Spatial Analysis of Flood and Landslide Vulnerable Areas
(Case Study in Trenggalek Regency)

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Abstract. Floods and landslides occurred almost every year in various regions in Indonesia, especially in hilly or bumpy areas. Floods and landslides as natural phenomena may cause severe disaster, due to high rainfall with small capacity of river cross section that resulted in water overflow through the dike and inundated lower areas. Flood and landslide risk mapping provides spatial information as initiation for mitigation purposes and is very beneficial in minimizing casualties and damages. To avoid landslide disaster, we need to reduce some causing factors, such as the factors that cause unstable slope conditions. The landslide distribution map contains information on geological maps, slope class maps, land cover maps and geomorphological maps; these maps are referred to as factor maps. Overlay method was implemented to analyse flood and landslide-prone areas. The purpose of this paper was to obtain information on areas in Trenggalek Regency that were vulnerable to flood and landslide. Risk analysis was done spatially with good accuracy, so that it can be used for disaster mitigation purposes.

1. Introduction

Global climate change has affected rapid environmental changes at global, regional and local levels. Natural disasters such as floods and landslides were some of immediate impacts, occurred as a natural relaxation effort to the changes itself [1]. Historically, floods and landslides happened repeatedly, with various vulnerabilities and damages, and in some cases caused human casualties. Even though floods and landslides occurred almost every year, but the number of human casualties and loss of properties tended to increase from year to year.

In hilly areas, landslides often occurred at the hills whereas floods occurred at the flat plains. However, highly vulnerable areas may not necessarily have high risk, when the areas have low population and little economic activities. On the contrary, some areas with low to moderate vulnerability may have high risk because of their high population and economic activities.

Changes in physical condition of the environment accelerated by climate change will cause natural disasters such as floods and landslides at a local scale in a region. Availability of flood and landslide hazard map becomes very important and urgent because such map is a crucial element for regional planning. Incorporating this hazard map into the regional planning is expected to reduce casualties and property damages due to disasters. This research aimed to map areas prone to floods and landslides by using Geographic Information System.

Traces of flood can be identified by the soil characteristics, especially signs of spotting soils. Therefore landform analysis can be done to locate flood-prone areas. Areas vulnerable to landslides can be analyzed by overlaying geological map, rainfall map, slope map, land use map, soil map, and landform map [2].
1.1 Investigated field
This study was located in Trenggalek Regency, East Java. Trenggalek regency stands in the south part of East Java Province, geographically in between Longitude 111°24’ – 111°50’ East and Latitude 7°53’ – 8°34’ South as shown in Figure 1. This research was done from July until November 2017 at the Geospatial Information Agency of Indonesia (BIG).

![Figure 1. Research location map](image)

1.2 Materials and data used
The materials used in this study consisted of images and history of flood events as presented in Table 1. The tool used for spatial data processing was a set of computers with Microsoft Office 2010 software, Global Mapper V.10, ER Mapper 7, Ilwis 3.85 and ArcGIS 10.2.

| Materials       | Remarks       |
|-----------------|---------------|
| Topographic map | Scale 1:25,000|
| Geological map  | Scale 1:100,000|
| Land used map   | Scale 1:25,000|
| Rainfall        |               |

2. Methodology

Flood Risk Mapping
Mapping of flood prone areas was presented as a flood risk map at a scale of 1:25,000. Flood analysis needed to be supported by data on river flow capacity and river discharge (both average and peak discharge). This data could determine the ability of a river to drain the water to estuary. Interviews with local residents about floods were directed to find out the depth, frequency and duration of floods. Flood risk was obtained by analysing the secondary data and the result of interview collected during field surveys (Figure 2).
Figure 2. Flow diagram of flood risk mapping

Classification of flood vulnerability according to [3], with modification, could be seen on Table 2 below.

Table 2. Criteria for flood vulnerability classes

| No. | Vulnerability Classes       | Frequency       | Duration     | Depth (m)    |
|-----|-----------------------------|-----------------|--------------|--------------|
| 1.  | Not vulnerable              | Never           | -            | -            |
| 2.  | Low vulnerable              | Every 1-2 years | < 1 day      | < 0.5        |
| 3.  | Moderate vulnerable         | Every 1-2 years | 1-2 days     | 0.5 – 1.0    |
| 4.  | High vulnerable             | Every year      | 2-15 days    | 0.5 – 2.0    |
| 5.  | Very high vulnerable        | Always (permanently inundated) | 8-12 months | 0.5 – 3.0    |

Every flood occurrence was analyzed in term of its associated risks. Some risk factors of flood which were taken into account included rainfall, soil (permeability), vegetation (land cover), slope, and land form. Based on the five factors, spatial distribution of flood could be predicted. In this model, flood risk was obtained by integrating the level of flood disaster with land use [3]. This mapping model could give a comprehensive view of the flood risk and possibility of risk development, such as prevalence of diseases due to the flood [4].

To get the level of flood disaster, each risk factor was given a certain weight depending on its impact to a flood. Rainfall would give more impact than slope, therefore given a larger weight, then within the rainfall classification, heavy rainfall was given higher score than light rainfall [6]. Assuming that the total maximum weight would be 100, then from larger to smaller weighted factors consecutively were rainfall (weighted 40), slope (25), vegetation (15), soil (10), and land form (10). Score which determined the role to flood disaster for each factor could be uniformly classified, which were 1 for low, 2 for moderate, 3 for high. For example, regarding the land form, basin was given score 3, flat area was given score 2, while hilly up to mountainous area was given score 1. Based on the weighted score values, the highest total value indicated the largest level of disaster level and vice versa. The flood risk map was obtained by overlaying the level of flood disaster with land use.

Landslide Vulnerability Mapping

Landslide analysis was based on five factors, which according to [5] were:

1. Geology, including rock physical and technical characteristics, rock/soil weathering, stratigraphy, and geological structure.
2. Morphology, including slope and surface.
3. Rainfall, including rain intensity and duration.
4. Land use, including land processing and vegetation.
5. Seismicity, including intensity of earthquake.
Based on the above mentioned factors, landslide vulnerability were classified base on criteria on [6], with modification, as in Table 3.

| No. | Vulnerability Classes | Criteria |
|-----|-----------------------|----------|
| 1.  | Not vulnerable         | a. Landslide never or rarely happened, except at the river bank  
|     |                       | b. Topographically flat or a bit wavy  
|     |                       | c. Slope < 15%  
|     |                       | d. Slope rock material was not clay or talus  |
| 2.  | Vulnerable            | a. Landslide rarely happened, unless the slope was disturbed  
|     |                       | b. Topographically oblique up to very steep  
|     |                       | c. Slope was 5-15% and <= 70%  
|     |                       | d. Vegetation was sparse to dense  
|     |                       | e. Slope rock material was generally thick weathering  |
| 3.  | High vulnerable       | a. Landslide frequently happened  
|     |                       | b. Old and new landslide happened actively  
|     |                       | c. High rainfall  
|     |                       | d. Topographically oblique up to very steep  
|     |                       | e. Slope was 5-15% and >= 70%  
|     |                       | f. Vegetation was sparse to very sparse  
|     |                       | g. Slope rock material was thick weathering and breakable  |

Mapping landslide prone areas was done using morpho-dynamic approach. Conceptually, necessary data for analysis could be seen in Figure 3.

Landslide is influenced by internal and external factors. The internal factors come from the material itself, such as type of lithology, soil texture, soil depth, and shear density [7]. Some of the external factors are rainfall, slope, and land cover. Both factors were used as parameters in spatial modelling of landslide vulnerability. Similar to flood risk mapping, each factor was given a certain weight. The most influencing factors were slope and geological characteristics, thus were each given higher weight (3), while land cover and rainfall were each given smaller weight (2). Total score could be formulated as follow:

\[
\text{Total score} = \sum (\text{score for each factor}) \times (\text{weight})
\]

Landslide normally happened at areas with steep (extreme) slope. It was also influenced by the thickness of soil solum and above average rain intensity [8]. Geological factor was associated with the thickness of soil solum and the weathering. The thicker and more weathering material, the higher risk of the material to move.
Land use was also a rather influential factor. The land use at a non-vegetated and steep land would have more risk than the same use at a densely vegetated area [9]. Nevertheless, some researches also suggested that highly dense vegetation (forest) at a steep slope, would become additional burden to the soil underneath. For this situation, when the soil became moistened, the landslide risk would be quite high [10]. Therefore, vegetation thinning in such areas would be necessary.

Rainfall factor was essential to landslide occurrence. However, it was given a lower weight due to relatively rare frequency. Nevertheless, most landslide occurrence were initialized by high rainfall which caused the soil became moistened and heavier, thus landslide happened [11].

3. Result and Discussion

3.1 Flood Analysis

Due to the use of various data source for this research, the map reference systems need to be synchronized first. This process would have added value because it could then be used to valuate more detail disaster risks, and could also be used as inputs to disaster mitigation process.

Result of the flood model showed that out of 14 districts in Trenggalek Regency, only two districts were not at risk, as shown in Table 4.

Table 4. Areas of flood risk zone for each district (in hectare)

| No | District   | Risk Level | Total |
|----|------------|------------|-------|
|    |            | High       | Moderate | Low   | None   |       |
| 1  | Bendungan  | 1.63       | 9,064.02 |       | 9,065.66 |       |
| 2  | Dongko     |            | 14,238.05 |       | 14,238.05 |       |
| 3  | Durenan    | 630.25     | 1,877.29 | 419.38 | 4,842.50 | 7,769.42 |
| 4  | Gandusari  | 2,540.39   | 511.93   | 5,341.85 | 8,394.17 |       |
| 5  | Kampak     | 362.50     | 113.82   | 7,764.28 | 8,240.61 |       |
| 6  | Karangan   | 374.68     | 1,703.85 | 420.25 | 4,541.32 | 7,040.10 |       |
| 7  | Munjungan  | 221.64     | 200.01   | 14,798.56 | 15,283.28 |       |
| 8  | Panggul    | 500.49     | 303.34   | 13,174.43 | 14,106.48 |       |
| 9  | Pogalan    | 586.62     | 1,928.56 | 354.55 | 4,802.11 | 7,671.83 |       |
| 10 | Pule       |            |          | 11,588.36 | 11,588.36 |       |
| 11 | Suruh      | 77.52      | 57.62    | 5,639.17 | 5,774.31 |       |
| 12 | Trenggalek | 338.33     | 1,206.19 | 628.08 | 6,144.12 | 8,316.71 |       |
| 13 | Tugu       | 303.36     | 848.49   | 273.05 | 7,066.73 | 8,491.61 |       |
| 14 | Watulimo   | 952.07     | 399.72   | 15,560.23 | 16,912.01 |       |
|    | Total      | 2,955.37   | 12,001.84 | 3,369.69 | 124,565.73 | 142,892.60 |

Source: GIS Analysis

Table 4 showed area of flood risk zone in every district in Trenggalek Regency. In total, the flood risk zone was 18,326.90 Ha (12.83% of total area of Trenggalek Regency). Flood disaster with quite large impact in Trenggalek Regency occurred in the middle, including Tugu, Karangan, Trenggalek, Durenan, and Pogalan Districts. Those districts were highly populated and activities were mostly in agriculture (especially paddy fields). The area was situated in a very large alluvial basin, with enough water supply and soil material was formed by volcanic sedimentation on the top, making it very fertile, thus many agricultural activities. Landform of the southern part of Trenggalek Regency was karst and structural, with relatively this soil solum with very good permeability, making it a relatively dry area. Panggul and Munjungan Districts in southern Trenggalek each had flood risk zone of 8% and 7%, consecutively, of the district areas. At these areas, agriculture was a vital economic activity, thus flood occurrence might have a large impact (Figure 4).
Calculation results showed that Dongko and Pule Districts were not at risk at all. At Bendungan District, only 1.63 Ha was at moderate risk. The highest risks occurred at Durenan, Panggung, and Pogalan Districts which reached over 500 Ha. At these districts, more areas were also at moderate and low risks.

This model could be easily adapted and modified with more detail data inputs. For example, settlements could be classified into dense, moderate, and sparse, or could also be classified by the economic values of the settlements. Similarly, agriculture objects could be classified into vegetation types, and so on.

3.2 Landslide Analysis

Northern part of the research site was dominated by steep slopes (> 35%), and the soil material was resulted from weathering volcanic rocks with quite thick soil solum. This area was initially covered with production forest, however due to land clearing for agriculture and plantation activities, this area became highly vulnerable to landslide disaster.

Southern part of Trenggalek Regency was also dominated by steep slopes. This includes Watulimo, Munjungan, Panggul and Kampak Districts. Soil material was dominated by karst and structure, with relatively thin soil solum. Rain intensity in these areas was lower compared to the northern part of Trenggalek Regency, therefore potential landslide risk was quite low. Result from spatial modelling of landslide risk is presented in Table 5.

Table 5. Areas of landslide vulnerable zone for each district (in hectare)

| No | District    | Vulnerability Level | Total |
|----|-------------|---------------------|-------|
|    |             | High    | Moderate | Low    | None  |       |
| 1  | Bendungan   | 308.67  | 4,839.41 | 3,544.73 | 376.26 | 9,069.07 |
| 2  | Dongko      | 95.23   | 2,825.54 | 8,573.79 | 2,945.91 | 14,440.47 |
| 3  | Durenan     | 544.86  | 1,743.12 | 2,560.07 |       | 4,848.04 |
| 4  | Gandusari   | 308.72  | 1,110.67 | 3,293.33 | 629.47 | 5,342.19 |
| 5  | Kampak      | 820.36  | 2,428.54 | 4,054.56 | 463.42 | 7,766.88 |
| 6  | Karangan    |         | 257.76   | 1,523.85 | 2,759.70 | 4,541.31 |
| 7  | Munjungan   | 2,551.16| 8,272.24 | 4,047.78 | 168.30 | 15,039.47 |
| 8  | Panggul     | 602.35  | 6,593.36 | 5,909.40 | 143.51 | 13,248.62 |
| 9  | Pogalan     | 0.66    | 298.13   | 1,574.42 | 2,930.05 | 4,803.26 |
| 10 | Pule        | 43.32   | 3,908.89 | 7,968.87 | 23.07  | 11,944.15 |
| 11 | Suruh       | 11.12   | 1,023.57 | 3,918.67 | 687.17 | 5,640.54 |
| 12 | Trenggalek  | 48.29   | 934.22   | 2,743.58 | 2,423.01 | 6,149.09 |
| 13 | Tugu        | 78.47   | 1,833.77 | 4,853.02 | 304.72 | 7,069.96 |
| 14 | Watulimo    | 810.03  | 4,725.63 | 8,800.00 | 1,379.43 | 15,715.09 |
|    | Total       | 5,678.38| 39,596.59| 62,549.12| 17,794.09 | **125,618.14** |
Figure 5 showed that Munjungan District had the widest area of landslide threat, including over 16% area had high risk and over 50% area had moderate risk. Next high vulnerable districts included Kampak, Watulimo, and Panggul Districts. This valuation of landslide vulnerabilities was only based on existing physical land as parameters.

This vulnerability factors do not necessarily have positive correlation with risk factors. For example, Munjungan District which had a wider area prone to landslide compared to Bendungan District. However, since the later district had more population, thus the risk might be higher there. Therefore, in order to obtain landslide disaster risk, other more complex spatial data would be necessary, such as infrastructure, social economy, and so on.

4. Conclusion and Recommendation

4.1 Conclusion

Geographically, risks to flood disasters in Trenggalek Regency was quite high. Therefore the Local Government needs to anticipate the occurrence of such disasters thoroughly in order to minimize casualties and loss of properties. Analysis results showed that the area of high risk zone was smaller than that of moderate risk zone, due to other factors such as population density.

The landslide vulnerability map, which was the result of spatial modelling using GIS, showed good accuracy of 90%, and was proven in the field. Indication of illegal land uses by community which demanded land clearing, could be the trigger of landslide especially when the rainfall intensity was high. The condition of thick soil solum during heavy rain could become heavy burden to the soil, thus could cause landslide.

4.2 Recommendation

Disaster mapping in larger (more detail) scale can provide great benefits to Government of Trenggalek Regency for disaster mitigation efforts. Spatial data need to be updated regularly so they can be used in further analysis for sustainable use of the natural resources. The maps resulted from this research should be used by the Government of Trenggalek Regency as additional tools for regional development of Trenggalek Regency.
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