Flood Hazard Assessment Based on Analysis of Geomorphic Flood Index and History of Flood Events (Case Study in Kemuning Watershed, Sampang)

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Abstract. Sampang is one of regency in Madura which always experiences floods every year. The frequency of flood events reach the number of 15 to 18 Sampang regency is divided into 6 watersheds that consist of Kemuning, Nedung, Blega, Samajid, Tambengan, and Tamberu watersheds events annually. From all watersheds, Kemuning watershed has the biggest area and become the priority in management of critical land management due to the impact of floods. The Length of Kemuning watershed is 54.11 kilometres with a watershed area of 354.50 km square consisting of 6 sub-districts, namely Sampang, Omben, Kedungdung, Robata, Torjun, and Camplong. The objective of the paper is to analyse the hazard index in Kemuning watershed, Sampang. The disaster hazard level is divided into 3 classes; low (hazard index <0.333), medium (hazard index: 0.333 - 0.666), high (hazard index> 0.666). The method used is a analysis which combines/overlays parameters of flood-prone areas and History of Flood Events data. The result is a flood hazard map that with details of 3476.18 hectare (51.71%) high level, 2614.37 hectare (38.89%) medium level, 631.61 hectare (9.39%) low level.

Keywords: flood, flood hazard, multi criteria analysis, geomorphic flood index

1. Introduction

Indonesia is currently facing an increasing threat of disasters, as well as greater challenges in managing and reducing these risks. Disasters that occur in 2002 to 2015 showed that number of disasters have been increased from year after year, and 95% of them are hydro-meteorological disasters (related to water and weather) such as floods, flash floods, droughts, forest fires, landslides and tidal waves [1].

Floods (in technical terms) is the stream of the river that is overflows beyond the capacity of the river, and thus the overflow of the river will pass through the river bank and inundate the surrounding area [2]. The causes of flooding are triggered by several factors including natural factors such as climate change that increase the frequency, magnitude and extreme events [3], high rainfall intensity, and human factors such as urbanization that increase runoff [3], changes in land use and enhancement of settlement construction in flood-prone areas [4]. Throughout the world increased damage caused by floods over the past decade reinforce the perception that the risk of flooding dramatically increased due to a combination of different causes. Anthropogenic pressure such as urban and industrial expansion on...
protected floodplains increase the potential for flood losses and damage. Incredible floods events that occur at this time, are related to high hazard intensity, significant damage and socio-political consequences, therefore causing some problems for the authorities and risk management policy stakeholders [5].

According to Sampang district is in 2017 figures, Sampang Regency is one of four districts located in Madura Island (Bangkalan, Pamekasan and Sumenep). The total area of Sampang Regency is around 1233.33 km² which is divided into 14 districts and 186 villages/kelurahan with a total population (end of 2015) of 919,825. Sampang Regency is located around the equator with a tropical climate. Sampang Regency according to Indonesia Disaster Risk Index (IRBI) Year 2017 issued by BNPB is a disaster-prone area with score of 155 and is included in the high-risk class with flooding as dominant threat, which happen almost every year.

Floods in Sampang City occur almost every year (see table 1) and inundate almost the entire area of Sampang City. The floods in 2002 were the biggest flood ever. This incident was allegedly caused by the amount of Kali Kemuning debit because in general the soil structure is in the cathedral alluvial area so the percolation rate was very low, besides it was influenced by small flow capacity of Kali Kemuning and the small infiltration in the Kemuning watershed, so it was unable to accommodate water runoff from the main Kali Kemuning or its tributaries.

| Number of Events | Number of Affected Areas | Number of Human Affected |
|------------------|--------------------------|-------------------------|
| 2016             | 18 events                | 7 Village               | 3280 KK                                |
| 2017             | 15 events                | 13 Village              | 27054 person                           |
| Jan-Marc         | 9 events                 | 12 Village              | 22064 person                           |

Source : BPBD of Sampang Regency

Another factor that causes flooding in Sampang Regency is that the topography of Sampang Regency tends to be flat and bumpy, the altitude between 0-300 m above the sea level and the average slope between 2 – 25 %. This kind of topography is strongly supports the occurrence of soil erosion processes which essentially carry sediment from the upper part which in turn sedimentation is deposited in river streams and causes silting of the river so that the continuous capacity of the river for rainwater will cause flooding [6].

Disaster risk assessment (disaster risk mapping) is a qualitative or quantitative approach to determine the nature and level of disaster risk by analysing potential hazards and evaluating existing exposure and vulnerability condition that may endanger people, property, services, livelihoods and the environment in which they depend on [7]. Disaster risk assessments consist of hazard assessment, vulnerability assessment, and capacity assessment [8]. Mapping areas that have a flood hazard level needs to be done so that the government can make the right policies to overcome them.

The hazard map determines the area where certain natural events occur with a certain frequency and intensity, depending on the vulnerability and capacity of the area, which can cause a disaster [9]. This study will analyse the hazard index in the Kemuning Watershed of Sampang Regency using combines/overlays parameters of flood-prone areas and History of Flood Events data. This study also Estimate the number of village/kelurahan possibly affected by flooding with difference levels of hazard index in Kemuning Watershed.

2. Study Area
The study areas is in kemuning watershed in the Sampang Regency. Kemuning watershed has a length of 54.11 kilometres with a area of 354.50 km square consisting of 7 sub-districts, namely Sampang, Omben, Kedungdung, Robatal, Torjun, Camplong, and Ketapang. Kali Kemuning has many fan-shaped tributary, which hydrologically causes rainwater to get faster and gather in the main river so it will easily floods. In addition, the type and nature of the soil in the watershed area consists mostly of clay that does
not absorb water and is easily eroded, which results in accumulation of sediment in the river. The high sedimentation in the river causes a decrease in river capacity so that the amount of runoff that enters the river is not accommodated and causes overflow to the surrounding area. Problems will arise when the area affected by overflow of the river water (flood) is a productive agricultural area or a densely populated residential area.

Figure 1. Kemuning watershed

3. Defining and Terms

3.1. Flood
In the glossary of the IPCC SREX report, floods are defined as: “the overflowing of the normal confines of a stream or other body of water or the accumulation of water over areas that are not normally submerged. Floods include river (fluvial) floods, flash floods, urban floods, pluvial floods, sewer floods, coastal floods, and glacial lake outburst floods.” These various classes of floods are generated by different mechanisms [10].

If an event is submerged by water in an area that threatens and disrupts the life and livelihood of the community, resulting in human casualties, environmental damage, property losses, and psychological impacts, the flood is considered as flood disaster [11].

3.2. Hazard
A process, phenomenon or human activity that may cause loss of life, injury or other health impacts, property damage, social and economic disruption or environmental degradation Hazard may caused from natural, anthropogenic or socio natural in origin. Natural hazards are predominantly associated with natural processes and phenomena. Anthropogenic hazards, or human-induced hazards, are induced entirely or predominantly by human activities and choices. This term does not include the occurrence or risk of armed conflicts and other situations of social instability [7]. Flood are sociological, since it is a combination of natural and anthropogenic factors, including environmental degradation and climate change.

3.3. Hazard Map
Determines the area where certain natural events occur with a certain frequency and intensity, depending on the vulnerability and capacity of the area, which can cause a disaster [9].

4. Materials
The data used in this study can be classified as follows:

4.1. Flood Event Data
- Data on flood events in Sampang district in 2015-2018 (see table 2 and 3)

| Table 2. History of flood events in 2015-2018 |
|-----------------------------------------------|
| Village/Kelurahan | District | Inundation Height |
|-------------------|----------|-------------------|
| 1                 | Banyumas | Sampang           | 200 cm |
| 2                 | Dalpenang| Sampang           | 170 cm |
| 3                 | Gunung Maddah | Sampang   | 210 cm |
| 4                 | Gunung Sekar | Sampang   | 80 cm  |
| 5                 | Kamoning | Sampang           | 200 cm |
| 6                 | Karang Dalem | Sampang | 100 cm  |
| 7                 | Pangelan | Sampang           | 200 cm |
| 8                 | Panggung | Sampang           | 120 cm |
| 9                 | Paseyan  | Sampang           | 170 cm |
| 10                | Polagan  | Sampang           | 50 cm  |
| 11                | Rontengah| Sampang           | 100 cm |
| 12                | Tanggumong | Sampang   | 200 cm |

Source: BPBD of Sampang regency

| Table 3. Flood prone area in Kemuning river at 2013 |
|-----------------------------------------------|
| Village/Kelurahan | District | Area (hectare) | Inundation Height |
|-------------------|----------|----------------|-------------------|
| 1                 | Karangdalem | Sampang   | 7,336           | 60-150 cm |
| 2                 | Polagan   | Sampang     | 66,260          | 60-80 cm  |
| 3                 | Banyuanyar | Sampang    | 246,237         | 50-60 cm  |
| 4                 | Rontengah | Sampang     | 76,81           | 60-70 cm  |
| 5                 | Dalpenang | Sampang     | 21,445          | 80-200 cm |
| 6                 | Gunung Sekar | Sampang | 73,406          | 100-300 cm |
| 7                 | Gunung Maddah | Sampang | 95,513          | 50-60 cm  |
| 8                 | Panggung  | Sampang     | 315,068         | 80-100 cm |
| 9                 | Paseyan   | Sampang     | 215,885         | 100-250 cm |
| 10                | Tanggumong| Sampang     | 203,451         | 60-80 cm  |
| 11                | Kamuning  | Sampang     | 12,654          | 60-100 cm |
| 12                | Pakalongan| Sampang     | 10,119          | 40-60 cm  |
| 13                | Tamansareh| Sampang    | 12,654          | 40-60 cm  |
| 14                | Baruh     | Sampang     | 10,119          | 40-60 cm  |
| 15                | Pangelen  | Sampang     | 104,233         | 60-80 cm  |
| 16                | Banyumas  | Sampang     | 161,271         | 80-100 cm |

Source: Department of public work and water resources, Sampang regency
4.2. Analysis of Hazard Data

- Topographic and geomorphology data with DEM (Digital Elevation Model) Satellite Imagery (source: DEMNAS)
- River basin and river network data (source: ministry environment and forestry Republic of Indonesia, 2011)
- Regional administration data (source: BPS, 2011)

5. Methodology or methods

The method used in this study is an analysis which combines/overlays parameters of flood-prone areas and History of Flood Events data (see figure 1). Flood-prone areas are identified by the geomorphic flood index method (GFI) using DEM data and river networks (see figure 2). Data on flood inundation histories in the village/kelurahan area are used as elevation reference data on the identified river/canal network data then simulated an increase in altitude from the closest river/drainage surface with height above the nearest drainage (HAND) method.

[Diagram of Flowchart of flood hazard Index method]

Figure 2. Flowchart of flood hazard Index method

[Diagram of Flowchart of flood prone area analysis]

Figure 3. Flowchart of flood prone area analysis
5.1. Geomorphic Flood Index (GFI)
Geomorphic flood index method (GFI) was developed [12]. This index compares each point of the water depth of the $hr$ [m] variable with the difference in elevation $H$ [m]. $hr$ is calculated as a function of the contribution of the area $Ar$ [m$^2$] (accumulated flow) at the closest point of the river/drainage network that is hydrologically connected to the point being tested. Therefore, considering the approximate $hr$ of the water level in the closest element of the river/drainage network means that the nearest river/drainage is seen as a source of danger.

![Figure 4](image)

**Figure 4.** Description of the GFI. representation of the parameter $H$ and $hr$ in cross section [12]

5.2. Height Above the Nearest Drainage (HAND)
The HAND method is a method of determining elevation height (vertical distance) above the river surface/drainage, where each river/drainage network is made as a relative datum. This method was developed [13]. This method normalizes topography according to the local relative heights found along the river/drainage network or a drainage normalized model of a digital elevation model.

5.3. Fuzzy Logic
The concept of fuzzy logic was first introduced by Professor Lotfi A. Zadeh from the University of California, in 1965. It is a method that has the ability to process variables that are fuzzy or which cannot be accurately described as high, slow, noisy, etc. In fuzzy logic, fuzzy variables are represented as a set whose members are a crisp value and the membership function in the set. Fuzzy is a value that can be valued right or wrong simultaneously [14]. But how much the truth value and error depends on the degree of membership it has.

In fuzzy logic, the value of the hazard class grouping based on the inundation value can be translated into an ideal distribution of fuzzy membership based on the specified rules. Fuzzy membership from the inundation height determined the rule that the greater the inundation value (> 1.5), then the value of the fuzzy membership of inundation will be closer to the value of 1 or at the value limit which can be referred to as high hazard class. Conversely the smaller the inundation value (≤0.75), then the value of the fuzzy membership of inundation will be closer to the value 0 or at the value limit which can be referred to as a low hazard class.

6. Result and Discussion
The flood hazard assessment step as follow:

6.1. DEM Correction
DEM 3D is corrected based on RBI map topographic data to obtain elevation values that are appropriate to the actual conditions. Land cover in the form of built land (settlements) and sloping areas on non-hilly areas is eliminated in the DEM data, because it is considered as a surface object that affects elevation values. Furthermore, the DEM data was interpolated with the Multilevel B-Spline Interpolation method to obtain the corrected DEM results.
6.2. **Flood Prone Area**
Flood-prone areas are identified by the geomorphic flood index method (GFI). The result can be found at Figure 6.
6.3. **Potential Inundation Height**

Data on flood inundation histories in the village/kelurahan area are used as elevation reference data on the identified river/canal network data then simulated an increase in altitude from the closest river/drainage surface with HAND method. The Potential Inundation Height is shown in Figure 7.

![Figure 7. Potential Inundation Height](image)

6.4. **Flood Hazard Index**

The result is a flood hazard index with details of 3476.18 hectare (51.71%) high level, 2614.37 hectare (38.89%) medium level, 631.61 hectare (9.39%) low level, shown Figure 6. Number of villages on District according to the flood hazard index is shown in Figure 7.

![Figure 8. Flood hazard index map](image)
Figure 9. Histogram of the number of villages on flood hazard index

7. Conclusion
Most part of southern region Sampang regency has high level prone category to floods. This situation caused by region tend to be flat and low that it could potentially be a bin of water when it rains so that it can make flood. Another factor that causes flooding in Sampang Regency is that the topography of Sampang Regency tends to be flat and bumpy, the altitude between 0-300 m above sea level and the average slope between 2 - 25%. This kind of topography is strongly supports the occurrence of soil erosion processes which essentially carry sediments from the upper part which in turn sedimentation is deposited in river streams and causes silting of the river so that the continuous capacity of the river for rainwater will cause flooding. For flood analysis, it takes a good Digital Elevation Model (DEM) quality in the form of digital terrain model (DTM) and need to detail the location of flood inundation points for validation.

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Acknowledgments
We would like to express our sincere gratitude to acknowledge assistance or encouragement from colleagues, special work by technical staff or financial support from National Authority for Disaster Management (BNPB) Indonesia.