Evaluation of flood risk as a step in determining the "Acceptable Risk" criteria. Case study: Dengkeng River, Klaten, Central Java

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Abstract. The planning of a flood control system in Indonesia is based on the planning criteria issued by the Ministry of Public Works. Flood control planning is based on flood discharge with a specific return period depending on the order of the river and the number of protected populations. Flood events in areas where the flood control system has been planned continue to occur almost every year, meaning that the probability of being exceeded is not as planned. This study is intended to evaluate the criteria for the magnitude of the designed flood discharge in flood control planning that considers the acceptable risk. Potential risks are evaluated against system reliability. The probability of failure of the flood control system occurs if the resistance is smaller than the load expressed as a performance function. By knowing the performance function associated with the level of flood risk, then the flood discharge can be selected with the appropriate return period according to the acceptable risk.

1. Introduction

A flood is a disaster that occurs in most of the floodplain areas. Several factors causing flooding include reduced river capacity, increased flood discharge due to changes in land use, damage to flood control buildings, and others. This event can be reduced if we understand that there are many uncertainties in hydrological analysis, which aims to determine the amount of flood discharge.

In general, there are two flood protection efforts, namely structural and non-structural approaches. Structural measures are divided into extensive and intensive measures. The extensive structural measures include reshaping the land surface, soil conservation, flow delay, and infiltration increase. The intensive measures consist of four categories: levees and dikes, water storage, increase of channel flow capacity, and floodplain polders and platforms. In planning for flood control buildings, it is necessary to have a planned flood discharge with a specific return period. The criteria for the amount of flood discharge planned for each country are generally different depending on their financial or economic capabilities. The magnitude of this flood discharge will ultimately affect the magnitude of the risk that may occur.

Some of the challenges of flood management are the increasing number of human activities, climate change, and policy changes, so to minimize losses due to flooding, it is necessary to carry out risk management because completely safe conditions are impossible to achieve. Considering the high level of losses caused by the flood disaster, strategic steps are needed to reduce the risk due to the disaster. One of them is doing flood risk mapping [1].
In determining the level of risk of an area from flooding and considering the factors of uncertainty that occur, it is also necessary to evaluate the magnitude of the planned discharge against the risks that may befall an area. Evaluation of the discharge plan is intended so that the risk level that occurs in an area is at least tolerable or even an acceptable level.

The study's purpose is to evaluate the determination of the criteria for the magnitude of the designed flood discharge in flood control planning that considers the acceptable risk. For the case study in this research, the Dengkeng river is used in Klaten Regency, Central Java Province.

2. Literature review

2.1. Flood risk

Risk is used in various contexts in a natural process perspective and social, economy, security, and environment in different definitions, understanding, and implementation. As a society, managing the uncertainty related to various aspects of the risk process is needed. Various approaches have been developed to define, analyze, and control the risk. Risk assessment is generally divided into three methods: qualitative method, semi-quantitative method, and quantitative method [2].

In this paper, risk assessment refers to the quantitative method because the assessment based on this method is about the concept and measurable. Risk assessment is generally affected by two main components, which are hazard vulnerability in which both can be defined as:

a. Flood hazard is defined as the probability of a flood's situation that can destroy the inside section. In a specific period, vulnerability means to be the consequences of the flood [3].

b. Vulnerability means loss level from a specific element that has risk or a group of elements that are produced from natural phenomenon with a certain magnitude and expressed in scale from 0 (no loss) to 1 (full loss) [4].

A complex interaction from partial factors creates a difficulty to calculate the risk level or potential damage impact correctly so that in practical application, vulnerability is represented by damage or loss curve, widely used in the insurance sector [5]. Potential or consequences of damage caused by flood can be stated as follows [6]:

\[ D = V \times E \]

\[ V = f (H) \]  \hspace{1cm} (1)

Where,

- \( D \) is potential damage,
- \( V \) vulnerability;
- \( E \) is property value, and
- \( H \) is the flood depth.

2.1.1. Flood characteristics analysis. Analysis of flood characteristics was carried out to determine flood losses. The characteristic flood parameters reviewed were the inundation area, inundation depth, water velocity, and velocity x depth of inundation. Flood analysis was carried out with the help of HEC RAS 5.0.3 software with a 2-dimensional model.

2.1.2. Flood hazard analysis. Flood hazard is defined as the probability of a situation in which the flood can destroy the inside section, and in a specific time, while vulnerability means to be the consequences of the flood [7]. The risk analysis was assessed based on flood inundation modeling at the research site. Risk analysis is assisted by using a Geographic Information System to make it easier to read the information provided. In conducting a risk analysis, the reviewed things are the level of vulnerability and danger.

Based on the conceptual model of the risk process, in evaluating risk needs to consider several components [8]:

- Nature and probability of hazard (p)
- The degree of exposure of the receptors (number of people and property) to the hazard (e)
- The susceptibility of the receptor to the hazard(s)
- Receptor value (v)
So the risk can be written as follows:

\[ \text{Risk} = \text{(Probabilities)} \times \text{(Consequence)} \]

The level of flood hazard for each region should have different categories depending on the topography and characteristics of the existing floods in the area. Therefore the limit of the level of human hazard for Indonesia needs to be added with speed and multiplication criteria. Speed and depth [8].

| Parameters | Classification |
|------------|----------------|
| D (m)      | V (m/s)        | D x V (m²/s) |
| < 0.9      | < 2.4          | < 0.75       | Low          |
| 0.9 < D < 1.2 | 2.4 < V < 3   | 0.75 < DV < 1.1 | Moderate  |
| > 1.2      | > 3            | > 1.1        | Significant  |

2.1.3. Flood vulnerability analysis. Flood risk analysis involves flooding, flood hazard, and characteristics of elements at risk: socially or living systems, the built environment, and the natural environment. The extent of flood damage depends not only on the flood characteristics but also on the area’s vulnerability to inundation.

3. Result and discussion

3.1. Evaluation of designed flood discharge

Evaluation of planned flood discharge is based on analysis of social and economic losses to determine risk criteria. In her study, Sarminingsih [8] created a risk level matrix that can intervene in the plan return period for the design so that the risk is minimally tolerable.

3.1.1. Analysis of designed flood. The designed flood discharge was analyzed based on the maximum daily discharge recorded in the Paseban AWLR. The magnitude of the planned flood discharge for various return times is as shown in Figure 1.

3.1.2. Channel capacity analysis. Bank capacity analysis is carried out to determine the capacity of the river to hold water. The bankful capacity analysis was carried out on a cross-section of the Dengkeng River downstream, namely at the initial location where flooding began. Based on the bankful capacity analysis results on the cross-section of the starting point of the flood downstream of the Dengkeng River, it shows that the discharge capacity of the Dengkeng River is lower than the flow rate in each analyzed return period. The return period of bankful capacity in the initial cross-section of the flood downstream of the Dengkeng River is analyzed based on the relationship between the magnitude of the discharge and the return period so that the return period of bankful capacity is 1.4 years. An overview of the channel capacity evaluation is shown in Figure 2.

![Figure 1. Flood discharge in many return periods of Dengkeng River.](image-url)
3.1.3. Inundation evaluation of flood plain. Based on the results of inundation analysis on the floodplain, the discharge of the 2-year return period has caused flooding in residential areas and cultivated areas. The number of the inundated area is shown in Figure 3.

![Figure 3. Flood inundation area on flood risk elements.](image)

3.2. Hazard evaluation for humans
The classification of flood hazards for humans is based on the multiplication of flow velocity and inundation depth [8].

| Parameters     | Classification |
|----------------|----------------|
| D (m)          | V (m/s)        | D x V (m2/s) |
| < 0,9          | < 2,4          | < 0,75       | Low |
| 0,9 < D < 1,2  | 2,4 < V < 3    | 0,75 < D x V | Moderate |
| > 1,2          | > 3            | > 1,1        | Significant |
Flood classification by considering depth and speed is based on the instability of people when hit by flood flows, either due to sprawling moments or shear forces. The hazard level classification is adjusted to the characteristics (height and weight) of Indonesian people in general.

Based on the analysis results based on the depth of the flood ($D$), a high level of flood hazard has a larger area than the level of flood hazard based on $DV$. So that in determining the level of flood hazard in the study area, it is determined based on the most critical level of the area, which is based on the depth of the flood ($D$).

![Figure 4. Flood hazard map to people as a function of depth (D) for TR 2 years.](image)

### 3.3. Flood vulnerability analysis

Based on the spatial map of the inundation depth resulting from the flood simulation and the vulnerability value of each element at risk, the vulnerability level can then be made based on the classification, as shown in Table 3. In the study area, the flood-exposed areas are settlements and activity sites grouped into the categories of settlements and paddy fields and fields/fields. Grouped in the agricultural category. The level vulnerability of elements at risk is used to calculate the potential for financial flood losses.

### 3.4. Flood risk analysis

#### 3.4.1. Economic losses

The value of economic losses at the study site is calculated based on the level of risk elements exposed to flooding. The accuracy of the loss value is influenced by the division of the height of the inundation depth and the area of the affected area. The calculation of losses in this study is divided into height and depth for each 0.1 m interval.

In the study location, the majority of flood-affected areas are classified as residential and agricultural. In calculating this loss, no field survey was carried out for the level of losses in the field so that the unit value was used as an assumption. The value of the housing unit is assumed after depreciation of IDR 2,040,000 - per m², while the value of agricultural production refers to data based on the Central Statistics Agency in 2019, which is IDR 17,200,000 - per ha per growing season.

| Category  | Residential | Industry | Agriculture | Factor Damage (%) |
|-----------|-------------|----------|-------------|-------------------|
| Very Low  | <2          | <2       | <0.5        | < 20              |
| Low       | 2 - 3.5     | 2 - 3.5  | 0.5 - 1     | 20 - < 40         |
| Medium    | 3.5 - 4.5   | 3.5 - 4  | 2-Jan       | 40 - < 60         |

Table 3. Category vulnerability classification based on water depth (m).
3.4.2. Social losses. Social losses are losses to humans caused by floods. Calculation of social losses based on the components of depth and velocity of flooding by modifying the Wallingford and Cox equations [9,10].

Social loss refers to the number of people exposed to flooding. In this social loss analysis, the population is assessed by sub-district. The results of the flood inundation analysis show that there are at least ten flood-affected districts spread over three districts. Population data used data from the Central Statistics Agency in 2019.

In calculating social losses, it is also necessary to calculate regional vulnerability. The regional vulnerability parameter refers to DEFRA, as shown in Table 3 [11]. The vulnerability level for the Dengkeng watershed based on the speed of flooding has a value of 1 (low risk), based on land use, it has a value of 2 (medium risk), while based on the early warning system using existing standards which is two so that the level of regional vulnerability in the Dengkeng watershed has a value of 5. The analysis of flood losses on humans produces predictions of the number of people injured and dead, as shown in Table 4.

| Category    | Residential | Industry | Agriculture | Factor Damage (%) |
|-------------|-------------|----------|-------------|-------------------|
| High        | 4.5 - 5.5   | 4 - 4.5  | 3-Feb       | 60 - < 80         |
| Very High   | > 5.5       | > 4.5    | > 3         | 80 - 100          |

Table 4. Predicting social losses using DV map delineation.

| Return Period (year) | Risk To Humans | Annual Risk |  |
|----------------------|----------------|-------------|---|
|                      | Injuries | Fatalities | Economical (x Billion Rupiah) |
| 2                    | 68      | 0          | 204.97 |
| 5                    | 118     | 1          | 109.38 |
| 10                   | 142     | 1          | 63.92  |
| 20                   | 170     | 1          | 37.11  |
| 25                   | 183     | 1          | 31.31  |
| 50                   | 238     | 2          | 19.23  |
| 100                  | 263     | 2          | 9.93   |

3.5. Evaluation of return period of designed flood

Risk criteria that occur in the Dengkeng watershed are assessed based on economic losses and social losses. The economic risk criteria are based on the GRDP value in the flood-affected areas, while the social risk criteria are based on the number of people exposed to floods who were injured or died. Based on the risk level matrix, losses in the Dengkeng watershed are classified as very high risk. In ensuring the security of an area, the risk level of an area is at least at a moderate level or a risk that can be tolerated. Calculation of the evaluation of the amount of the planned return period is carried out by conducting an annual risk assessment. The value of the annual loss is compared with the standard category of consequences; in this case, the focus is on the economic value. Based on the analysis, results show that the risk value can be tolerated or allowed at a probability of 0.1% - 1%. In the Dengkeng watershed, to reduce regional risk, it is necessary to design a flood design intervention with a return period of at least 50-100 years. Evaluation of the Flood Return Period in the Dengkeng Watershed as shown in Figure 4.
4. Conclusion

4.1. Conclusion

The conclusions obtained from this research are:

In general, the Dengkeng River can no longer accommodate the planned 2-year return period flood discharge. At the initial point of the flood, the Dengkeng Lower River segment has a cross-sectional capacity of 122.6 m$^3$/s, a 1.4-year return period discharge.

Assessment of the level of flood hazard for humans in the Dengkeng watershed is carried out spatially based on inundation depth (D) and multiplication of depth and velocity (D x V), but analysis of flood hazard level based on inundation depth (D) gives safer results than D x V.

The level of economic loss in the Dengkeng watershed is at a very high level in the 2-year plan return period, while the level of human loss is only moderate, so it can be concluded that in the 2-year return period, the risk level of the Dengkeng watershed is at a very high level.

To reduce risk in the Dengkeng watershed, it is necessary to evaluate the return period of the flood management plan to an acceptable level, namely a minimum return period of 100 years.

![Figure 5. Evaluation of the flood return period in the Dengkeng Watershed.](image)

4.2. Suggestion

Suggestions from the author for the next research are:

In this study, the study area covers the entire watershed, so for non-structural analysis of flood reduction that directly touches the community, such as determining evacuation areas and preparedness, it is necessary to study in more detailed areas, such as at the kelurahan or RW level.

In the analysis of structural flood risk reduction, such as the construction of embankments, it is necessary to take into account the maximum discharge of the return period that may occur, as an uncertainty value based on the discharge.

In a more detailed analysis of risk reduction in the Dengkeng watershed, a return period evaluation matrix needs to be developed based on more detailed conditions in the Dengkeng watershed.
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