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# Tsunami vulnerability assessment mapping for the west coast of Peninsular Malaysia using a geographical information system (GIS)

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**Abstract.** The catastrophic Indian Ocean tsunami of 26 December 2004 raised a number of questions for scientist and politicians on how to deal with the tsunami risk and assessment in coastal regions. This paper discusses the challenges in tsunami vulnerability assessment and presents the result of tsunami disaster mapping and vulnerability assessment study for West Coast of Peninsular Malaysia. The spatial analysis was carried out using Geographical Information System (GIS) technology to demarcate spatially the tsunami affected village's boundary and suitable disaster management program can be quickly and easily developed. In combination with other thematic maps such as road maps, rail maps, school maps, and topographic map sheets it was possible to plan the accessibility and shelter to the affected people. The tsunami vulnerability map was used to identify the vulnerability of villages/village population to tsunami. In the tsunami vulnerability map, the intensity of the tsunami was classified as hazard zones based on the inundation level in meter (contour). The approach produced a tsunami vulnerability assessment map consists of considering scenarios of plausible extreme, tsunami-generating events, computing the tsunami inundation levels caused by different events and scenarios and estimating the possible range of casualties for computing inundation levels. The study provides an interactive means to identify the tsunami affected areas after the disaster and mapping the tsunami vulnerable village before for planning purpose were the essential exercises for managing future disasters.

## 1. Introduction

The earthquake has triggered giant tsunami and the tsunami waves that propagated throughout the Indian Ocean caused extreme inundation and extensive damage, loss of property and life along the coasts of 12 surrounding countries in the Indian Ocean. The loss of lives also extended to the people from a total of 27 countries from other parts of the world. The number of casualties and missing person from the countries bordering Indian Ocean [1] is given in Table 1. The tsunami waves arrived at the North of Sumatra coastline in half an hour. The waves reached the coasts of Thailand, Sri Lanka, India and Maldives within hours and also arrived at Somalia in Africa, some hours later. The number of casualties and missing people are listed in Table 1 [1] and Figure 1 shows the recent earthquakes along the subduction zones had generated tsunami events (USGS). The total number of death toll in the list shows that this tsunami has been the most destructive ever experienced in human history. Because of its exceptional character, it is clearly seen that, the magnitude of North Sumatra Earthquake has not only triggered a tsunami and cause damage and loss of lives but also shaken the psychology, social life, scientific considerations, understanding of the hazards and priorities of mitigation measures in the region. This event will remain as the most important item on the agenda of assessment of natural hazards in the long run [2].

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**Table 1.** The number of casualties and missing from the Country Bordering Indian Ocean.

| Country | Dead | Missing |
|---|---|---|
| Indonesia | 125,598 | 94,574 |
| Thailand | 5,395 | 3001 |
| Sri Lanka | 30,957 | 5,637 |
| India | 10,749 | 5,640 |
| Myanmar | 61 | - |
| Maldives | 82 | 26 |
| Malaysia | 68 | 1 |
| Somalia | 298 | - |
| Tanzania | 10 | - |
| Bangladesh | 2 | - |
| Kenya | 1 | - |
| TOTAL | 173,221 | 108,879 |

Understanding the dynamics of the Indian Ocean Tsunami will provide us with very valuable experience, knowledge and sense to develop a better defense against natural hazards.

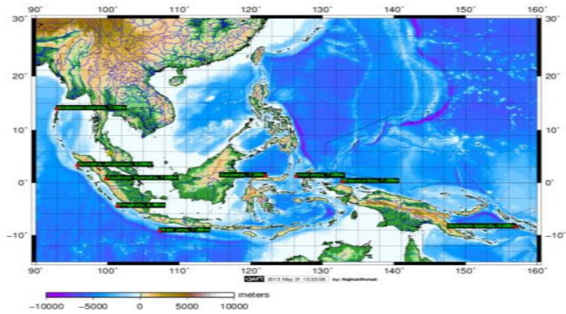

**Figure 1.** Epicenters of the recent earthquakes that generated the tsunami event.

## 2. Tsunami generation and propagation

Tsunamis are generated by submarine earthquakes, volcanic eruptions or landslides. Such submarine geological process produces water surface disturbance, or the tsunami source, which propagates toward the coasts. "Tsunami" is a Japanese term, meaning "harbor wave". A tsunami is usually small in Deep Ocean, but becomes larger and more dangerous toward shallow water and causes coastal damage. Tsunami propagation in Deep Ocean is rather simple; the velocity depends only on water depth. Once the initial condition, or the tsunami source, is known, the propagation and coastal behavior can be modeled by computer simulation.

### *2.1. Tsunami generation by earthquakes*

The earth's surface is divided into a dozen of tectonic plates which move each other. In the source area of Sumatra-Andaman earthquake, the Indian plate is sinking beneath the Burma microplate at a rate of about 5 cm per year. This subduction causes the upper plate to be dragged and deformed up to a certain limit. When the strain reaches the limit, the two plates are rebound to cause an earthquake. This motion, called faulting, is the mechanism of an interpolate earthquake, and largest earthquakes in the world occur in subduction zones. While the epicenter of the December event was located west of Sumatra Island, the aftershock zone extended through Nicobar to Andaman Islands; the total length of the fault is more than 1,000 km. The fault parameters can be estimated from seismological analysis. The product of fault length, width and slip, as well as rigidity near the fault, is known as seismic moment, and indicates the physical size of the earthquake source.

Once the fault parameters are known, seafloor displacement, which becomes the tsunami source, can be computed by using the elastic theory of dislocation. Recent seismological developments, both in theory and observation, make it possible to estimate the earthquake source parameters within minutes after large earthquakes and utilize it for the tsunami warning purposes. In addition, tsunami data, such as waveforms recorded on tide gauges, run-up heights measured by field surveys, damage data described in historical documents and tsunami deposits, are used to study the tsunami sources.

### *2.2. Tsunami propagation*

Tsunamis are considered as a shallow water, or long, waves. Depending on the relation between wavelength and water depth, water waves can be classified as shallow water (or long) wave or deep water (short) wave. The Indian Ocean or Andaman Sea is deep, up to 4,000 m or 4 km, but the wavelength of seafloor deformation is an order of 100 km, much larger than the water depth. Hence we can use the shallow water approximation for tsunamis generated from earthquakes. One of the characteristics of the shallow water is that the wave velocity is given as a square root of $g$ times $d$, where $g$ is gravitational acceleration, 9.8 m/s2, and $d$ is water depth in meters. If $d$ is 4,000m, the velocity is about 700 km/h. For shallow water, at 40 m, the velocity is about 70 km/h.

## 3. Tsunami observations

To document the 2004 tsunami, many scientists and engineers from all over the world visited the affected coasts. The measured tsunami heights in Sumatra Island, particularly around Banda Aceh, were mostly larger than 20 m with the maximum of 30 m. The tsunami heights along the Andaman Sea coast were highly variable; 5 to 15 m in Thailand but less than 3 m in Myanmar. The tsunami heights were up to 5 m on India's Andaman Islands. In Sri Lanka, the tsunami heights were 5 to 15 m. The tsunami height distribution is consistent with the damage distribution, and indicates that the source of the large and damaging tsunami was concentrated in the southern 700 km section of the aftershock zone. In Figure 2, the overall view of tsunami affected areas along the west coast of Peninsular Malaysia is shown.

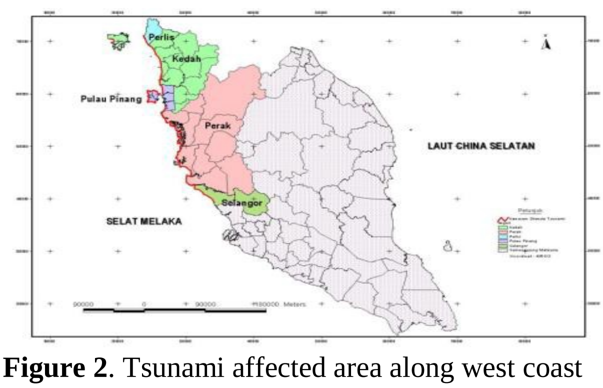


**Figure 2**. Tsunami affected area along west coast of Peninsular Malaysia (JPS, 2005).

## 4. Methodology

Vulnerability analysis is also known as vulnerability assessment. It is the process that defines, identifies, classifies and prioritizes the vulnerabilities in a system. Furthermore, vulnerability assessment can evaluate and predict the effectiveness of the proposed measures after they applied. The methodology described here to examine the vulnerability of West Coast of Peninsular Malaysia to earthquake hazards using GIS technology, readily available data, and a field work. The approach is meant to identify, and possibly prioritized, issue or specific areas for further, more detailed engineering or benefit analyses. As such, many of the GIS layers are portrayed with ordinal rankings of very low, low, medium, high and very high. GIS based quantitative results are summaries of asset exposure and not loss estimates. While this study uses GIS technology to perform spatial queries and summarized data, jurisdictions lacking GIS technology can rely on the proliferation of online mapping applications to conduct analyses outline here. Finally, additional detail on the creation of each individual GIS layer can be found.

A GIS operates by using two types of data which is spatial data and attribute data. These data sets may then be combined in order to answer the questions being investigated. The spatial data of the study area have to be digitized from an original topographic map that will allow the user to identify individual buildings and open spaces were used as a base map. The spatial data relates to each individual open space, road and stream. The attribute data (the parameters) such as the population of identified from the agencies. Attribute and spatial data were input into the GIS in the form of multiple coverages. A major advantage of our approach relates to the very fine scale at which primary data have been collected. The data were collected during a ground based home to home, a survey about the past event and also we check the elevation of the study area to make sure it can join with the spatial data.

## 5. Geospatial data processing

### *5.1. Land use vulnerability*

We assigned to each land use class as Land Use Vulnerability, ranging from 1 to 5. Highest vulnerability scores are assigned to urban areas follow up with agriculture, forest and mangrove. Table 2 shows the land use classes and we employed from [4]. Figure 3 shows the vulnerability map of land use of our study area.

**Table 2.** Land use classes.

| Land Use Classes | Score |
|---|---|
| Urbanized area (high density) | Very high (5) |
| Urbanized area (low density) | High (4) |
| Agriculture, beaches, aquaculture pools, lake and fresh water | Medium (2) |
| Forest and mangrove | Very Low (1) |

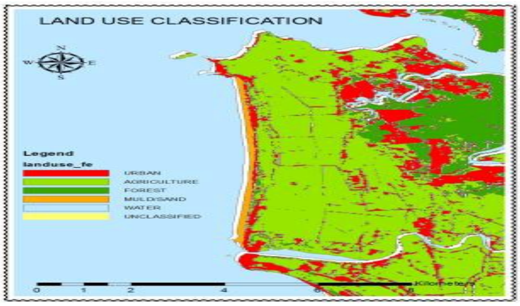


**Figure 3.** The vulnerability land use map.

### *5.2. Topographic elevation*

Topographic elevation is a primary condition to assess the tsunami vulnerability of a region. We used the Digital Elevation Model (DEM) from shuttle Radar Topography Mission (SRTM) to obtain the topographic elevation of the study area. The elevations were classified into five groups considering the tsunami run-up height at the coast (based on tsunami 2004). Table 3 shows the elevation vulnerability score and Figure 4 show the map of elevation vulnerability.

**Table 3**. Elevation vulnerability score.

| Elevation (m) | Elevation Vulnerability / Score |
|---|---|
| 0-5 | Very high (5) |
| 5-10 | High (4) |
| 10-15 | Medium (3) |
| 15-20 | Low (2) |
| >20 | Very Low (1) |

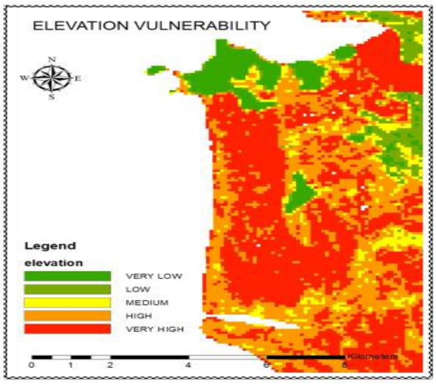


**Figure 4**. Map of elevation vulnerability.

*5.3. Distance vulnerability*

Distance from the coastline is associated with the possible reach of the tsunami. In general, vulnerability becomes higher when coastal distance decrease. Table 4 shows the distance vulnerability score while Figure 5 shows the vulnerability map of distance.

**Table 4.** Distance vulnerability from shoreline.

| Distance from shoreline (m) | Distance Vulnerability / Score |
|---|---|
| 0-100 | Very high (5) |
| 100-200 | High (4) |
| 200-300 | Medium (3) |
| 300-400 | Low (2) |
| 400-500 | Very Low (1) |

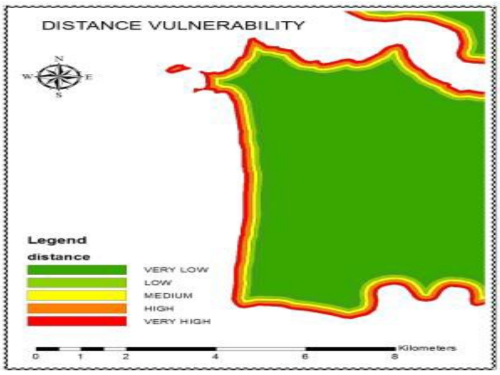


**Figure 5**. Map of distance vulnerability.

*5.4. Total vulnerability*

To integrate the three variable and produced tsunami vulnerability map, we intersect all the layers and calculate the total scores. Scores of 5, 3 and 1 were assigned to the categories high, medium and low respectively. Table 5 shows the scores of tsunami vulnerability assessment and figure 6 shows the tsunami vulnerability map of Kota Kuala Muda area.

**Table 5.** Total score.

| Total Value | Score |
|---|---|
| 11-15 | High |
| 6-10 | Medium |
| 3-5 | Low |

## 6. Conclusion

In this paper, we described a multi-criteria analysis of tsunami vulnerability at a regional scale using geospatial variables within a GIS. We combined 3 geospatial variables (elevation, distance, and land use) using GIS and create a tsunami vulnerability map of the West Coast of Peninsular Malaysia. Overlying the land-use classification on the tsunami vulnerability map showed that the urbanized area is particularly at risk if tsunami were to strike the study area. GIS analyses can be useful in a wide range of disaster assessment through the use of spatial functionalities such as topographic operation, buffer creation, raster reclassification and also intersection operations. Such approaches can aid in regional planning for management and mitigation of natural disaster, including tsunamis. However, such analysis can be limited by the availability of data necessary for estimating the risk of natural hazards.

## 7. Reference:

[1] AFP 2005 Death toll in Asian Tsunami Disaster

[2] Yalciner A C, Perincek D, Ersoy S, Presateya G, Hidayat R, Mcadoo B 2005 *Report on December 26, 2004, Indian ocean Tsunami, Field Survey*

[3] Jabatan Pengairan dan Saliran Malaysia 2005 *Laporan Penyiasatan Pasca-Tsunami 26 disember 2004*

[4] Dall'Osso D, Maramai A, Graziani L, Brizuela B, Cavalletti A, Gonella M, Tinti S 2010 Applying and validating the PTVA-3 model at the Aeolian Islands, Italy: assessment of the vulnerability of building to tsunami *Nat Hazard Earth System* SCI

[5] Stein S and Okal E A 2005 *Speed and Size of the Sumatra Earthquake, Nature* **434** 581-582

[6] Setyonegoro W 2009 *Tsunami Numerical Simulation Applied to Tsunami Early Warning System Along Sumatra Region*

[7] Satake K 1995 *Linear and Nonlinear Computation of the 1992 Nicaragua Eartquake Tsunami Pure Application Geophysics* **144** 455-470

[8] Hadibah I, Ahmad K A W, Ibrahim *2011Numerical experiments on tsunami propagation into the straits of Malacca*

[9] Satake K, Fuji Y 2006 The Asian Tsunami 2004: *Observation and Numerical Simulation Proceedings of the Eleventh Asian Congress of Fluid Mechanics*

[10] United State Geological Survey (USGS)

[11] United State Geological Survey (USGS)