SPATIAL ANALYSIS OF TSUNAMI THREAT LEVEL IN THE COASTAL OF JEMBER REGENCY, EAST JAVA, INDONESIA

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SPATIAL ANALYSIS OF TSUNAMI THREAT LEVEL IN THE COASTAL OF JEMBER REGENCY, EAST JAVA, INDONESIA

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Abstract– As the most vulnerable country for tectonic earthquakes, Indonesia is surrounded by 'ring of fire' from Eurasia, Indo-Australia and the Pacific plate. One of the most vulnerable areas in Indonesia is the coastal area of Jember Regency which is located in the south coast of Java. The development of mapping technology is one of the options in determining the location of disaster prone zones. The application of Geographic Information System based on technology combined with remote sensing data is one of computational media that can be used to determine tsunami threat level based on some physical parameters, thus producing new output in the form of thematic map. This study aims to determine the level of threat of coastal areas of Jember Regency against tsunami waves. Multi-criteria analysis based on Geographic Information System (GIS) and Remote Sensing (RS) to know the level of tsunami threat in Jember Regency, the researcher uses several geospatial variables from land elevation, land slope, coastal typology, morphology, distance from coastline, distance from river, land use, and terrestrial protection to build weighting schemes for geospatial variables. This paper reviews briefly the physical parameters (altitude, slope, coastal characteristics and distance from the coastline), as well as the determination of tsunami threat levels in Jember Regency based on spatial analysis. In general, Jember Regency has 4 districts that are highly threatened by the tsunami disaster. They include Kencong District, Gumukmas District, Puger District, and Ambulu District. While the other 2 districts of Wuluhan District and Tempurejo Districts possess low and very low threat levels.

INTRODUCTION

Indonesia as the most vulnerable country for tectonic earthquakes is surrounded by *'ring of fire'* from Eurasia, Indo-Australia and the Pacific plate, especially on the west coast of Sumatra, south coast of Java, along the south coast from the west and East Nusa Tenggara, northern Papua, Sulawesi and Maluku (Hartoko *et al.*, 2016). Indonesia ranks second as the country most frequently hit by the tsunami with 71 events or almost 9% of the total tsunami in the world. Underwater geologic processes produce surface water disturbances, or tsunami sources, which are spreading towards the coast (Najihah *et al.*, 2014).

Tsunami has a destruction effect to the settlements, severe coastal erosion, and injuries or even loss of life in disaster areas (Hart and Gemma, 2009). Therefore, a holistic approach on geology, geomorphology, ecosystem and potential risks and hazards from coastal areas is needed, since such an approach is essential for coastal policy makers / managers to decide on zoning in coastal areas such as for residential areas; development of industrial infrastructure; ecotourism or other uses (Hartoko and Helmi, 2005). Tsunami disaster should be examined carefully as many historical, industrial, and commercial structures are located near the coast (Aytore, 2016).

One of the most vulnerable areas in Indonesia is

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the coastal area of Jember Regency which is located in the south coast of Java. Based on its history, the Jember Coastal area experienced an Indian Ocean tsunami, in 1818, 1921, and 1994 (Supartoyo and Surono, 2008). The biggest impact of the tsunami that once hit the coast in Jember region occurred during the earthquake that accompanied the tsunami in Banyuwangi on June 3, 1994. The tsunami hit several beaches such as Sukamade Beach, Payangan, and Watu Ulo. This Jember Coast vulnerability to the tsunami disaster can be estimated from the depth of the epicenter of the earthquake with shallow depths located on the seabed around the coast (Maemunah, *et al.*, 2011).

Technological advances have not been able to anticipate exactly when each disaster comes (Priyowidodo and Jandy, 2013). Because the characteristic of the disaster is unpredictable, the only logical and rational choice is to make the impact of the disaster minimized (Baeda, 2010). One effort to minimize the impact of disasters is the use of remote sensing technology combined with geographic information systems for the creation of a tsunami hazard zone map.

Remote sensing, is a science to obtain information about the earth using sensing instruments, such as satellites that are useful for disaster management (Puturuhu, 2015). Satellite imagery offers accuracy, and almost often when a natural disaster strikes, remote sensing becomes the only way to see what is happening on the ground.

Geographic Information Systems (GIS) provides an appropriate platform for data acquisition and information management in tsunami disaster mitigation. This system can be used for a variety of disasters in its preventive phase, but that should be considered is the usefulness of geographic information systems in physical planning, for the mitigation phase (Erlingsson, 2005). In addition, Geographic Information Systems (GIS) provides an effective opportunity for detailed, detailed area investigations of possible impacts of these hazards (Wood and Good, 2004). If Geographic Information Systems and Remote Sensing are integrated, then each other can complement each other. The results of this blend can highlight the benefits of each system (Danoedoro, 1996).

Based on these, the assessment of coastal threat level in coastal Jember Regency needs to be done so that it can be used as an input in a planning in order to reduce to overcome the impact.

METHODOLOGY

This research area covered six districts in coastal area of Jember Regency East Java Indonesia, Kencong District, Gumukmas District, Puger District, Wuluhan District, Ambulu District, and Tempurejo District. Because of the 31 Districts in Jember Regency, these six Districts will experience direct impact if tsunami occurs. So the research of tsunami threat level of coastal area in Jember Regency is focused in six districts.

The data needed in this study is Digital Elevation Model (DEM) data from ALOS PALSAR with 12.5

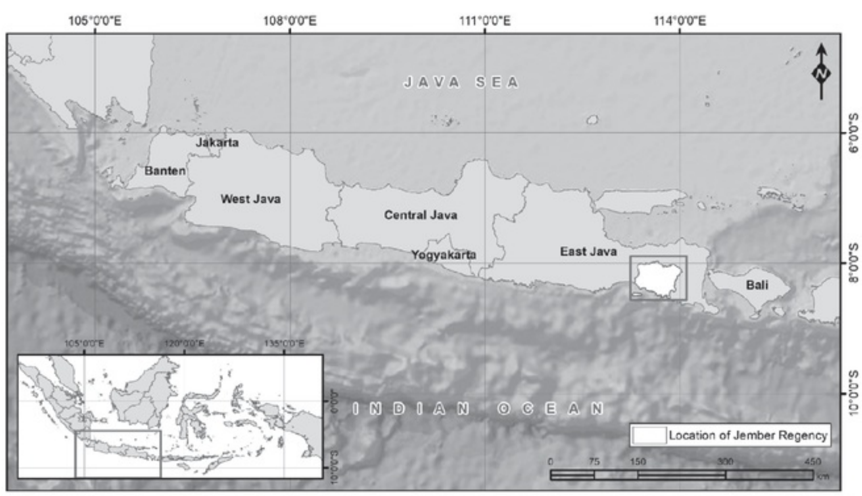

Fig. 1. Research location

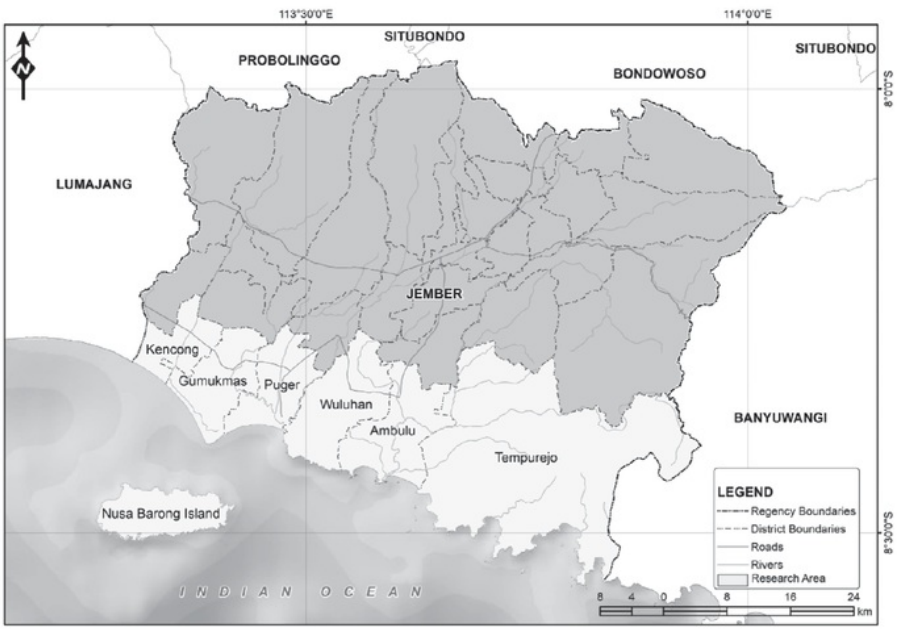

Fig. 2.. Focus of research area

meters' spatial resolution downloaded from www.vertex.daac.asf.alaska.edu/# as the basis for making elevation data and slope. High-resolution satellite images from Geospatial Information Agency (BIG) as the basis for creating coastlines, river networks, and land use. Spatial data processing using Quantum GIS which is Open Source (freeware).

Data processing of threat level parameters was done by utilizing GIS by means of blowing and weighting done on each parameter according to the magnitude of influence to the threat level of coastal area to tsunami hazard. The next step was to convert each parameter into a raster form. This was done because the raster data has a simple and easily manipulated data structure using simple mathematical functions.

$$LT = Elv + Sl + T + Lf + Ds + Dr + Lu + Tp$$

Where

- LT = Level of Threat
- Elv = Coastal Elevation
- Sl = Land Slope
- T = Beach Typology
- Lf = Geomorphology
- Ds = Distance from Shoreline
- Dr = Distance from Rivers
- Lu = Land Use
- Pi = Terrestrial Protection

RESULTS AND DISCCUSSION

Coastal Elevation

Tsunami propagation is strongly influenced by elevation of land. The lower elevation of the land will be increasingly vulnerable and cause very high damage. Conversely, higher land elevation will cause smaller vulnerability and less damage. DEM is essential for calculation of inundation in dryland and near-shore propagation. The terrestrial elevation was obtained from Digital Elevation Model (DEM) data of ALOS PALSAR satellite imagery which has a spatial resolution of 12.5 meters. Then, we grouped into five classes.

Table 1. *Tsunami* threat level in the terms of coastal elevation

Coastal Elevation	Score	Weight
< 5 Meter	5	0.125
5 - <10 Meter	4	
10 - <20 Meter	3	
20 - <30 Meter	2	
> 30 Meter	1	

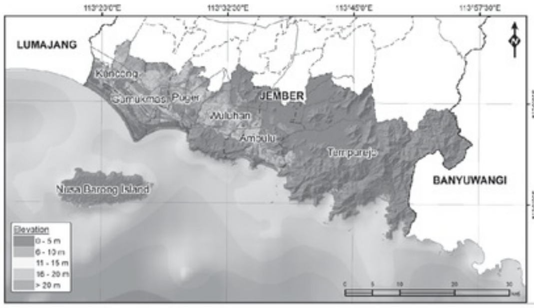

Fig. 3. Coastal elevation map

The result of DEM ALOS PALSAR data processing is known that the coastal area of Jember Regency is dominated with elevation class >20 meters with wide reaching 75,113.02 Ha or 69. 52%. While, the elevation class less than 5 meters with an area of 4,136.44 or 3.83% of the total area of coastal District in Jember Regency.

Based on the elevation map above, it is known that the coastal area of Jember regency, Wuluhan Distric, Ambulu District and Tempurejo Districts is dominated by high elevation (>20 meters), while Kencong, Gumukmas, and Puger Districts are more varied.

Seen from the point of view of elevation class of coastal area of Jember regency, specially Tempurejo and Wuluhan Districts tend to have lower threat level if compared with coastal located in Kencong District, Gumukmas District, Puger District, and Ambulu District. The existence of the highlands in Wuluhan and Tempurejo District (Figure 4) will be very useful for confronting the tsunami waves. Because with this Highland, the waves will be reflected back toward the sea.

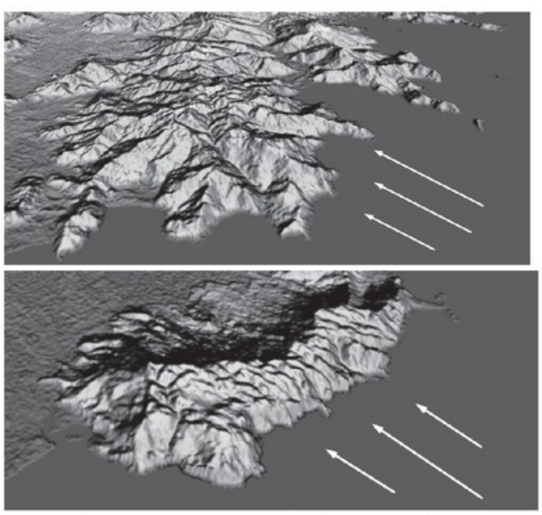

Fig. 4. Coastal elevation map in 3D terms of Tempurejo District (a) and Wuluhan District (b).

Land Slope

Slope of the land affects the impact of tsunami wave heights (run-up) on land. Steeper the slope, lower the tsunami wave height. Areas with sloping slopes are considered highly vulnerable while steep slopes are rated low risk (Kunte, *et al.*, 2014). This is because the steeper the land, the shorter the horizontal distance that the tsunami can take (Triatmaja, 2010).

The slope of the slope was obtained from the Digital Elevation Model (DEM) data processing of ALOS PALSAR satellite imagery using Quantum GIS (QGIS). Then, we grouped into five classes of altitude.

Table 2. Tsunami threat level in term of land slope

Land Slope	Score	Weight
d" 2 %	5	0.125
3 - 6 %	4	
7 - 13 %	3	
14 - 20 %	2	
> 20 %	1	

The slope of the coastal area of Jember Regency is dominated by elevation class >20% with the area reaching 42,329.49 Ha or 39.18%. While the slope class d"2% with an area of 10,067.2 Ha or 9.32% of the total area of coastal District in Jember Regency.

Viewed from the point of view of the slope class, the coastal area of Tempurejo District tends to have a lower threat level if compared to the others. In addition to Tempurejo District, Wuluhan District also has a low threat level, this is due to the existence of a class of >20% slopes facing directly to

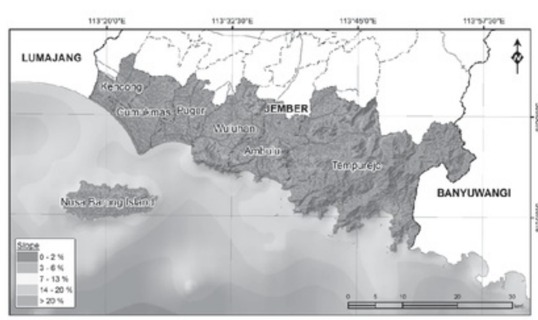

Fig. 5. Land slope map

the sea. While, four other Districts are Kencong District, Gumukmas District, Puger District (except Nusa Barong Island) and Ambulu District have higher threat level because it is more dominated by relatively flat slope class.

Beach Typhology

The winding coastline with some morphometry of the bay or cape certainly has a different impact with the straight coastline. The existence of the bay can be a means of energy concentration so that sea waves crashing towards the bay can have very strong energy. The coastal area with a V-shaped bay and lined up to resemble a sawtooth leads to a high tsunami wave (Diposaptono, 2008).

Table 3. Tsunami threat level in term of beach typology

Beach Typology	Score	Weight
Bay	5	
Sawtooth	3	0.125
Straight	1	

Typology data is obtained from observations of high-resolution satellite images. By utilizing this image beach typology will greatly facilitate researchers to perform identification. Visual observation results from satellite imagery data found that Jember Regency beach has three different types of typology, which include bay beach, serrated, and straight. Straight beach is located along the beach located in District Kencong, District Gumukmas, and District Puger. Jagged beaches are found in Wuluhan District, part of Tempurejo District, and most of the beaches are located on Nusa Barong Island (administratively in Puger District).

Based on the parameters of coastal typology, Ambulu and Tempurejo Districts have a high degree of threat, because these two districts have typology of bay beach and serrated. While the District Kencong, District Gumukmas, and District Puger possess a low level of threat.

Geomorphology

The shape of coastal morphology greatly affects the level of tsunami energy that will be slammed into the mainland. Tsunami wave energy will be greater if the coastal morphology supports for the strengthening of tsunami wave propagation to the mainland. The condition of coastal morphology is one factor that can influence the high run-up of tsunami waves when reaching the mainland (Yudhicara, 2008). As the tsunami waves crashing on land that has a flat morphology, the waves will easily enter further into the land area. But unlike when the waves that come to hit the land area with the morphology of hills and mountains, the waves will be broken and reflected so that the wave energy will be reduced.

Table 4. Tsunami threat level in term of geomorphology

Geomorphology	Score	Weight
Plain (Marine Plain, and Volcanic Plain	3	0.125
Hills (Karst Hills, Structural Hills, and Volcanic Hills)	2	
Mountains (Volcanic Mountains	1	

Geomorphological spatial data is obtained from ecoregion map made by cooperation between Ministry of Environment (KLHK), Geospatial Information Agency (BIG), Meteorology Climatology and Geophysics Agency (BMKG) and Indonesian Institute of Sciences (LIPI, 2010).

Analysis of geomorphological spatial data shows that coastal area of Jember Regency consists of 48.63% of plains (marine and volcanic plains), 24.68% hills (solution /karst, structural and volcanic hills) and 26.49% structural mountains.

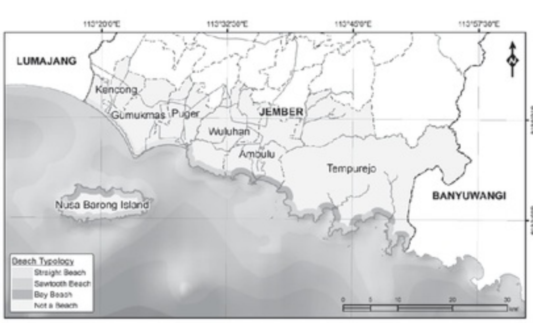

Fig. 6. Coastal typhology

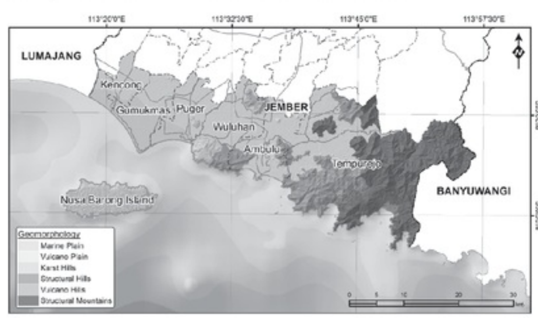

Fig. 7. Geomorphology map

The existence of hills and mountains, especially those on the beach such as those in Puger District, Wuluhan District, Ambulu Subdistrict, and District Tempurejo will be very useful to block the tsunami waves. Because with these hills and mountains, the waves will be reflected back toward the sea.

Distance from Coastline

Distance places from the coastline affect the level of threat in the event of a tsunami. The further distance from the shoreline the smaller the threat level, the closer the distance from the shoreline the higher the threat level will be (Mardiyanto, *et al.*, 2013). In general, the threat level becomes higher as the distance from the coastline approaches. Similarly, the opposite level of threat is lower with the distance from the shoreline. This is due to the further distance from the coastline; the strength of tsunami waves also decreases.

The distance class map from the coast is derived from visual observations of coastline based on high resolution satellite imagery. Then, we did the analysis of multiple buffer ring whose distance has been determined. We made it into five distance classes.

Table 5. Tsunami threat level in term of distance from coastline

Distance	Score	Weight
< 500 m	5	0.15
500 – 1,500 m	4	
1,500 – 2,500 m	3	
2,500 – 3,500 m	2	
> 3,500 m	1	

Distance from The River

The closer the distance to the river that is perpendicular to the shoreline will be vulnerable to tsunami waves, as tsunami waves if encountered by

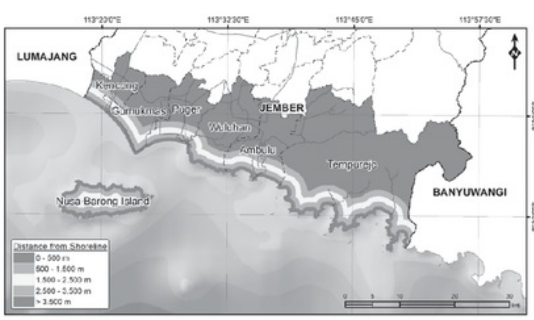

Fig. 8. Distance from coastline

the river can freely enter the land without any obstructions, thus damaging the objects in the river (Mardiyanto *et al.*, 2013). The distance class map from the coast was derived from visual observations (digits) of river networks based on high-resolution satellite images. Then, we did the analysis of multiple buffer rings whose distance has been determined to be five distance classes.

Table 6. Tsunami threat level in term of distance from rivers

Distance	Score	Weight
< 250 m	5	0.125
250 - 500 m	4	
500 - 750 m	3	
750 – 1,000 m	2	
> 1,000 m	**1**	

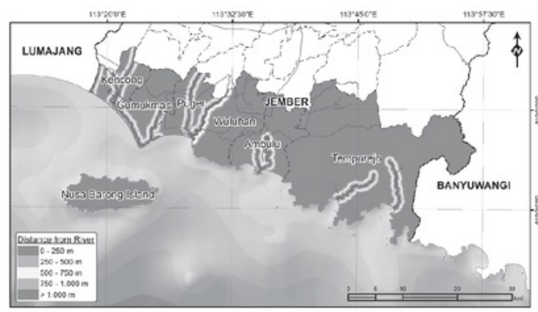

Fig. 9. Distance from the River Map

Based on the picture above can be seen that the distribution of rivers that are perpendicular to the beach spread throughout the coastal district of Jember regency. This will certainly increase the threat of tsunami waves. Because the river can be the entrance of waves to spread further into the land area.

Land Use

The type of land use in a region affects the rate (increase or decrease) of tsunami on land. The obstacles in the form of sturdy house buildings, trees, and infrastructure buildings that are able to survive the tsunami will be able to prevent the tsunami from rising to the mainland.

The baseline data to determine the type / variation of land use is obtained from high-resolution satellite image data. Techniques used to obtain land use data are delineated visually on screen on a given scale using the Quantum GIS open source software (QGIS). Purwadhi, *et al.* (2008) explains that image interpretation techniques manually have several elements, including: hue or color, shape, size, texture, pattern, shadow, site, and association.

High resolution satellite images are also used to obtain spatial data types / variations of land use that exist in the coastal district of Jember. Based on the results of the interpretation obtained 10 types / variations of land use in coastal Jember regency.

Table 7. Tsunami threat level in term of land use

Land Use	Score	Weight
Sand, Open Land	5	0.125
Field, Rice Field, and Shrubs	4	
Ponds	3	
Settlement	2	
Plantation, Forrest, Mangrove, and Mixed Garden	1	

Based on the result of delineation of high resolution satellite imagery know that coastal area of Jember Regency has dominant type of land use in the form of forest 52,914.73 Ha or 48.98%. The forest is spread over four districts namely Puger District, Wuluhan District, Ambulu District, and Tempurejo District. This is very good, because with the forest will be able to reduce the energy of tsunami waves so as not to get too far into the land area.

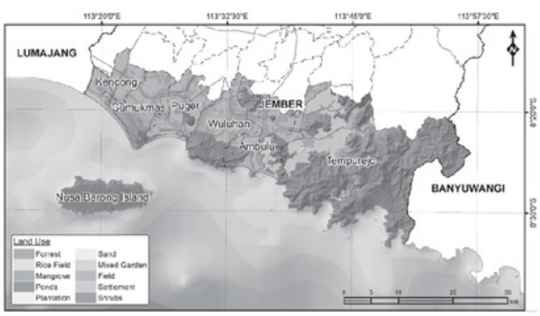

Fig. 10. Land use map

In contrast to Tempurejo District whose land use is dominated by forests, Kencong District, Gumukmas District, Puger District (excluding barong islands) is more dominated by land use in the form of agricultural land. Surely, this makes the area very threatened if a tsunami occurs because agricultural land is unable to block or inhibit the tsunami waves to enter the mainland.

Table 8. The area of each land use of Jember Regency

Land Use	Area (Ha)	%
Sand	959.64	0.89
Forrest	52,914.73	48.98
Mixed Garden	876.11	0.81
Field	5,056.65	4.68
Mangrove	6.43	0.01
Plantation	8,422.59	7.80
Settlement	15,904.26	14.72
Rice Field	22,286.20	20.63
Shrubs	731.24	0.68
Ponds	517.08	0.48

Source: Results of Satellite Deliniation Imagery High Resolution recording of 2015

Terrestrial Protection

The existence of islands or shallow areas capable of splitting tsunami waves. In other words, the coastal plains behind a back home will tend to be safer from the direct impact of the tsunami waves. Because the energy of the incoming wave into the land has been reduced due to crashing into the island in front of the main island.

Table 9. Tsunami threat level in term of land use

Terrestrial Protection	Score	Weight
Unprotected	5	0.1
Protected	1	

The map of terrestrial protection was obtained from the analysis of three different scenarios in the direction of different tsunami waves. So, we obtained four classes of terrestrial protection level that is class I, class II, class IV, and class V.

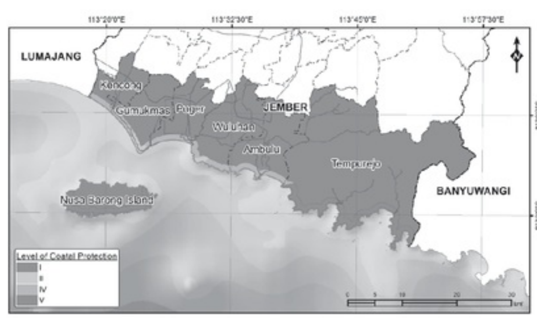

Fig. 11. Terrestrial protection map

Based on the results of analysis of the most unprotected areas are along the coast of P. Nusa Barong (Administratively District Puger) which is directly opposite the Indian Ocean. Then, those locations are in along the coast of Tempurejo District. This will cause the two areas to have a high degree of threat when compared to other areas.

Tsunami Threat Level

The results of data analysis of tsunami threat parameters such as land elevation, land slope, beach typology, coastal geomorphology, distance from coastline, distance from river, type of land use and terrestrial level of land acquisition resulted in a map of threat level to tsunami in coastal area of Jember Regency.

Based on the tsunami threat level map (Figure 12) analysis results can be seen that each district located in the coastal area of Jember Regency has a very varying threat level. Each district has a threat level ranging from very high to very low. It is known that each coastal district of Jember Regency has a very high threat level.

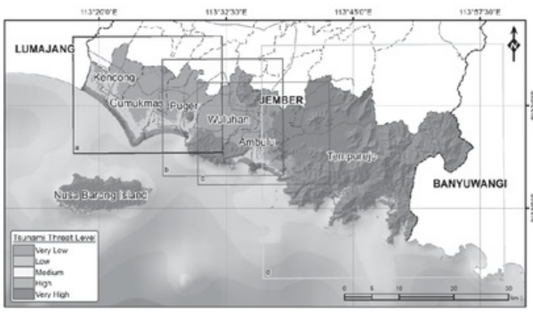

Fig. 12. Tsunami threat level map

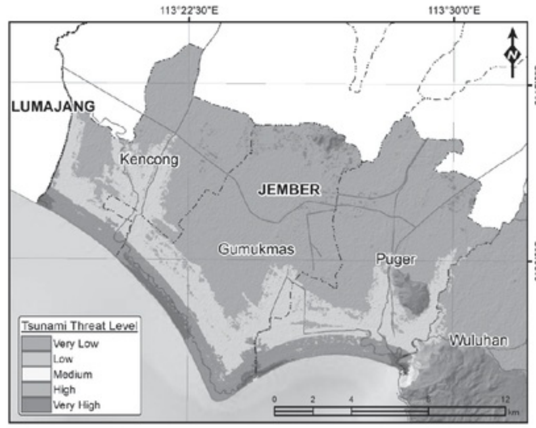

Fig. 12a. Variation of tsunami threat level in Kencong District, Gumukmas District, and Puger District.

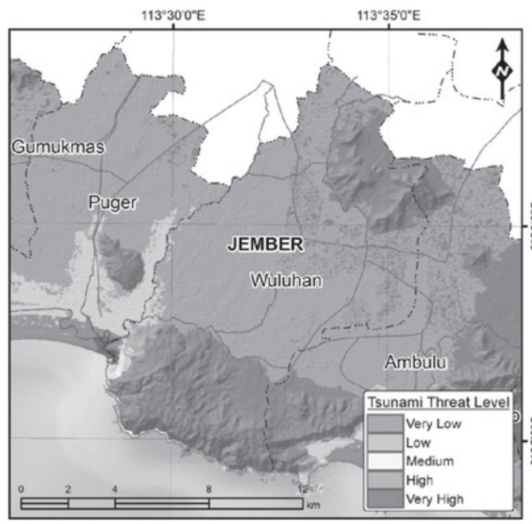

Fig. 12b. Variation of tsunami threat level in Wuluhan District

Three districts with similar threat characteristics are districts located in West Jember Regency covering Kencong District, Gumukmas District, and Puger District (excluding Nusa Barong Island). From Figure 12b, it is known that the threat level is very high around the estuary of the river located in each district (Bondoyudo River, Tanggul River, Getem River and Bedadung River).

The existence of rivers in these three districts greatly affects how far tsunami waves can reach deeper land. It can be seen in figure 12b that the threat level is reaching the land area up to ± 8.2 km in the river that borders between Puger District and Wuluhan District, and 7.1 km on the river which is in kencong. This proves that the presence of rivers affects tsunami threat levels in coastal areas.

Of these six coastal districts, Ambulu District has the largest distribution area of 312.3 Ha (Figure 11a), and Wuluhan District has the smallest distribution of 20.7 Ha. Ambulu District became the most threatened district to tsunami in Jember Regency. This can be seen from the large area that has a very high threat level. The threat is very high because Ambulu District has many factors that support the coastal area is dominated height <20 meters, the slope of the coastal land <13%, has a bay-type beach, the morphology of the plains (vulkanic plains), there are estuarine, land use in the form of Agricultural areas, As well as having a less sheltered land especially when tsunami waves come from the south, as well as from the southeast.

As for the distribution of the area with the lowest threat level is very large in Tempurejo districts that

Table 10. The width of each class of threat in the Coastal area of Jember Regency

District	Each class area of tsunami threat (Ha)				
	Very High	High	Medium	Low	Very Low
Ambulu	312.3	461.5	1,081.3	4,034.2	5,625.8
Gumukmas	280.7	972.4	2,037.5	5,671.3	296.1
Kencong	47.4	493.4	1,600.1	3,781.2	43.7
Puger	102.1	724.0	2,177.8	5,269.9	7,796.4
Tempurejo	27.8	440.1	795.6	1,084.3	50,481.9
Wuluhan	20.7	40.8	234.9	7,237.8	4,863.8
Total	791.2	3,132.5	7,927.2	27,078.8	69,107.6
(%)	0.7	2.90	7.34	25.1	63.9

Source: Analysis Results

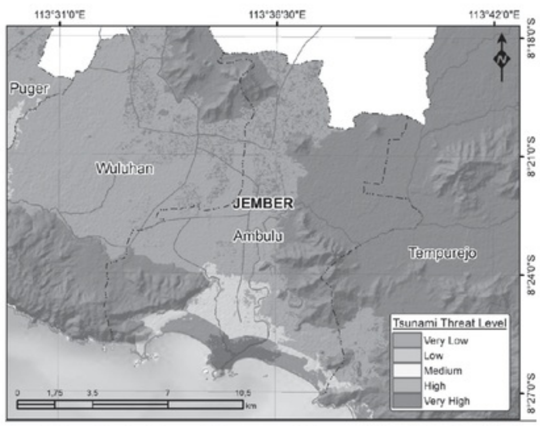

Fig. 12c. Variation of tsunami threat level in Ambulu District

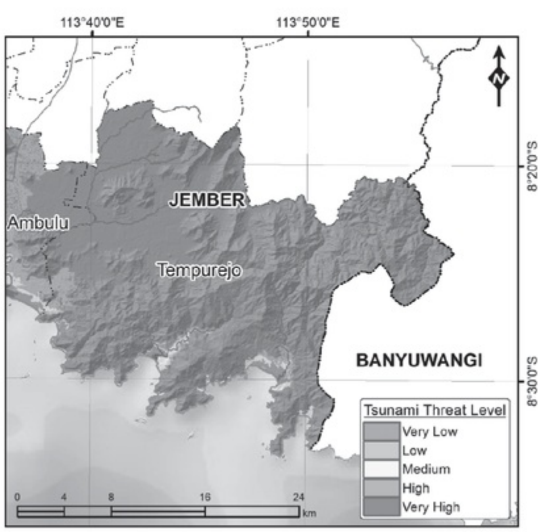

Fig. 12d. Variation of tsunami threat level in Tempurejo District.

reach 50,481.9 Ha, while the smallest is in Kecamatan Kencong is 43.7 Ha. The threat is very low because Tempurejo District has many factors that support the coastal area is dominated height >20 meters, the slope of the coastal land <30%, the morphology of hills and mountains (both structural and volcanic), land use in the form of forest areas,

CONLUSSION

In this paper, we have outlined a multi-criteria analysis to identify tsunami threat levels on a regional scale using geospatial variables. Combining eight geospatial variables (land elevation, terrain slope, beach typology, geomorphology, distance from coastline, distance from river, land use, and terrestrial protection) to create tsunami threat rate maps for Jember Regency.

In general, Jember Regency has 4 districts that are highly threatened by the tsunami disaster that are Kencong District, Gumukmas District, Puger District, and Ambulu District. While the other two districts of Wuluhan and Tempurejo Districts have low and very low threat levels.

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