What causes Ngancar River in Wiroko Temon sub-watershed vulnerable to flooding?

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Abstract. The vulnerability to flooding becomes a concern in every region to optimize the mitigation strategy, hence the disaster impact can be reduced from the environment. What factors become the main triggering issue toward water-related disasters? Every region has a different answer. Can a river that does not have historical flood events become vulnerable to flood today? This study investigates the flooding factors in Ngancar River, Wiroko Temon sub-watershed, Wonogiri. The research employs hydrological and hydraulics analysis. The results reveal that Ngancar River experienced land-use changes over time which lead to the dynamic of the discharge return period being bigger. As a result, river capacity today cannot accommodate the flooding volume. The research concludes that the hydraulics condition needs to be improved for flood mitigation. Further hydrological analysis is suggested to be conducted.

1. Introduction
Flooding becomes threat worldwide, hence countries are struggling to minimize the impact of the disaster to the environment through various ways [1]. In structural path, government construct dam, modify river canal, and increase the water infrastructure resilience to fight the flooding [2]. On the other side, non-structural methods present top decision strategies from various stakeholders to decrease flooding impact to the environment [3].

How can we know that a region is vulnerable to flooding? What factors can trigger that phenomenon? This research identifies a phenomenon of flooding in Ngancar River, Wiroko Temon sub-watershed, Wonogiri region. According to the historical events, hydraulics factors in the study area do not affect the flooding happened. Meanwhile, several disaster events in the past years reveal that rivers cannot accommodate the flood volume. Does Ngancar River in Wiroko Temon sub-watershed vulnerable to flooding due to hydraulics factors? This research is a case study to investigate the hydraulics condition [4] of Ngancar River towards the flooding characteristics in the study area and expected to conclude whether river capacity becomes the main factor of the disaster.

2. Methods
This research employs hydrological analysis to obtain the return period discharge in the study area [5]. Nakayasu hydrograph synthetic unit is used to analyse the flooding in return periods presented [6]–[8]. This data becomes the basis to simulate the flooding through HEC-RAS modelling approach as hydraulics analysis supporting tool [9]. This software can visualise the river water profile and identify the flooding volume in several river segments [10]. The actual existing hydraulics of river condition is
obtained from Google earth features to be coupled with HEC-RAS features. As a scenario of flooding mitigation in the future time, new design of river is presented even there is still no evidence that flooding volume exceeds the river capacity.

Initially, sub-watershed is identified as depicted in Figure 1. Three rainfall stations are presented as hydrological analysis, depicted in Figure 2 (a) and affect two main regions of sub-watershed, as depicted in Figure 2 (b). Firstly, the research will employ Thiessen method, as shown in Figure 2 (a). Meanwhile, there are only two affected areas in the study area, hence, the research uses average rainfall method to analyse the rainfall data [11], as observed in Figure 2 (b).

![Figure 1. Ngancar River in Wiroko Temon sub-watershed [12]](image)

3. Results and discussion

The results in this research reveal the hydrological analysis condition and hydraulics condition of Ngancar River supported by HEC-RAS software [13].

3.1. Flood analysis

The study of natural resources cannot be separated from hydrological analysis. With the hydrological analysis, we get the rainfall data as the basis for searching for flood discharge data. Flood discharge data analysis can be done with several methods, one of the methods is the Nakayasu hydrograph synthetic unit (HSU) method. Before getting flood discharge data, the research employed rain data using the Normal method, Log Normal method, Log Pearson Type III method, and Gumbel method [14]. The final result of discharge return period from Nakayasu HSU is shown in Table 1 and Figure 3.
Figure 2. (a) First condition: Thiessen method analysis plan and (b) Existing condition: areas affected by rainfall stations will be analysed by average rainfall method

Table 1. Nakayasu hydrograph synthetic unit

| Return period discharge | Q\text{max} (m^3/s) |
|-------------------------|---------------------|
| 2 years return period   | 34.17               |
| 5 years return period   | 44.29               |
| 10 years return period  | 54.29               |
| 25 years return period  | 73.77               |
| 50 years return period  | 94.27               |
| 100 years return period | 126.65              |
| 500 years return period | 327.97              |
| 1000 years return period| 701.76              |

Figure 3. Flood hydrograph from Nakayasu HSU

The rainfall analysis used in this study was expected to obtain the calculation of the flood discharge at the 2, 5, 10, 25, 50, 100, 500, and 1000 years return periods. With this flood discharge calculation, it is expected that it will become the initial data for flood prevention in the future.
3.2. Validation of data analysis

To validate the discharge analysis result, a previous analysis from other research is presented in this research. Table 2 provides the results from the research.

Previous research by Mulyanto [12] observes the flood discharge in the Tirtomoyo sub-watershed, meanwhile Wiroko Temon is part of its sub-watershed. Hence, the discharge happened in the study area is smaller than research result by Mulyanto [12]. As initial hypothesis, the result can be validated but need more depth investigation in the future research about this. A result provided by Pediano et al. [15] by using other methods, Muskingum-Cunge and Hydrocad methods reveal that the data cannot be compared. Comparison should meet the same methods to obtain better validity. Hence, further analysis will not need any supporting data from different approaches.

In the Wiroko Temon sub-watershed there are land uses that change over time which can trigger the dynamic change of water resources. Therefore, the discharge analysis is needed using the land cover coefficient data of Wiroko Temon sub-watershed. To complete this step, the data needed in this research are cover area percentage, land use, coefficient of land use [16].

| Return period discharge | Mulyanto, et al. [12] with Nakayasu method | Pediano, et al. [15] with Muskingum-Cunge and Hydrocad methods | This research with Nakayasu method |
|-------------------------|--------------------------------------------|---------------------------------------------------------------|----------------------------------|
| 2 years return period   | 197.42 (m³/s)                              | 0.5356 (m³/s)                                               | 34.17 (m³/s)                    |
| 5 years return period   | 254.30 (m³/s)                              | 3.1488 (m³/s)                                               | 44.29 (m³/s)                    |
| 10 years return period  | 287.76 (m³/s)                              | 6.6097 (m³/s)                                               | 54.29 (m³/s)                    |
| 25 years return period  | N/A                                        | 14.4799 (m³/s)                                              | 73.77 (m³/s)                    |
| 50 years return period  | 312.87 (m³/s)                              | 23.1901 (m³/s)                                              | 94.27 (m³/s)                    |
| 100 years return period | 352.66 (m³/s)                              | 33.9149 (m³/s)                                              | 126.65 (m³/s)                   |
| 500 years return period | N/A                                        | N/A                                                         | 327.97 (m³/s)                   |
| 1000 years return period| 450.99 (m³/s)                              | 84.0819 (m³/s)                                              | 701.76 (m³/s)                   |

Table 2. Data validation analysis

Figure 4. Contour inserted to the HEC-RAS features (a) by drawing a river and (b) put the river sections observed in the study.

The data above is obtained from the product of Water Resources Department of the Ministry of Public Works and Housing, Indonesia. The calculation of runoff coefficient analysis can be done by...
multiplying the percentage of land use with the coefficient of land class (C) and will obtain a weighted C value. The weighted coefficients for the return periods of 2 years, 5 years, 10 years, 25 years, 50 years, and 100 years are 0.449, 0.483, 0.505, 0.547, 0.579, and 0.643, respectively.

3.3. HEC-RAS analysis
The hydraulics analysis in this research concern on one of the rivers in the sub-watershed, Ngancar River. The channel modelling of the Ngancar River uses the help of the HEC-RAS application on both two scenarios, the existing condition channel and the channel that has been redesigned [17] by using the previously obtained discharge data. This modeling is used to obtain prediction of flood discharge at the return period of 2, 5, 10, 25, 50, 100, 500, and 1000 years. The following stages are involved to model the river by obtaining a HEC-RAS modelling approach. Initially, insert the map downloaded from national digital elevation model (or usually known as DEMNAS) data into the HEC-RAS application and create a river flow [18] according to the existing contour on the map, as depicted in Figure 4. Then, determine cross-sections with a number of three segments each on the upstream, middle stream, and downstream. Next, enter the value of the Nakayasu method result calculation in the unsteady flow program on the 2, 5, 10, 25, 50, 100, 500, and 1000 year return periods. To get the results of the unsteady flow analysis, run the data that has been entered. Finally, the research is getting run results from unsteady flow.

![Figure 5](image_url)

**Figure 5.** Normalization scenario for flood mitigation

Due to the results of the 100 years return period analysis, several points experienced flooding or water overflow in several places, as depicted in Figure 6. The next step is remodelling the river to avoid flooding. How to model this scenario? First, make a design as planned. Input all data of discharge return period with the condition of unsteady flow to run the flooding, as depicted in Figure 5. Make sure the analysis of the new design can accommodate the flooding volume according to the hydrological analysis.

As the presented result, Ngancar River cannot accommodate flooding for 100-year return period but can load flood volume below it. The hydraulics condition factor reveal that flooding events in the study area are correlated. It means, the hypothesis that hydraulics factors play an important role in causing flooding is validated through the analysis.
4. Conclusion and Recommendation
To conclude, the research hypothesis deals with the research result that flooding events in Ngancar River is triggered by river capacity which cannot accommodate the hydrological condition in the study area. For further investigation, analysis regarding discharge validation needs to be improved. Moreover, several mitigation scenarios to prevent flooding can be presented to provide better decision for mitigation strategies to fight flooding.

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