be conducted. Some conclusions related to the problems that occur are, first, the absence of activities and studies that investigate the causes of flooding while evaluating quantitatively the causes of the flooding. Second, the absence of a map prone to flooding in the Cikalumpang River. Third, there are no studies related to the effects of climate change on hydrology and hydraulic conditions in the Cidanau watershed.

From the initial conclusions obtained then the determination of the objectives of the study to be carried out. The purpose of the study to be conducted is to answer several existing problems, namely:

1. To investigate the causes of flooding in the Cikalumpang River
2. To build the correct flood inundation model for the Cikalumpang River
3. To aassess the causes of flooding in the Cikalumpang River in the period March 2018 using a flood inundation model.

2 Methodology

Generally, the study process is based on the stages that have been compiled and illustrated in the flow chart as follows.

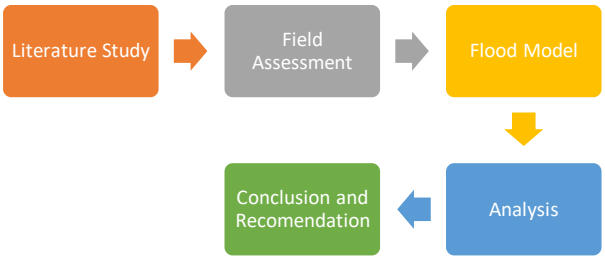

Fig. 2. Step by step of study

The study begins with a literature study, both previous studies in the study area and studies related to methods or theoretical studies. From the literature study activities, steps will be taken to work on the following research software used in this study. Then field observations were carried out to obtain field observation data such as flood depth at several observation points, as a basis for the analysis process and reference in the simulation process. From field observations, information will also be obtained regarding problems related to the floods that occurred.
Then the simulation process, some of the processes carried out in the simulation stage are:

- Rainfall-Runoff Model: Kure and Yamada (2005)
- Flood Routing: 1D Model, unsteady flow
- Flood Inundated Model: 2D Model, unsteady flow

The modelling results will be verified both location and depth of inundation from the results of field observations. Finally, conclusions will be made from the results of research carried out then recommendations containing suggestions and input for further research activities.

The basic principles in hydraulic modelling both in the river and in the drainage system are continuity equations and momentum equations. These equations are developed in such a way with the addition of several constants or variables in accordance with the characteristics of the object under study in order to increase the accuracy of the calculations in the simulation to be carried out. Then it was developed to several coordinate axes to obtain 1D, 2D and 3D models.

Governing Equations:

Continuity Equation

$$\frac{\partial A}{\partial t} + \frac{\partial Q}{\partial x} = q_1 \quad (1)$$

Momentum Equation

$$\frac{\partial Q}{\partial t} + \frac{\partial (uQ)}{\partial x} = gA\frac{\partial (h)}{\partial x} - \frac{gn^2|Q|Q}{R^{4/3}A} \quad (2)$$

where:

A = Area
Q = Discharge
q_1 = Lateral Flow
u = Velocity
h = water depth

While the inundation simulation uses the following equation:

$$\frac{\partial h}{\partial t}+\frac{\partial p}{\partial x}+\frac{\partial q}{\partial y}=0 \quad (3)$$

$$\frac{\partial q}{\partial t}+\frac{\partial}{\partial x}\left(\frac{p^2}{h}\right)+\frac{\partial}{\partial y}\left(\frac{pq}{h}\right)+gh\frac{\partial \zeta}{\partial x}+\frac{gp\sqrt{p^2+q^2}}{C^2.h^2}-\frac{1}{\rho_w}\left[\frac{\partial}{\partial x}(h\tau_{xx})+\frac{\partial}{\partial x}(h\tau_{xy})\right]=0 \quad (4)$$

$$\frac{\partial q}{\partial t}+\frac{\partial}{\partial y}\left(\frac{q^2}{h}\right)+\frac{\partial}{\partial x}\left(\frac{pq}{h}\right)+gh\frac{\partial \zeta}{\partial y}+\frac{gp\sqrt{p^2+q^2}}{C^2.h^2}-\frac{1}{\rho_w}\left[\frac{\partial}{\partial y}(h\tau_{yy})+\frac{\partial}{\partial y}(h\tau_{xy})\right]=0 \quad (5)$$

where:

C(x,y)	= Chezzy Coefficient
ρ_w	= Water Density
ζ(x,y,t)	= Water Elevation
τ	= Effective Stress
p, q	= flux density
h	= water depth
g	= gravitational acceleration

3 Result and analysis

Based on field observations that have been carried out both with direct observations to the river and aerial photographs found several findings, including the river losing the border due to the construction of settlements right on the riverbank (Fig 3). Then the capacity of the river which is quite small with the width of the river which ranges from 10-15 meters and when seen from the results of aerial photographs will be found the river embankment is still in the form of natural dikes this is marked by the many trees and rice fields on the riverbanks.

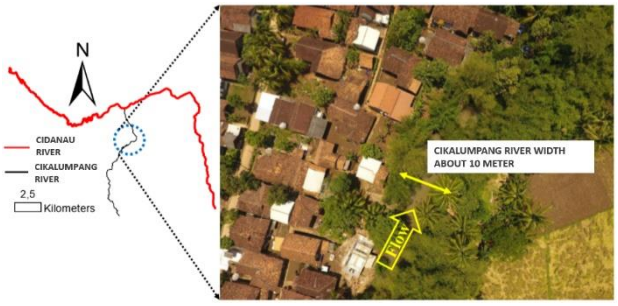

Fig. 3. Aerial photography of Cikalumpang river

Then based on land use data, it was found that generally, the land cover in the Cikalumpang watershed was in the form of rice fields, and forests (Fig 4). This means that there is no problem with the capacity of infiltration of Cikalumpang Watershed. And also shows that in the land cover and the topographic characteristics of the Cikalumpang watershed tend to be flat, so the water will tend to be infiltrated rather than flowing directly into the river. But instead of rapidly flowing the water, the flat area will widen the inundated area if the flood occurs. Besides that, when viewed from the layout of residential areas that are between rivers and rice fields, this is not good in terms of settlement layout. Because if heavy rain occurs the water will overflow into new settlements inundating rice fields.

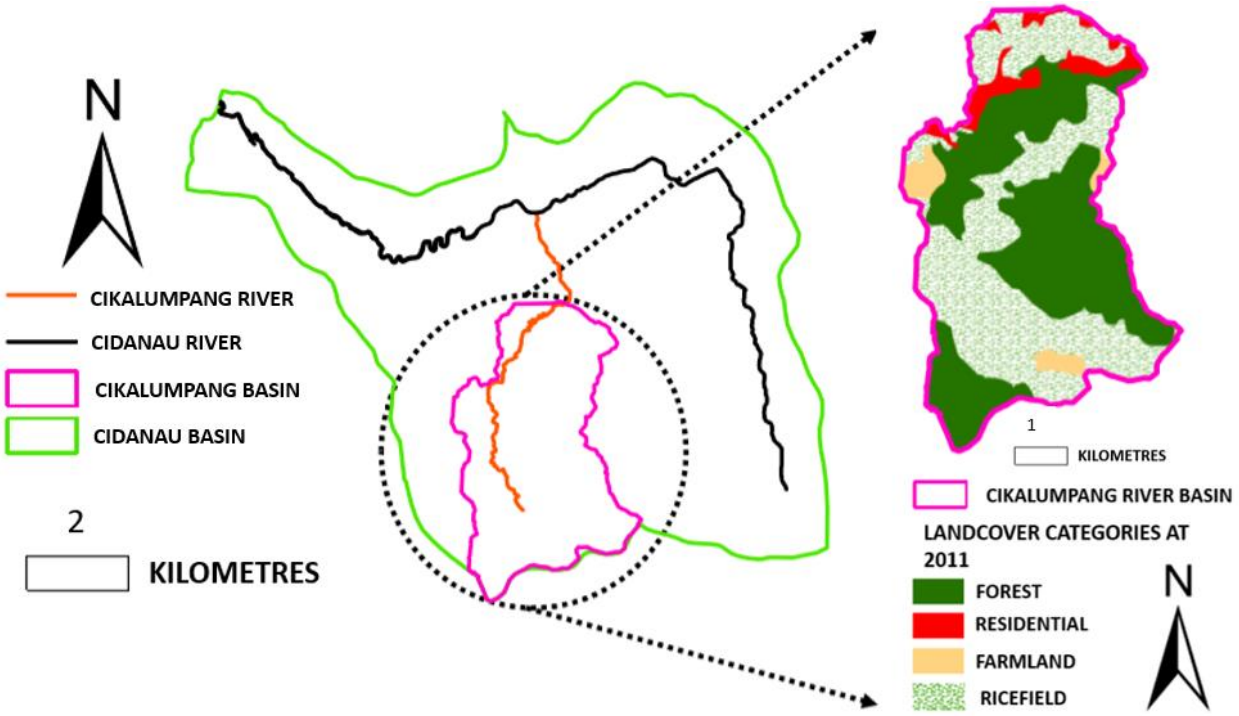

Fig. 4. Land cover of Cikalumpang river basin

It is also known that there is a large swamp area in the lower reaches of the Cikalumpang watershed known as Rawa Danau and some swamp areas are used as rice fields. This can cause the backwater effect of the lake swamp area plus topography which tends to be flat downstream resulting in the Cikalumpang River downstream easily inundated.

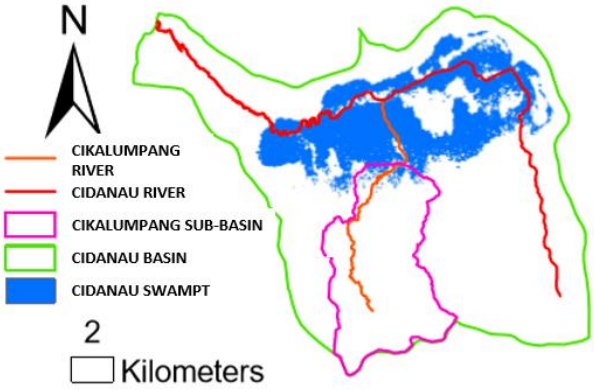

Fig. 5. Ancient wetland in Cikalumpang river basin

Other findings are sedimentation and waste problems in the Cikalumpang River. The sediment and the waste problems reduce the capacity of the river itself. So that when a high flow discharge occurs, water cannot flow well downstream and tends to overflow into the nearest flat area (ricefield and settlements) and inundate it.

Fig. 6. Sediment and rubbish in Cikalumpang river

Then, from the rainfall data obtained from the satellite during the period March 5th-9th 2018, rain occurred throughout the period, with the largest rainfall occurring on March 7th, 2018, with a rain height of 43-51 mm / day. Rain data is then processed to obtain the amount of discharge produced, with a discharge value of approximately 40m^3/s (Fig 8). This value is obtained from satellite rainfall data and in accordance with observational data where the inundation occurs in the period March 5th-9th, 2018. And based on a study conducted at Cikalumpang River in 2015, the discharge that occurred on March 7th, 2018, is equivalent to a 50 years return period of flood discharge.

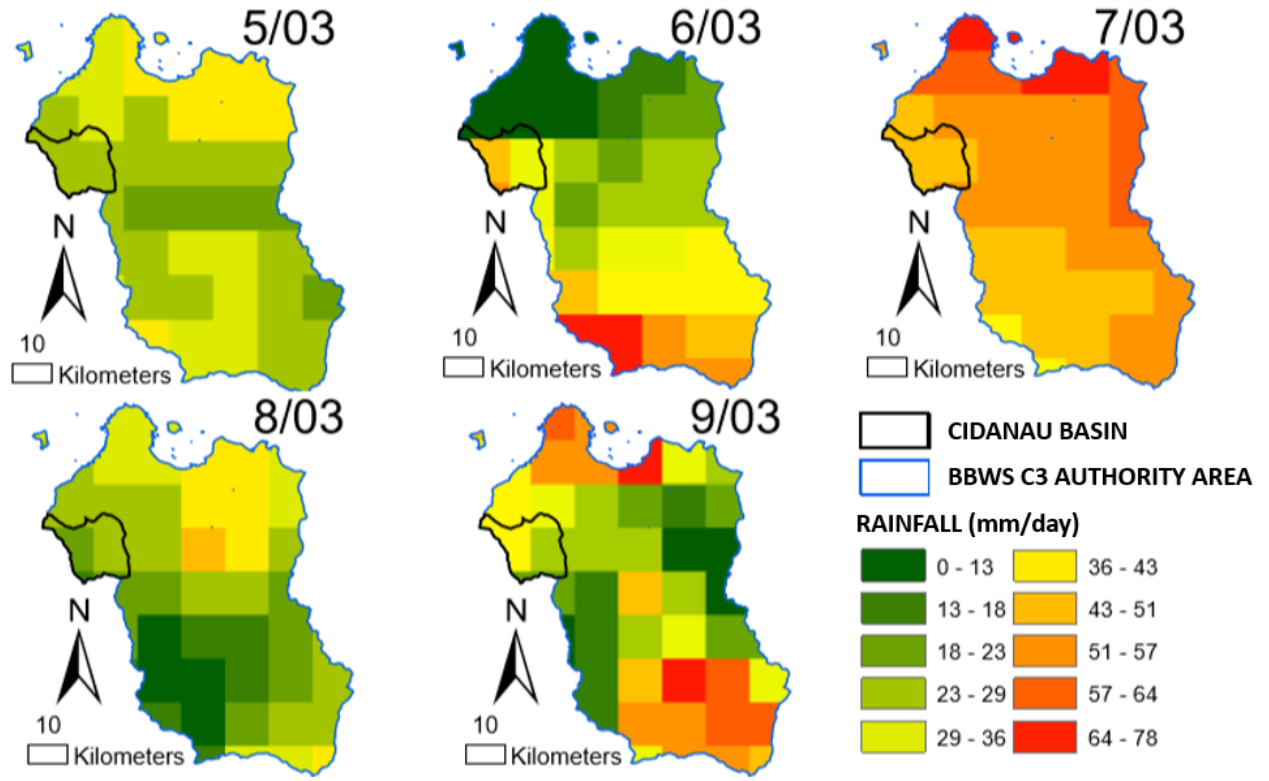

Fig. 7. Gridded rainfall during the March 5th-9^{th,} 2018

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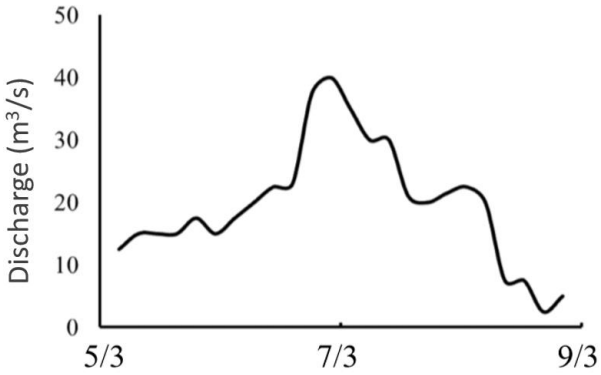

Fig. 8. Hydrograph due to the rain on March 5th-9th, 2018

Then after the flood modelling, the results were quite well and shows a fair agreement, this is shown in Fig 9 where the form of the inundation area generated from the inundation simulation resembled the results of the field mapping carried out during the flood events that occurred in the March 5th-9th, 2018 period.

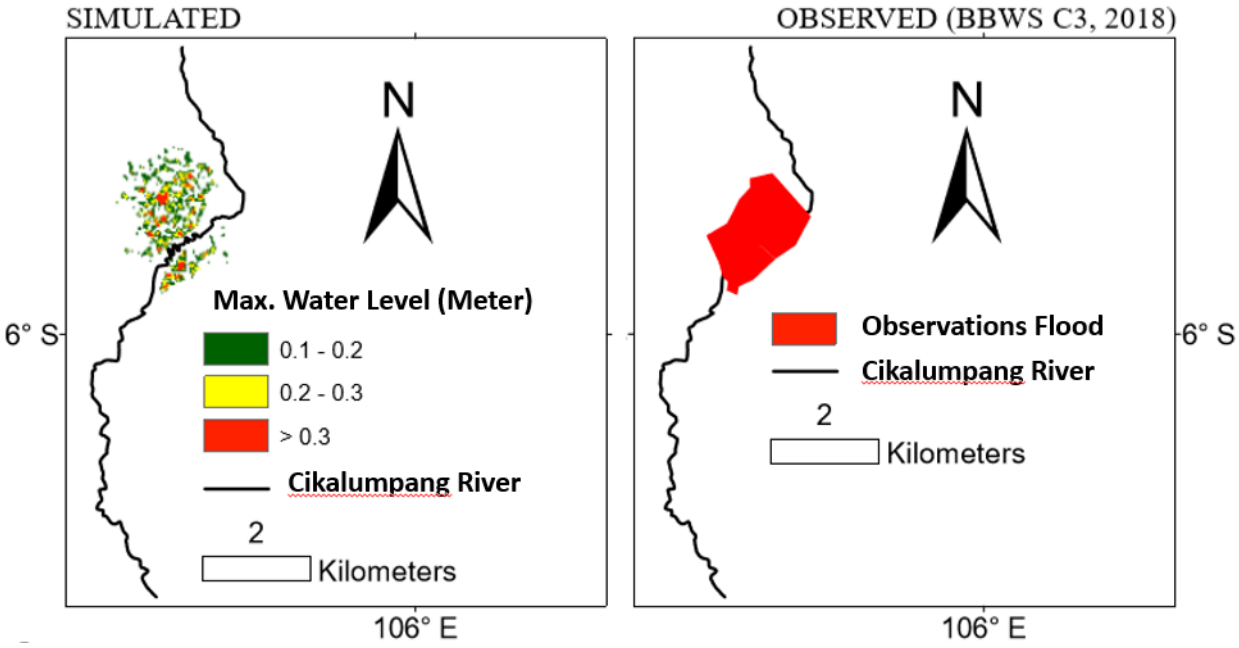

Fig. 9. Inundation area from inundated model and observation data

The shape of inundation area from the simulation process and observation data shows that the model was well calibrated and the flood event during March 5th–9th, 2018 well simulated.

The inundation area of the simulation results during the March 5th-9th, 2018 flood period ranges from 1.2 km^2 with a pool volume of about 3.6 x105 m^3. Then another supporting thing is related to inundation depth. The depth of inundation that occurs is based on field observations of approximately 30-40 cm. Whereas based on the results of the puddle simulation, it was found that the inundation depth values were similar to an observations data. This can be seen from the comparison in Fig 9 and the results of field observations shown in Fig 10.

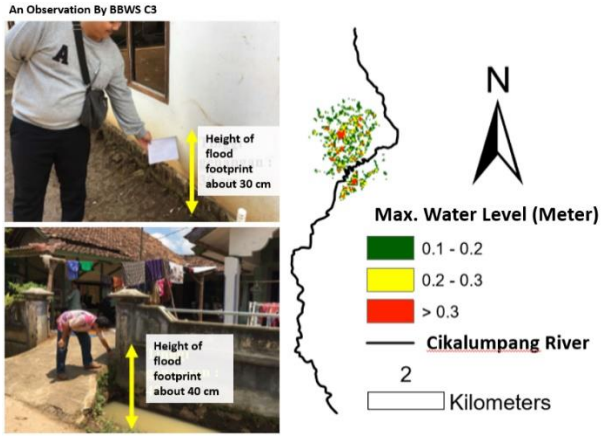

Fig. 10. Depth of inundated area from observation and simulation results

4 Conclusion and recommendation

4.1 Conclusion

From the results of the studies carried out, there are several conclusions, among them are:

1. The causes of flooding that occurred in the Cikalumpang River were high rainfall, topographical conditions in the study area, reduction of river capacity due to sedimentation and settlements on the riverbanks.
2. The Inundation Flood Model of Cikalumpang River was conducted and calibrated with a fair agreement
3. Based on topography and land cover conditions, the downstream of the Cikalumpang River is a lake swamp area, in consequence, if there is an increasing amount of water flow to that area, the area is easily inundated.
4. The degradation capacity of the downstream of Cikalumpang River due to the illegal house development on the riverbank and high sedimentation is one of the triggers of the flood events in the Cikalumpang River.
5. Floods that occurred on March 5th-9th, 2018 were also caused by rain that occurred from March 5th-9th, 2018 in a row.

4.2. Recommendation

Further study will be needed to know the better solutions to break the back the flood at Cikalumpag River. Several studies or acts that will help to solve the flood is:

1. There should be some adaptation solutions both structural and non-structural to reduce inundated area at Cikalumpang River.
2. The result of this study (flood map) can be developed to be a flood hazard maps by BBWS C3 as an institution who has a privilege to manage the Cikalumpang Basin.
3. There should be an evaluation to know the main problem of Flood in Cikalumpang River quantitatively.
4. The structural solution should be evaluated quantitatively using a simulation of flood inundation, it needs to be evaluated together with the benefit-cost analysis in order to get the optimum solution.
5. There should be a regulation to save the lake swamp ecosystem as regulatory efforts.

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