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Tsunami Vulnerability Mapping Using Remote Sensing and GIS Techniques: A Case Study of Kollam District, Kerala, India

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Abstract

Tsunamis are caused by the displacement of a large volume of water, generally in an ocean or a sea. Submarine earthquakes, volcanic eruptions, underwater explosions, continental shelf landslides, glacier calvings, meteorite impacts, and other powerful submarine disturbances have the potential to generate a tsunami. Tsunami vulnerability zonation and mapping is very important to mitigate the impact due to tsunami disaster. The coastal areas of Kollam district, the present study area were seriously affected by the catastrophic Indian Ocean tsunami of December 26, 2004. This study aims to demarcate tsunami vulnerable areas in Kollam district using Remote Sensing and GIS techniques. A multi criteria decision analysis has been carried out using five parameters, namely land use/land cover, slope, elevation, geomorphology, and distance from shoreline and based on thematic maps prepared with respect to them. The prepared vulnerability map area was classified into five zones: safe, rather safe, moderate, rather vulnerable, and vulnerable. The village boundary was overlaid on the vulnerability map in order to identify and highlight the vulnerable villages. This study provides an interactive method to identify tsunami affected areas after a disaster in addition to mapping tsunami vulnerable areas before a disaster, in an effort to help manage future disasters.

Keywords: *Tsunami, Coastal areas, Indian Ocean Tsunami, GIS, Vulnerable areas.*

1. Introduction

A tsunami is a series of ocean waves typically caused by large submarine earthquakes or volcanic eruptions. The foci of tsunami triggering submarine earthquakes usually fall within or close to tectonic-oceanic plate boundaries. Tsunami waves initially show very large wavelengths, but low amplitude. These high energy waves move towards land at great speeds. However, because of their low amplitude they may go unnoticed by the fishermen engaged in the open ocean. As these waves approach the shoreline the amplitude increases to alarming and awesome scales. The waves of water may reach several tens of meters and cause widespread destruction when they crash ashore [1]. Although the impact of tsunamis is limited to coastal areas, their destructive power can be enormous and they can affect the entire ocean basin. Tsunamis can cause loss of lives and damage to property. The 2004 Indian Ocean tsunami, measuring 8.9 on the Richter scale was among the deadliest natural disasters in human history with over 230,000 people killed in 14 countries bordering the Indian Ocean [2]. Its epicenter was near the west coast of Sumatra in Indonesia. During this tsunami, three countries including India, Indonesia, and Srilanka were severely battered.

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The coastal villages of Kollam district in India were severely attacked by the catastrophic Indian Ocean tsunami of December 26, 2004. The tsunami that hit the coast was 3 to 5 meters high. The massive and powerful tidal waves cause considerable damage to property along the coast and the tragic loss of 131 lives. On the Kerala coast, tsunami waves penetrated 1 to 2 km inland. High waves swept a 40 km long coastal stretch from Sakthikulangara of Kollam district in the south to Thrikunnapuzha of Alappuzha district in the north. Locating the spatial distribution of a catastrophic event such as a tsunami and assessing its impact is of vital importance in disaster management.

A number of studies have examined the 2004 Indian Ocean tsunami, which originated near Sumatra. [3-7] assessed the geomorphological changes caused by the tsunami. [8-10] conducted studies on the impact of the tsunami on natural environments. [11] delineated the tsunami vulnerable areas of Jembrana Regency in Indonesia using GIS techniques. The factors selected for the study were topographic elevation, topographic slope, topographic relation to tsunami direction, coastal proximity, and coastal shape. Analytic Hierarchy Process (AHP) method was used to construct the weighting scheme. [12] demarcated the tsunami vulnerable areas on the western coast of the Malaysian peninsula using GIS techniques. The parameters considered were land use, topographic elevation, slope, and distance from shoreline. The objective of the present study is to delineate the tsunami vulnerable areas in Kollam district using Remote Sensing and GIS techniques. The criteria selected are geomorphology, distance from shoreline, slope, elevation, and land use/land cover.

1.1. Study Area

Kollam is one of the 14 districts of Kerala state, India. The district is located on the south-west coast of India, bordering the Lakshadweep Sea to the west, the state of Tamilnadu to the east, Kerala district of Alappuzha to the north, Pathanamthitta to the northeast and Thiruvananthapuram to the south. For the present study, 51 villages from the coastal side of the district were selected (out of 104 villages in the district). The selected area is bounded between 8°46'00" and 9°08'00" N latitude and 76°27'00" and 76°49'00" E longitude (Figure. 1).

2. Materials and Methods

The present study area was delineated from the Survey of India (SOI) toposheets of 1:50,000 scale (Toposheet Numbers: 58 C/8, 58 C/12, 58 D/9, and 58 D/13). A multi criteria decision analysis [13, 14] was carried out using ArcGIS 9.3 and ERDAS Imagine 9.2 software tools. The thematic layers selected for this study were land use/land cover, slope, elevation, geomorphology, and distance from shoreline. The land use/land cover and geomorphology maps were prepared from the IRS-P6 LISS-III satellite image of 23.5 m resolution. The satellite image was pre-processed and a supervised classification was done using ERDAS Imagine software and later analysed using ArcGIS tools. A field visit and data collection using GPS was carried out to check the accuracy of the land use/land cover and geomorphology maps. The slope and elevation maps were prepared from the Cartosat – 1 DEM (30 m resolution) at a 10 m contour interval using ArcGIS spatial analyst and 3D analyst tools. The shoreline of the study area was digitized from the SOI toposheets, while the distance from shoreline map was prepared using ArcGIS spatial analyst tools. These thematic maps were classified according to Natural Breaks (Jenks) method [15-18]. Weights were assigned to each class of the thematic maps to prepare weightage maps. The vulnerability map was prepared by combining these weighted thematic maps using ArcGIS weighted overlay analysis method, after assigning proper ranks. The rank and weight details are shown in Table 1. The boundaries of the villages located within the study area were overlaid on the vulnerability map in order to identify and highlight the vulnerable villages. Finally the vulnerability map was validated using the tsunami inundation data of the study area (Figure. 2) collected through a field survey of the area.

3. Result and Discussion

3.1. Geomorphology

Geomorphologic feature is an important factor controlling the tsunami run up in an area. It has been observed that elevated landforms are less prone to tsunamis compared to low lying landforms, which lack resistance. The geomorphology classes in this study area are coastal plain, water body, pediplain, and plateau. Highest weight is assigned to the coastal plains, as the vulnerability to tsunamis is high in these areas. The geomorphology map is shown in Figure 3.

3.2. Distance from Shoreline

Distance from the coastline is associated with the possible reach of a tsunami. In general, vulnerability becomes higher as coastal proximity increases [11]. The distance from shoreline is grouped into five classes: 0 – 3.1 km, 3.1 – 6.4 km, 6.4 – 9.7 km, 9.7 – 13.0 km, and 13.0 – 17.9 km. Highest weight is assigned to the class having distance range 0 – 3.1 km and lowest weight is given to the class having distance range 13.0 – 17.9 km. The distance from shoreline map is shown in Figure 4.

Table 1. Weight and rank details of the factors

Factor	Class	Weight	Rank
Geomorphology	Coastal plain	8	5
	Water body	6	
	Pediplain	4	
	Plateau	2	
Distance from shoreline (km)	0 – 3.1	10	4
	3.1 – 6.4	8	
	6.4 – 9.7	6	
	9.7 – 13.0	4	
	13.0 – 17.9	2	
Elevation (m)	0 – 15	8	3
	15 – 27	6	
	27 – 44	4	
	44 - 117	2	
Slope (degree)	0 – 0.9	8	2
	0.9 – 2.6	6	
	2.6 – 13.1	4	
Land use/Land cover	Built up	6	1
	Water body	4	
	Mixed vegetation	2	

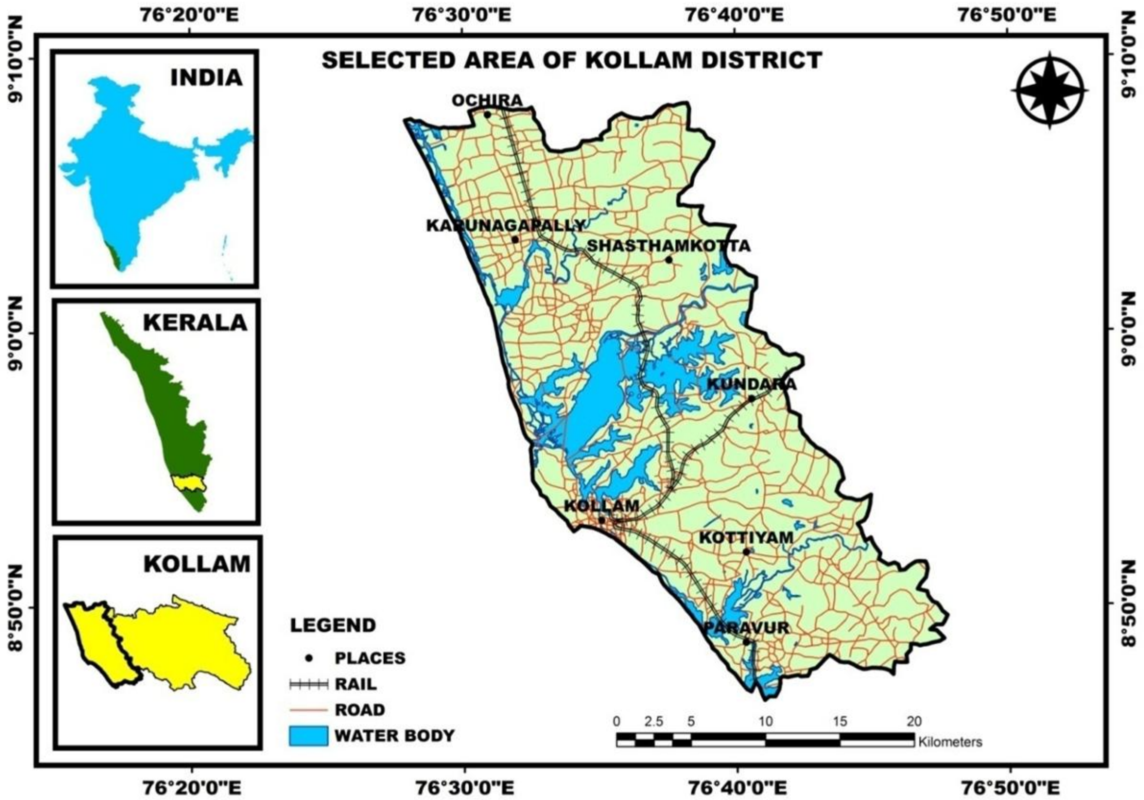

Fig. 1. Location map of the Study Area

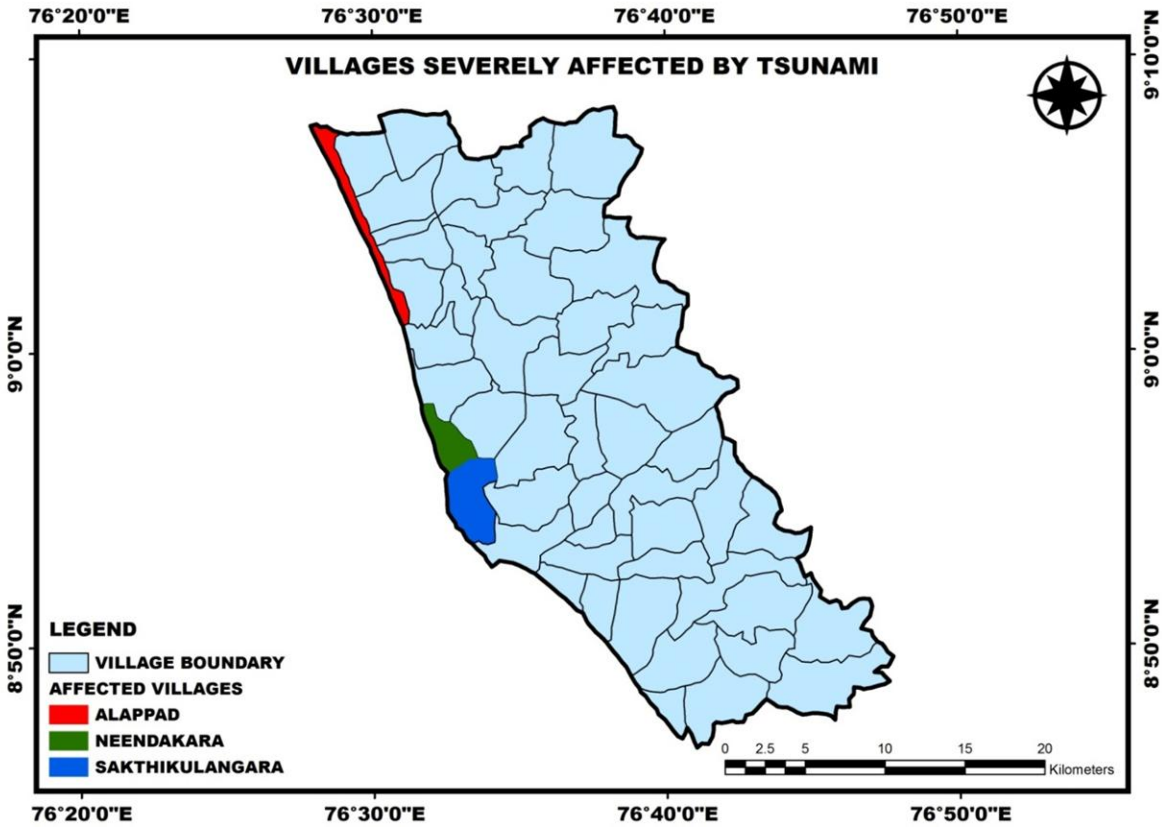

Fig. 2. Tsunami affected villages

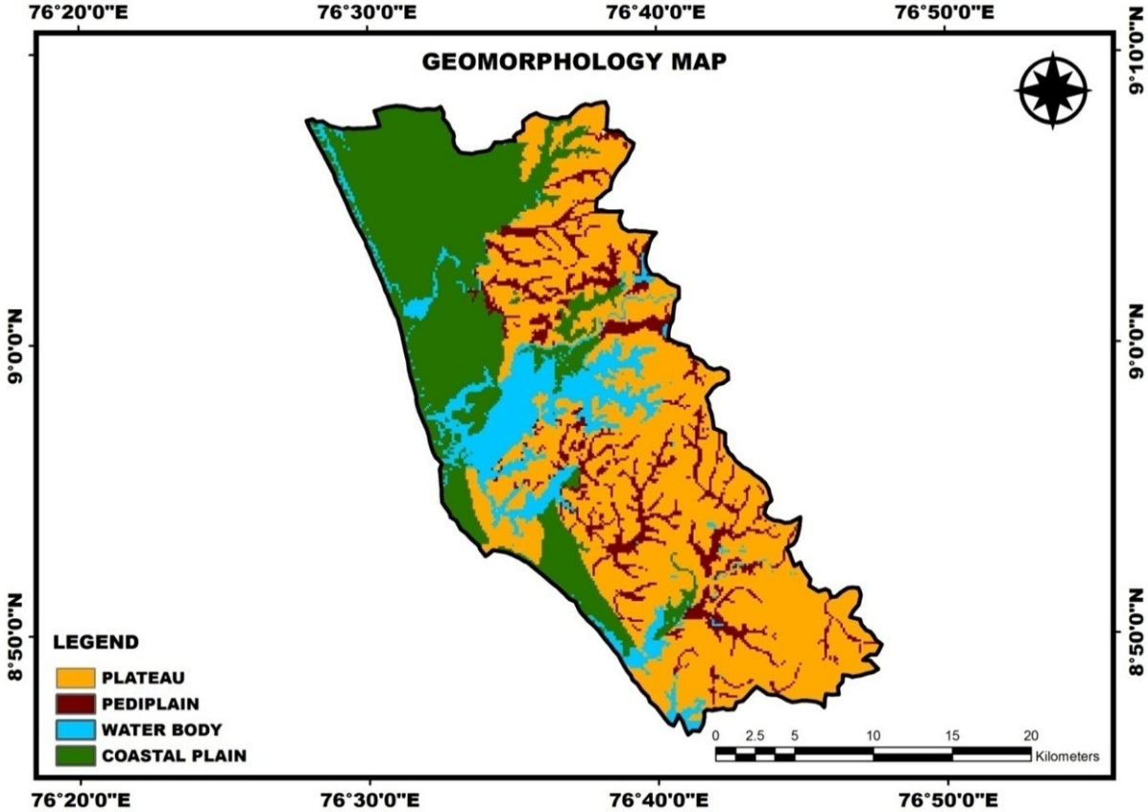

Fig. 3. Geomorphology map

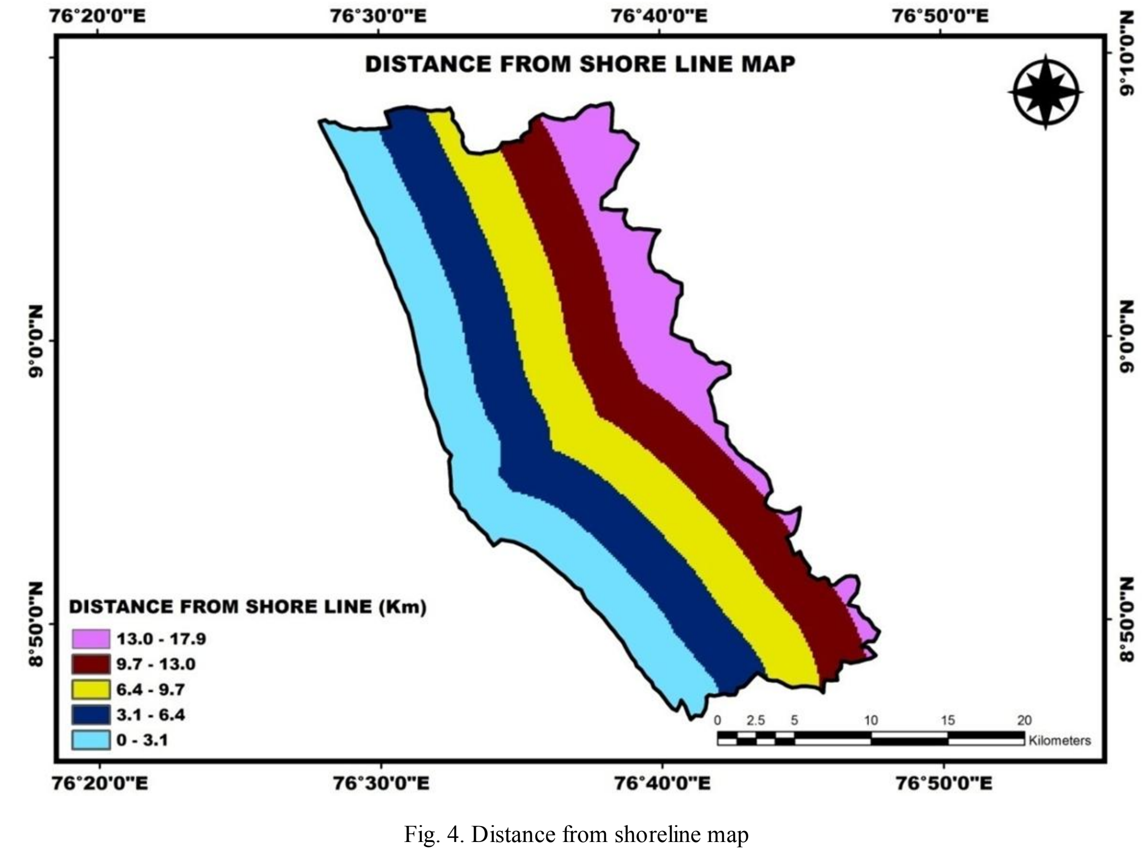

Fig. 4. Distance from shoreline map

3.3. Slope

Tsunami run-up can be severe in areas of relatively flat topographic slope because the tsunami can easily flow onto flat areas, but may be detained or deflected by hills bordering the beach [11]. The slope of the study area is divided into three classes: 0 – 0.9°, 0.9 – 2.6°, and 2.6 – 13.1°. Highest weight is assigned to the class with lower slopes. The slope map is shown in Figure 5.

3.4. Elevation

Generally areas with higher elevation are least affected by a tsunami, whereas those areas with lower elevation are seriously affected. The elevation of the selected area is divided into four classes: 0 – 15 m, 15 – 27 m, 27 – 44 m, and 44 – 117 m respectively. Highest weight is given to the class with lower elevation (0 – 15 m) and lowest weight is assigned to the class with higher elevation (44 – 117 m). The elevation map is shown in Figure 6.

3.5. Land use/Land cover

Land use/land cover is also an important factor controlling the tsunami run up in an area. Areas with vegetation will obstruct the free flow of water. Hence those areas are less vulnerable to tsunamis. The land use/land cover classes in the study area are built up, water body, and mixed vegetation. Highest weight is given to the built up. The land use/land cover map is shown in Figure 7.

3.6. Tsunami Vulnerablity

For Tsunami vulnerability mapping five geospatial variables were used, namely geomorphology, elevation, slope, distance from shoreline, and land use/land cover. These variables were combined by GIS techniques to prepare the vulnerability map. Geomorphology was given the highest rank, whereas lowest rank was given to land use/land cover. The area of the prepared vulnerability map is divided into five classes: safe, rather safe, moderate, rather vulnerable, and vulnerable. The prepared tsunami vulnerability map is shown in Figure 8. The final map is validated using the tsunami inundation data of the study area collected during the field survey. From the vulnerability map it is clear that, all three villages (Alappad, Neendakara, and Sakthikulangara) severely affected by past tsunami falls over the vulnerable areas. Similarly the villages which were partially damaged also fall within the vulnerable areas. Therefore it can be concluded that the vulnerability map prepared during the present study can be used as a reference map for taking preventive measures to mitigate the disastrous effect of any tsunami in future.

4. Conclusions

The present study has considered five geospatial variables to make a tsunami vulnerability map of the coastal stretches of Kollam district. The prepared vulnerability map is useful in recognising the most disaster prone areas. The study has come to the conclusion that the vulnerability to tsunami disaster in this area can be correlated with coastal geomorphology. Therefore it is suggested that in order to mitigate the disasters due to any tsunamis in future, geomorphological characteristics must be given utmost importance in developing residential areas along coastal zones. It is also useful in designing infrastructure, especially roads and drainage more suitable for tsunami prone areas. Further it has been proved that tsunami vulnerability mapping of an area and a multi criteria decision analysis with respect to that can be carried out using Remote Sensing and GIS techniques.

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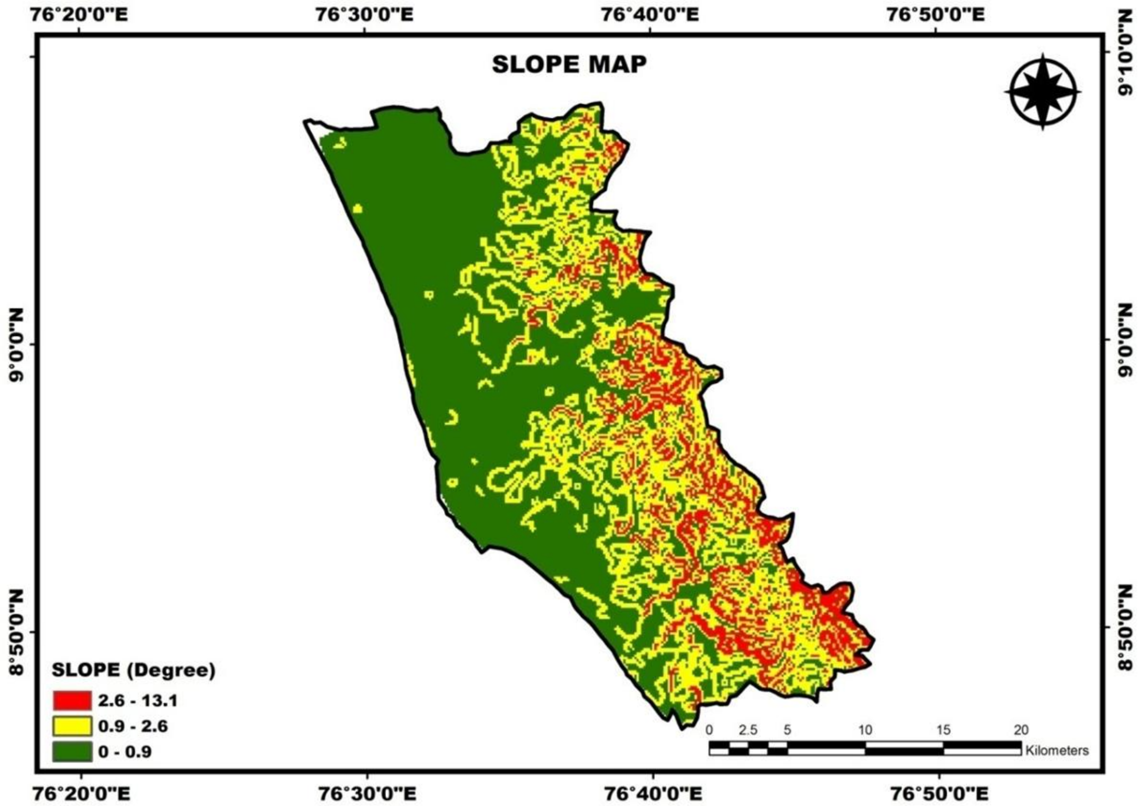

Fig. 5. Slope map

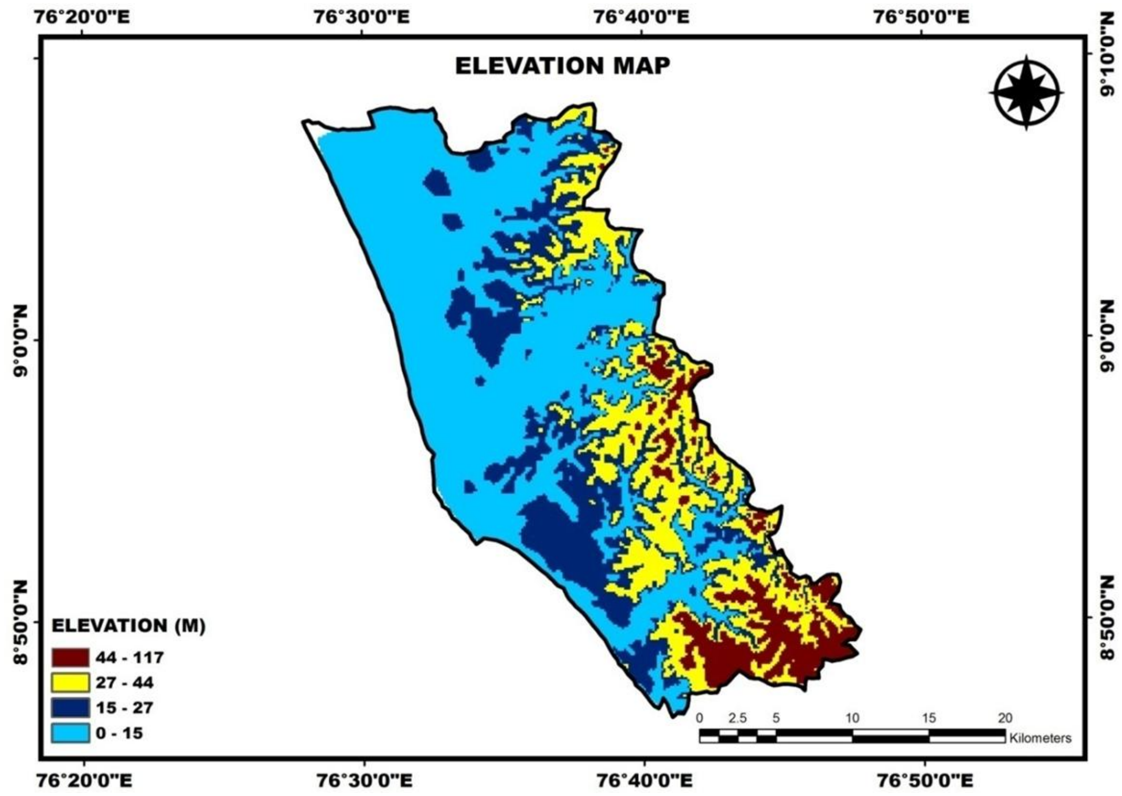

Fig. 6. Elevation map

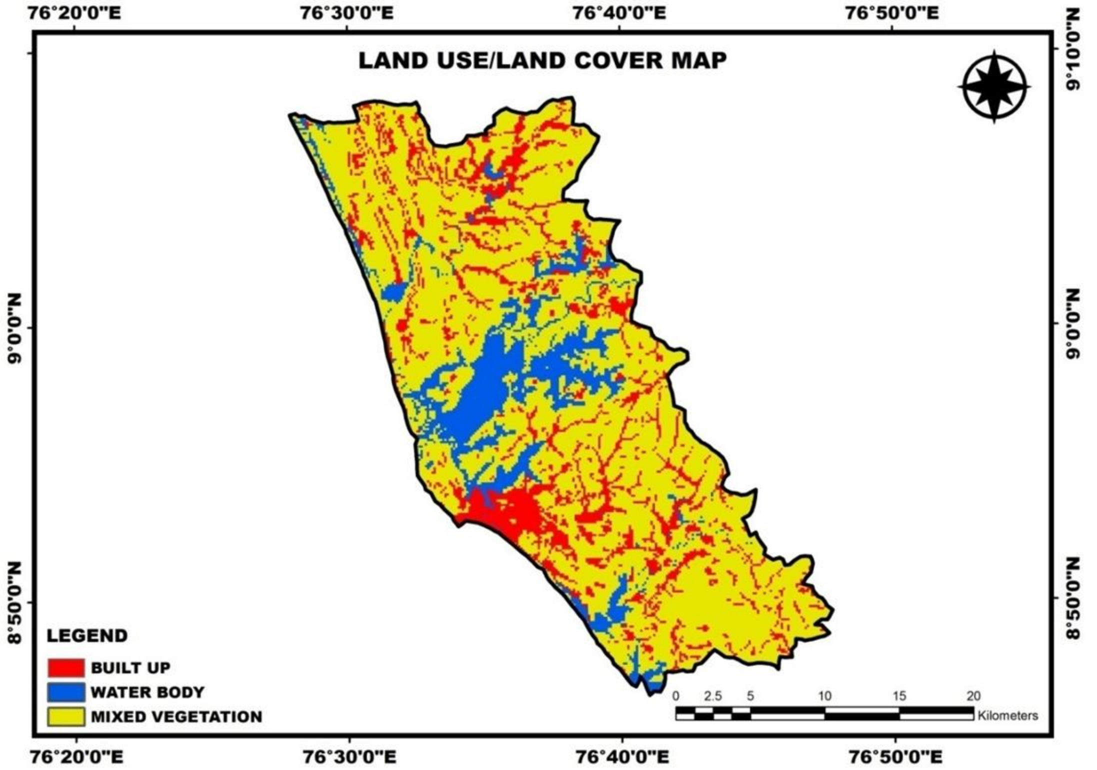

Fig. 7. Land use/land cover map

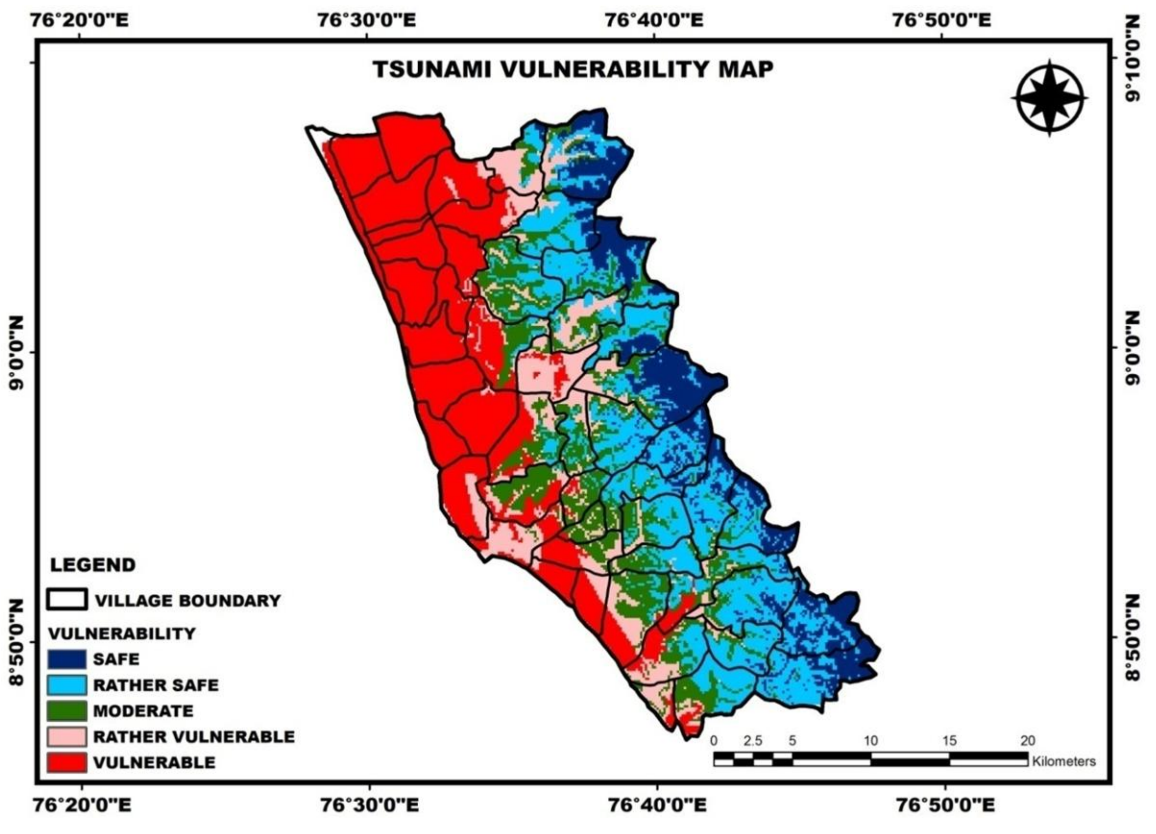

Fig. 8. Tsunami vulnerability map

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