Analysis of water surface profile and flood discharge of Cijangkelok river

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Abstract. The downstream of Cimasemgarung River Basin is often affected by floods with an increasing degree of intensity every year. For instance, the 2017 severe floods caused economic losses and fatalities, especially along the border of Cirebon and Brebes Regency. The flood was attributed to high rainfall intensity and the meeting point between Cimasemgarung River and the Cijangkelok River. Therefore, a study on the flood in this area is highly vital to reduce the affected area in the future. This study aims to analyze the maximum flood discharge capacity in the Cijangkelok River and analyze cross-sectional river capacity using numerical model simulations. Based on the hydrological calculations and analysis, it is known that the planned flood discharge in the Cijangkelok River in the 5-year return period is 256,25 m³/s, the 10-year return period is 310,35 m³/s, the 25-year return period is 392,91 m³/s, and the 50-year return period is 465,93 m³/s. The analysis of the water surface profile of each flood discharge return period shows that overflow occurs in the cross-section 4090, 8254, 9166, 9753, and 11970. It is also revealed that the existing cross-section of the Cijangkelok River is unable to accommodate hydrological discharge. Field visit results show that the river has siltation or sedimentation, the river embankments are irregular, and land-use changes around the Cijangkelok River that affects the river.

1. Introduction

Based on the Minister of Public Works Regulation No. 04/PRT/M/2015 concerning Criteria and Determination of River Areas, the Cimasemgarung watershed area covers the area of 1,000.24 km². Geographically, this area includes the Cimasemgarung River Basin Area which is located at coordinates 105 ° 20'- 108 ° 47' East Longitude and 6 ° 45' - 7 ° 12' South Latitude. Based on its geographical position, the river is located in the eastern part of West Java, on a regional road link that connects Cirebon City with the East Priangan region and an alternative road in the middle lane that connects Bandung-Majalengka with West Java.

Flooding is a severe problem, especially in the area along the Cimanuk-Cimasemgarung River Basin. The floods in the Cimanuk Cimasemgarung River Basin are primarily due to river morphological damage and high sedimentation rates entering several rivers (Balai Besar Cimanuk-Cimasemgarung River Region, 2015). Floods in the Cimanuk Cimasemgarung River Basin are almost evenly distributed in all regions; the most flood-prone areas include Indramayu, Majalengka, Cirebon, and Brebes Regencies. The downstream of Cimasemgarung River Basin is often affected by floods with a higher degree of intensity every year. The severe 2017 flood, for example, caused economic losses and fatalities, especially along Cirebon and Brebes Regencies. The eroded upper Cimasemgarung watershed and its
tributaries and the reduced capacity of the river due to river bed aggradation impeded several places from flowing flood discharge and thus leading to overflowed river capacity. Therefore, it is necessary to study the flood to reduce the affected area in the future, especially in the Cijangkelok River as a tributary of the Cisanggarung watershed that was severely affected by the 2017 flood. It was noted that at that time, the Cijangkelok River highly contributed to the flow of flood discharge in the Cisanggarung River, making the study of this area as an essential thing to do.

Given the above situation, this study aims to analyze the maximum flood discharge capacity in the Cijangkelok River, analyze the discharge capacity at the river's cross-section, and evaluate the flood model on several return periods of flood. Hydrological data processing was carried out to examine the average discharge and explain the flood discharge redesign. The data were used as input to the simulation of the hydraulics model. The hydraulic modeling application is expected to help analyze the river cross-section and study the profile condition before the water in the event of a flood.

2. Literature review

2.1. Catchment area

According to Kodoatie (2002), Watershed Area is a naturally formed water management area, from which the rainfall flows into the rivers and generated tributaries. The Watershed Area is also known as Catchment Area. This area is vital since the utilization of watershed natural resources without taking the ability and environmental sustainability into account will harm the ecosystems and water systems. Therefore, in planning the watershed management, we need to use the most appropriate technological advancement based on additional rules of watershed management (Kodoatie, 2002). According to Susanto (1994), Watersheds are physically and biologically integrated area under the same watershed management, which influences the ecosystem. Consequently, the problems that occur in the upstream, such as organic solution (chemical pollutants), will affect the downstream. At present, Watershed Management becomes very important for maintaining the potential of water resources. The destructed upstream area will lead to the damage in the downstream areas, such as floods, landslides, or increasing groundwater levels.

2.2. Flood

Some flood control systems can indeed reduce the damage caused by small to moderate floods but they incur unaffordable cost during massive waves—that may take place around the high river embankment. Excessive runoff on the dam at the time of flooding out of the predicted flooding may collapse the dam, and thus creating a tremendous flow velocity through the destruction of the dam, causing severe flooding. The causal relationship in the flood problem indicates the complexity of the problem. The current tendency of land use changes, increasing population requiring additional infrastructure, and economic interests drive the decreasing land carrying capacity that leads to the escalating flood frequency and intensity.

The Flood Control Study in the Cisanggarung River Basin (BBWS Cimanuk-Cisanggarung, March 2016) was conducted to determine the efforts of flood mitigation and flood control planning in the Cisanggarung River Basin. This study resulted in a master plan for flood control in the Cisanggarung watershed. Similarly, the study on Preparation of Potential Flood and Drought Map of Cimanuk-Cisanggarung river area (BBWS Cimanuk-Cisanggarung, June 2016) was carried out to provide thematic geospatial data and information about the flood prone and drought prone areas as an integrated preparation for flood and drought mitigation in regencies and cities passed by the Cimanuk Cisanggarung River Basin. These studies result in disaster-prone map for each Regency/City and a multi-map digital map with a scale of 1: 50,000.
2.3. Unit hydrograph
The unit hydrograph is a direct runoff hydrograph produced by an active rain (net rainfall), which occurs evenly throughout the watershed and with fixed integration for a specified unit of time. The unit hydrograph indicates a direct runoff hydrograph at the downstream end of the river flow, which piled up with active rain of one millimetre. It was considered equivalent to the watershed's surface based on the specified provisions (Triatmodjo, 2008). In a purer form of resolution, the watershed unit is a direct runoff caused by an active rain unit, divided equally in time and space (Soemarto, 1999).

2.4. Hydraulics analysis
An analysis of river hydraulics intended aims to study the profile of floodwater levels in rivers with various times of return from the discharge plan. The hydraulic study will examine the extent of the current flood control influence. Based on the analysis support, we can conduct topographic measurements along the river to measure the extent of the problem, and the longitudinal, and transverse cross-section.

The Saint Venant equation was used to model flows in open channels, such as rivers and model of flood tracking (Pratiwi et al., 2013). Flood alignment was calculated using the equation of continuity and steady-flow momentum (Rinaldi et al., 2018). These measurements are described in the following mathematical equation:

\[
\frac{dA}{dt} + \frac{\partial Q}{\partial x} - q_e = 0
\]  
(1)

\[
\frac{\partial Q}{\partial t} + \frac{\partial (\alpha \frac{Q^2}{A})}{\partial x} + gA \left( \frac{\partial h}{\partial x} + n^2 g \frac{Q}{AR^2} \right) = 0
\]  
(2)

where:
- \( A \) = the total cross-sectional area of flow
- \( Q \) = discharge
- \( q_e \) = lateral discharge per unit length
- \( R \) = hydraulic radius
- \( g \) = gravity velocity
- \( x \) = distance
- \( t \) = time
- \( n \) = Manning coefficient
- \( \alpha \) = distribution momentum coefficient

3. Research Methods

3.1. Study area
This research focuses on the Cijangkelok River, a tributary of the Cisanggarung Main River. Incoming Discharge from the Cijangkelok River influences the amount of Discharge in the Cisanggarung River that leads to frequent flooding in the downstream of the Cisanggarung River and the meeting area between Cisanggarung River and Cijangkelok River (figure 1).
3.2. Data collection and data processing
The study used hydrological data, hydraulic data, and topographic data. The steps and stages in the research methods are presented in a flow chart (figure 2) with the following description:

3.2.1. Hydrology data. The collected rainfall data consists of daily rainfall data taken from each rain station considered on watershed of Cisanggarung and Cijangkelok watershed sub. Flood
discharge design was done using rainfall data from several rain stations in the Cisanggarung and Sub Cijangkelok watersheds. The study used rainfall data from 6 (six) rain stations, namely Garawangi, Ciniru, Luragung, Ciawigebang, Cibeureum, and Cibendung Rain Stations. Given the limited availability of data in this study, the researcher used the daily rainfall data recorded for nine years from 2010-2018.

3.2.2. Hydraulic data. River geometry data were used as an input for analyzing water level profiles using spatial data from the Digital Elevation Model (DEM). Data obtained from DEM were in the form of cross-section data, hydraulic structure, and depth.

3.2.3. Return periods scenarios. The calibrated model was simulated with 5, 10, 25, and 50-years return period of discharge inputs.

3.2.4. Conclusion and analysis. This stage provides an explanation of the results of the river cross-sectional water profile simulation. It was conducted to analyze the existing channel capacity to determine the ability of the channel to receive flood discharge. It also aimed to identify whether it was necessary or not to do channel dimensions planning or other alternative solutions to cope with the existing flood discharge. At this hydraulic stage, the analysis was conducted using the MIKE 11 assist program. Input data used include cross-section geometry data, unit hydrographs, and Manning coefficients.

4. Results and discussion

4.1 Hydrological analysis
A hydrological analysis aimed to determine the hydrological characteristics of the Cijangkelok River drainage area. In particular, it was done to determine the amount of flood discharge plans in a water building plan. The planned flood discharge in this study was conducted using rainfall data, since the rainfall data are one of the few data that can estimate the magnitude of the proposed flood discharge.

Based on the analysis, the Cijangkelok River sub-Basin has an area of 165.57 km2, with a river length of 36.61 km. A summary of the rainfall plan was used to analyze the flood discharge plan from the rainfall data and the watershed area. Due to their topographic conditions and the number of eligible stations for the Thiessen method that can handle the calculation, the rainfall analysis obtained 6 hours of rain that occurred in the Cijangkelok River sub-Basin.

In general, discharge of flood plans were used to conduct water disposal that leads to zero puddle occurrence. This analysis classifies the soil types according to the current status of land-use in the Cijangkelok River sub-Basin. It was revealed that the Cijangkelok River sub-Basin is classified as A and D soil types. Based on these results, Curve Number and Impervious data were used to analyze flood discharge plans. figure 3 and table 1 present the result of flood discharge analysis with the return periods of 5-years, 10-years, 25-years, and 50-years.

Table 1. Return period flood discharge

| Peak Discharge (m³/s) | Q_5 | Q_10 | Q_25 | Q_50 |
|-----------------------|-----|------|------|------|
|                       | 256,25 | 310,35 | 392,91 | 465,93 |
4.2 Modeling hydraulic
This hydraulic analysis consists of a summary of the existing cross-section of the planned channel—Mike 11 helps analyze the Existing cross-section, with discharge and cross-section data as input data. The analysis using MIKE 11 aims to determine the current condition of the Cijangkelok River. It shows the flow of water discharged through the river and the water level at the cross-section. MIKE 11 will display the model of the channel according to the provided input data. Figure 5 shows geometric data on the Cijangkelok River.
Figure 6 shows an example of a Cijangkelok River's cross-section with irregular shape and siltation due to sedimentation in the river.

The unsteady flow feature helps analyze the existing cross-section, and the input data was conducted using a flood discharge plan based on the return period, including a rough coefficient data and cross-profile data.

4.3 Result
Figure 7 shows the profile of surface simulation by return period of 5, 10, 25, and 50-years of Cijangkelok River. These analyses indicate the overflow occurring in cross-sections 4090, 8254, and 11970 by a 5-year return period. Moreover, there was a significant increase in the return period of 10, 25, and 50-years. It shows the water level of overflow simulation and occurrence in the same cross-sections with a return period of a 5-years, but different in the amount of Discharge.
From the picture above (figure 8), simulation results show that the existing channel cannot drain the existing Discharge. It is indicated that the maximum water level profile has increased the left and right embankments. This condition is the same as the real condition on the ground where the Cijangkelok River often floods during heavy rains (figure 9).

Once we know the Cijangkelok River's cross-section capacity, we can propose an alternative flood management to solve the problem, namely by way of channel normalization, pump procurement, or pond pool planning. If we decide to use channel normalization as an alternative treatment, we need to re-analyze the river cross-section suitable for flooding in the Cijangkelok River by enlarging or redesigning the cross-section. River normalization can also start by giving embankments to the river to prevent the overflow from entering the land. The data used for embankment planning were obtained from the evaluation on the Cijangkelok River's cross-section capacity. The cross-sectional capacity evaluation results indicates the parts of the river that flood—based on the analysis of the river's cross-section by MIKE 11 application and using data of the return period of flood discharge. We can also use the dike planning. However, in case of flood after normalization, we can use a pump if the river cannot accommodate the existing flood discharge.
5. Conclusion
Based on the above analysis and discussion, we can draw the following points as conclusions, namely:

1. Peak discharge of Cijangkelok river in the return period of 5-years is 256.25 m³/s, the return period of 10-years is 310.35 m³/s, the return period of 25-years is 392.91 m³/s, and the 50-year return period is 465.93 m³/s.

2. The analysis on the existing capacity to accommodate the Cijangkelok River indicates that the location cannot accommodate the design of flood discharge. The overflow at downstream is caused by the siltation on the riverbed and the damaged embankment.

3. Based on the analysis on each flood discharge return period, it is revealed that the existing cross-section of the Cijangkelok River is unable to accommodate the flood discharge. Such condition is attributed to several factors, such as river siltation or sedimentation, irregular river embankments, and land-use changes around the Cijangkelok River.

4. The current handling solution is to normalize the river given the fact that only several cross-sections that overflowed.

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