Tsunami Vulnerability Assessment and Its Implications for Disaster Risk Management in the coastal area of Purworejo Regency

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Abstract. Tsunamis are disasters with unpredictable events, but the occurrence of tsunamis in Indonesia always has a significant impact on every sector of life, especially the economy and society. The position of the Indonesian State, which is located in the subduction zones as well as the increasing human activity in coastal areas, are the factors that trigger the tsunami, which is accompanied by losses and damages. One of them is Purworejo Regency, which is directly adjacent to the Indian Ocean. Vulnerability assessment is the focus of this paper. This study uses a quantitative analysis approach with analytical methods in the form of scoring analysis. Weighted cell-based data processing is the main cog in vulnerability assessment. The combination of economic and social parameters creates a vulnerability. Financial vulnerability is measured based on GRDP and productive land, while social vulnerability is estimated based on population density and vulnerable communities. The vulnerability analysis results are in the form of total vulnerability level in the medium class, the level of economic vulnerability in the low, quality, and social vulnerability in the medium class associated with the implication of disaster risk management.

Keywords: Tsunami, Purworejo, Vulnerability, Risk Management.

1. Introduction

Tsunamis are rare catastrophic events, not all seismic activities on the seabed can cause tsunamis[1]. The level of occurrence of a tsunami is challenging to predict, but if it has occurred, it can cause enormous damage if prevention is not prepared. The destructive power of a tsunami disaster can be significant if it has entered the coastal area and can reach a reasonably wide area from the coastline. The distance of the tsunami inundation depends on the coastal zone [2]. The impact of tsunami disasters, such as human casualties and economic losses, has increased more than 100 times over the past twenty years compared to the previous two decades[3].

Indonesia is surrounded by converging plate boundaries so that it has the opportunity to display patterns of repeated earthquakes, tsunamis, and tsunamis from volcanic eruptions. For example, in the last two years (2017-2018), there have been 15 fatal seismic events and two disastrous tsunamis with a death toll of> 5,500 deaths.[4]. The impact of earthquakes continues to grow due to increased vulnerability and exposure in earthquake-prone areas. Human vulnerability to earthquake hazards increases due to the proliferation of high-risk objects increased population in earthquake-prone regions and significant

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destabilization of cities[5]. The most massive earthquake and tsunami events that have occurred in Indonesia include Aceh and Palu-Donggala with a total death toll of 128,645 for the tsunami that occurred in Aceh[6] and 2,037 for the tsunami that occurred in Palu-Donggala[7].

Java Island is located in the southeast of Sundaland, which has two plate motion systems, namely the Eurasian Plate in the north and the India-Australia Plate in the south. Recent records of significant earthquakes (> magnitude 6) by the USGS show that Java experienced three quiescent intervals of earthquakes followed by increased seismic activity. The seismic pattern indicates that the Java Trench plate boundary accumulates potential movement at a rate of 7 cm/year for 30-40 years, followed by 30-40 years of more significant and more frequent earthquake events. However, only a small part and the movements accumulated over the last 40 years of seismic calm have been released, which means it is very likely that the Java region will experience a significant earthquake generating a tsunami shortly [8]. There are about 4.35 million people threatened by the tsunami along the southern coast of Sumatra, Java, and Bali. The population boom is high, along with the increasing level of risk along the south coast of Java in particular.

Tsunami risk in Central Java Province is classified as medium to high, written in [9] with physical vulnerability reaching 2,677,841,000, economic vulnerability reaching 359,862,000, and social vulnerability reaching 130,608,000. One of the districts in Central Java Province, which is directly adjacent to the coastline is Purworejo Regency. Three sub-districts, including Grabag, Ngombol and Purwodadi are located on the coast. Purworejo Regency is one of the areas adjacent to the Eurasian subduction zone and the Indo-Australian plate. This fact causes Purworejo Regency to have the potential for a tsunami that comes from a tectonic earthquake. Large-scale tectonic earthquakes in shallow water have the potential to generate tsunamis with high destructive force. Geomorphologically, Purworejo Regency has a mountainous area, namely Menoreh Hill. Tectonically it represents the volcanic arc of the central part of Java Island from the tertiary era. The area has a stratigraphy that varies from the oldest to the youngest. The geological structures found in Menoreh Hill are in the form of joints and later slip faults. The volcanic rock found in Menoreh Hill has weathered extensively and extends to a thickness of up to 5 meters.

Purworejo Regency is in an area with a flat slope category. In this regard, a risk assessment must be carried out in the context of disaster management development in the Purworejo Regency area. Purworejo Regency has three sub-districts bordering the coastline, which have tectonically active status. This condition is a strong basis for the occurrence of a tsunami disaster in this area. Therefore preventive measures are needed to reduce the value of the risks that may occur. The coastal area of Purworejo Regency is indicated by the phenomenon of settlement development for 15 years, which happened as a result of land conversion from non-settlement to residential land as a result of social housing construction.[10]. The development of human activities in Purworejo Regency is also influenced by two main axes, namely Jalan Lintas Selatan (JLS) Daendels and New Yogyakarta Airport (NYIA) in Kulon Progo. The coastal area of Purworejo Regency, which is directly adjacent to the Indian Ocean, is not the right zoning area for human activities.

Tsunami readiness is an essential key in reducing tsunami risk. One important information to improve the preparedness of coastal communities to the tsunami is an accurate tsunami vulnerability assessment. Many risk assessments have been carried out to calculate the potential losses caused by a tsunami. Integrated geospatial data analysis is critical in the tsunami risk assessment phase. Tsunami risk is formed based on the hazard posed as well as the vulnerability that occurs. Tsunami susceptibility is analyzed after the evaluation of tsunami potential and probability. It depends on how close the community is to the source of the hazard and its social and economic characteristics[11].
The incidence of the tsunami in Indonesia greatly affected almost every sector of the economy, including agriculture, fisheries, tourism, transportation, housing, and health [12]. In order to build a better tsunami disaster mitigation, it is necessary to have proper analysis related to tsunami vulnerability and risk assessment. Many simulators and geospatial analysis applications for tsunami susceptibility and risk assessment have been developed. For example, Arikawa and Tomita [13] combine Storm and Tsunami simulators in the ocean and Pacific coastal areas. Hazard mapping to display the characteristics of these hazards both from the nature and type of hazard that occurred, the time of the disaster, and the duration of the impact and the area of influence as hazard zones that are useful for disaster mitigation measures. This study examines the potential for tsunami-affected regions, where the tsunami vulnerability area will be calculated using economic and social vulnerability parameters, which will later be used in tsunami disaster risk management planning.

2. Methods

2.1. Research area

In this study, tsunami vulnerability mapping uses social and economic vulnerability parameters applied in the coastal area of Purworejo Regency, Central Java (Fig.1). This area is bordered by Kebumen Regency and Kulonprogo Regency in the west and east. Of course, it is also directly adjacent to the Indian Ocean in the south. Purworejo Regency is based on its astronomical location at 07° 32′ - 7° 54′ South Latitude and 109° 47′28″ - 110° 8′20″ East Longitude. Purworejo Regency is divided into 16 districts with an area of 103,481 ha and a 22 km coastline.

Determining the group or population as a description of the study [14] is used in determining the research sample in this study. 16 Villages directly adjacent to the coastline were selected using the cluster random sampling method as samples in this study. The selection of the number of samples in this study used the results of the calculation of the Slovin formula on the total population of the study, which obtained a sample size of 104 people spread across 16 villages.

2.2. Dataset

Parameters of economic vulnerability and social vulnerability are needed to make a map of tsunami vulnerability in the study area. The parameters of economic vulnerability include Gross Regional Domestic Product (PDRB) and productive land in rupiah. Meanwhile, the parameters of social vulnerability consist of population density, poor people, gender, age, and disability. Productive land area
data is obtained from land-use maps and district or sub-district books in numbers converted into rupiah, while GRDP is obtained from sector or district reports in figures. Social vulnerability data is collected from the Indonesian Central Bureau of Statistics.

2.3. Geospatial Analysis
Data analysis was carried out through geospatial analysis. They are starting with the determination of parameters, pre-processing, geospatial analysis, and results. Data consists of two types of data, excel, and vector. IKONOS imagery as raster data is used to create land use maps. All parameters are classified into three classes based on the economic vulnerability of the tsunami. Social vulnerability data is taken from the Indonesian Central Bureau of Statistics. Information is classified and scored based on social tsunami vulnerability criteria. It consists of population density, gender, age, poor and disabled people.

Table 1. Parameters for the Preparation and Scoring of Economic Vulnerability.

| Parameters                  | Weight (%) | Score                  | Class       |                 |                |                |
|-----------------------------|------------|------------------------|-------------|----------------|----------------|----------------|
| Productive Land             | 60         | Class / Max Grade Value| Low         | 50 – 200 million| >200 million    |                |
| PDRB                        | 40         | Class / Max Grade Value| Low         | <100 million    | 100 – 300 million| >300 million    |                |

Economic Vulnerability = (0.6*productive land) + (0.4*PDRB)

Table 2. Parameters for the Preparation and Scoring of Social Vulnerability.

| Parameters                              | Weight (%) | Score                  | Class       |                 |                |                |
|-----------------------------------------|------------|------------------------|-------------|----------------|----------------|----------------|
| Population density                      | 60         | <500 people/km²        | Low         | 500-1000 people/ km² | >1000 people/ km² |                |

Gender Ratio (10%)

The ratio of Vulnerable Age Groups (10%)

Poor Population Ratio (10%)

The ratio of Disabled People (10%)

Social Vulnerability = (0.6*log(population density /0.01)/ log(100/0.01)) + (0.1* gender ratio) + (0.1* ratio of vulnerable age groups) + (0.1* poor population ratio) + (0.1* ratio of disabled people)

Data analysis for creating a tsunami vulnerability map as a combination of economic and social tsunami vulnerability was carried out using cell-based modeling about geographic information systems. All parameters applied in the model are converted to a raster dataset. This data consists of a matrix of cells and is classified under different weights. A weighted overlay is a type of conformity analysis that helps analyze geographic data based on several criteria. Weighted overlays allow users to combine the pressures of several kinds of information and visualize them, where several factors can be evaluated at once[15].
3. Results and Discussion

3.1. Economic vulnerability:
Two parameters of economic vulnerability are processed in the tabular form then converted into spatial data, which is then converted into raster cell types and analyzed using a weighted overlay to create a tsunami vulnerability map. Raster cells of all parameters are classified based on their value into three classes of vulnerability representing low, medium, and high vulnerability. Vulnerability classes and their weights are described in Table 1, and tsunami vulnerability maps are described in Figure 2.

Figure 2. Economic Vulnerability Map

Figure 2 depicts a tsunami vulnerability map in the coastal area of Purworejo Regency based on economic parameters. The entire Purworejo area is described as low vulnerability due to the economic conditions of the coastal community of Purworejo Regency when faced with a tsunami disaster, and they can still take precautions. It can be seen from the productive land, which is scattered along the coastal area, which is still relatively large.

3.2. Social Vulnerability

The social vulnerability can be interpreted as a form of limitation of a community group or individual to the impact of an event, in this case, a tsunami disaster, which will affect the ability to prevent and recover from these impacts. The social vulnerability map is created using four parameters and is weighted. The calculations are based on criteria as described in Table 2. Social vulnerability map as described in Figure 3.
Figure 3 illustrates that the entire Purworejo area is described as moderate vulnerability. The population explosion is very pronounced in Purworejo Regency, especially in its coastal area. This becomes a special note in the event of a tsunami disaster. There needs to be a direction for the people living in the area, especially those classified as vulnerable communities.

3.3. Vulnerability

The combination of economic and social parameters for assessing tsunami-prone areas using cell-based modeling is one approach to support risk analysis. Cell-based modeling calculates each parameter pixel based on its score and weight. The analysis follows the arithmetic logic below

\[
\text{Total vulnerability} = \sum (\text{physical vulnerability} \times \text{weight}) + (\text{social vulnerability} \times \text{weight})
\]

The total vulnerability describes the area of vulnerability due to the tsunami in which two parameters of economic vulnerability and four parameters of social vulnerability are combined as described in Figure 4.
The vulnerability map, as described in Figure 4 includes information on the total area per vulnerability class (Table 3). The information contained in the map above plays an important role in establishing an effective early warning system. Social vulnerability maps provide information about villages or sub-districts with relatively high vulnerability. By integrating economic and social vulnerability in the early warning system, coastal communities will be aware of the risks. As a result, tsunami preparedness will increase.

3.4. Disaster risk management

Based on the previous calculation of vulnerability, it was found that people living in the coastal area of Purworejo Regency have a moderate level of vulnerability to tsunami disasters. The involvement of economic and social factors in disaster risk reduction is very important because it is felt that these two factors overlap directly in daily life. The ability of the coastal community of Purworejo Regency to rebuild the economy after the tsunami disaster is still considered capable. People who live in the coastal area of Purworejo Regency still depend on nature for their lives, where it is proven that the area of productive land is larger than the area of non-productive land. That reason is the benchmark that the economic vulnerability of the coastal community in Purworejo Regency is low.
One of the points that must be considered is the social skills possessed by the coastal community of Purworejo Regency. The population density and gender ratio, which are still not equal, cause social vulnerability to be classified as moderate. There needs to be a real movement so that there are not too many casualties during the tsunami disaster. Cultivating an understanding of disaster risk management in itself is one of the efforts that are felt to reduce the number of casualties who fall after a disaster. Disaster risk reduction can be made through risk management carried out individually or in groups. One of the forms of risk management that can be carried out personally is self-management, which includes management actions in the way of developing individual skills that support disaster activities. It is hoped that this will reduce the number of victims in the event of a tsunami disaster.

4. Conclusions
Weighted cell-based data processing represents a good outcome in assessing vulnerability. The combination of the economic and social vulnerability parameters in this assessment also represents a good approach for creating a tsunami vulnerability map. The map is important for determining the area that is likely to be affected by a tsunami wave. The results illustrate critical information in many applications to support disaster risk management. Furthermore, to obtain a more accurate vulnerability map and tsunami risk map, this method can be applied by adding other vulnerability parameters such as building density, mangrove forest area, distance from the coast, presence of barrier islands, beach type, and tsunami direction.

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