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Fractal Analysis on the Correlation of Coastal Line Geometry and Tsunami Impact in Maumere, Flores, Indonesia

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Abstract. Almost all of the Indonesian territories are high potential of geologic disaster, such as earthquake, tsunami, volcanic eruptions and landslides, because the country belongs to tectonically active areas of the world. There are three big lithospheric plates interacting one with one another and influencing the tectonic setting of Indonesia. The plates are Indo-Australia plate, Eurasia plate and Pacific plate. Indo-Australia plate moves relatively northward by about 9 cm/year, Eurasia plate creeps south eastward with approximately 7 cm/year speed, and Pacific plate moves to the west with around 11 cm/year velocity. In the meeting line of the plates, about 300 km to the south of Indonesian islands, there is the subduction zone that become places, where earthquake focuses are generated. Earthquakes from submarine source with more than 6.5 magnitude have the potential to generate tsunami. Areas situated along the south coast of Indonesia islands are vulnerable to tsunami, because directly facing the boundary lines between Eurasia plate and Indo-Australia plate. This study verified that there is positive correlation between coastal line geometry and the tsunami impact, based on fractal analysis. The case study is Maumere, Flores island, East Nusa Tenggara, Indonesia. Result of the study is expected to be used for predicting the tsunami impact intensiveness at other areas.

Introduction

Most of the Indonesian territories are highly potential of geologic disasters, such as earthquake, tsunami, volcanic eruptions, and landslides, because the country is tectonically active. The tectonic setting of Indonesia is influenced by three main plate interactions. The plates are Indo—Australia plate, Eurasia plate and Pacific plate. The most sensitive places of Indonesia to tsunami are areas located in the southern coast of Indonesian islands, because they are directly facing the plate boundaries between Eurasian plate and either Indo-Australian plate or Pacific plate. The study was done in Maumere, Flores island (Fig. 1).

On 12th of December 1992 there was earthquake and tsunami disaster in Maumere and its surrounding areas, killing thousands people and damaging millions rupiah values of infrastructure. There was a phenomenon that coastal area with a specific shoreline geometry was more vulnerable to tsunami than others. Therefore, in order to assess the correlation of curve geometry of coastal line and the intensity of tsunami impact, this study was done by applying fractal analysis. Results of the study are expected to be used to predict the impact intensity of tsunami in other areas with similar coastal line characteristics.

Method of study

This study combined field geologic surveys and fractal analyses, utilizing both primary and secondary data.

Application of fractal analysis in this study is to quantify the coastal lines curve values in the study area. Despite prepared on desk while determining fractal dimension, field surveying was also done in order to acquire data on geological condition and tsunami impact including victims and damages. The secondary data on victims were derived from local government offices.

Fractal scaling system is specified by non-integer numbers so called fractal dimension (Bunde and Havlin, 1994). Determination of fractal dimension is important in practical quantification problems. It helps find out the correlation of fractal objects and processes working on them. In order to compute fractal dimension in this study, box-counting method was applied, done by drawing grids with certain length side (r) over the fractal objects. Then the fractal dimension (D) is determined using equation:

$$D = \lim_{r \rightarrow \infty} \frac{\log Nr(F)}{-\log r} \quad (1)$$

Where, $Nr(F)$ is the number of boxes that cover the fractal set (F), and r is the length of the box side. The computation of $Nr(F)$ is repeated by changing the length of the box side (r), so that r approaches zero. $Nr(F)$ values and r are plotted on a log-log graph to derive the fractal dimension, e.g., the slope of the plot (Tricot, 1996).

To obtain fractal dimension values, the shorelines along the study area were divided into 28 segments in Table 1. The division were based on their curve pattern similarity, obtained from topographic map of 1:25.000, and air



Fig. 1. Location of the study area.

Table 1. Segments of Coastal Line and Fractal Dimensions of Maumere, Flores.

District name	Location name	Segment number	D Box
Palue	P. Palue / Tepetetu - Natu	1	1
	P. Palue / Waraloo	2	1.02
	P. Palue / Wolo Manunai - Nitunglea	3	1
	P. Palue / Watupuli	4	1.02
Nita	Bt. Lipilongo - Fata	5	1
	Tg. Liatua	6	1.02
	Kalisia	7	1.09
	Wolo Nusakutu - Wolowarnokarua	8	1.02
	Wolowarnokarua - Wairii	9	1
Alok	Nangahure - Wailiti	10	1
	Bebeng - Kotauneng - Maumere	11	1.04
	Wairotang - Waioti	12	1
Kewapante	Waipare - Kewapante	13	1.01
Waigete	Nangahale - Wairita	14	1
	Wairita	15	1.02
	Waigete - Nangahalelama	16	1
Talibura	Nangahale - Wairmude	17	1
	Lemiwair	18	1.09
	Nangamerah-Langloeng	19	1.05
	Baukremut - Kabal	20	1
	Tanahdewa	21	1.13
Maumere	P. Babi	22	1.17
Paga	Iliwolokoli - Paga	23	1
Legebai	Bhera - Wara	24	1
Lela	Tiget - Sikka	25	1
Bola	Hokor - Waigete - Doreng	26	1
	Hebing	27	1,02
	Hebing	28	1,04

photos of tracing of 1:30,000 scales. The fractal dimension of every coastal line segment was then determined by box counting method. Next, values got from the fractal dimension computation were compared to field data and information, especially related to the impact of tsunami is ever happened.

Geology

According to USGS (2005) data, the relative plates motion of Eurasia is southeastward by 4 cm/ year, Indo-Australia is northward by about 7 to 9 cm/ year, and Pacific is westward by 11 cm/year. Eurasia plate meets Indo-Australia plate along the southern part of Sunda and Nusa Tenggara Islands from Sumatra, Jawa to Nusatenggara.

Flores island belongs to East Nusa Tenggara Islands. Shape of the island is unique, bordered by a rough geometric of coastal line, with some active volcanoes in the middle parts. Some of the volcanoes are Ili Lewotobi Laki-laki (1584 m), Ili Lewotobi Perempuan (1703 m), Keli Bara (1631 m), Keli Mutu (1640 m), Mount Iya (659 m), Mount Rokatenda (P. Palue, 875 m), and Egon Mountains in the eastern Flores with some highs of 1703 m and 1838 m above sea level.

The oldest rock formation of Flores is of Miocene age, consists of volcanic breccia, lava, basaltic to rhyolitic tuff sandstone. This rock unit is interfingered to Nangapanda Formation that consists of calcareous fine grain clastic sediments and limestones. The rocks are unconformably overlain by volcanic products of Pliocene to Quaternary. The youngest rock units are coral limestone, coastal terrace deposits, and coastal alluvium deposits (Suwarna, *et.al.*, 1990).

Nusa Tenggara islands including Flores are characterized by complex geologic structures. There are some faults formed from plates interactions, crosscutting Flores island generally striking northeast – southwest and northwest – southeast. They not only exist in the south but also in the north parts of the island. The transformal and thrust faults in the north part often create shallow destructive earthquake.

Flores earthquake and Tsunami, 12 December 1992

Tsunami is usually triggered by seafloor earthquake of more than 6.5 magnitude. When subducting plate breaks, resulting in crust deformation, there will be volumetric spatial change in sea water absorbed into the space of deformation. This causes in general the occurrence of tsunami. Later, there will be such a great wave come back to the shore with high velocity and destructive energy. This happens due to hydrostatic and hydrodynamic balancing to reach its stability.

Some coastal areas of Indonesia especially those facing the plate boundaries are vulnerable to tsunami (Fig. 2). Since 1901 to 2006 period, there were more than 75 great tsunamis in Indonesia, about 85% of them occurred in the eastern part of Indonesia, including Nusa Tenggara islands where Flores is located. Maumere even though situated in the north part of Flores, is not able to avoid tsunami risk. This is caused by some transformal faults as a result of interaction between Pacific plate, Eurasia plate, and Indo-Australia plate. The subduction and transformal faults control the existence of active faults striking northeast – southwest and northwest – southeast of Flores.

There was a tectonic earthquake followed by tsunami attacking Flores on Saturday, 12th of December 1992 at

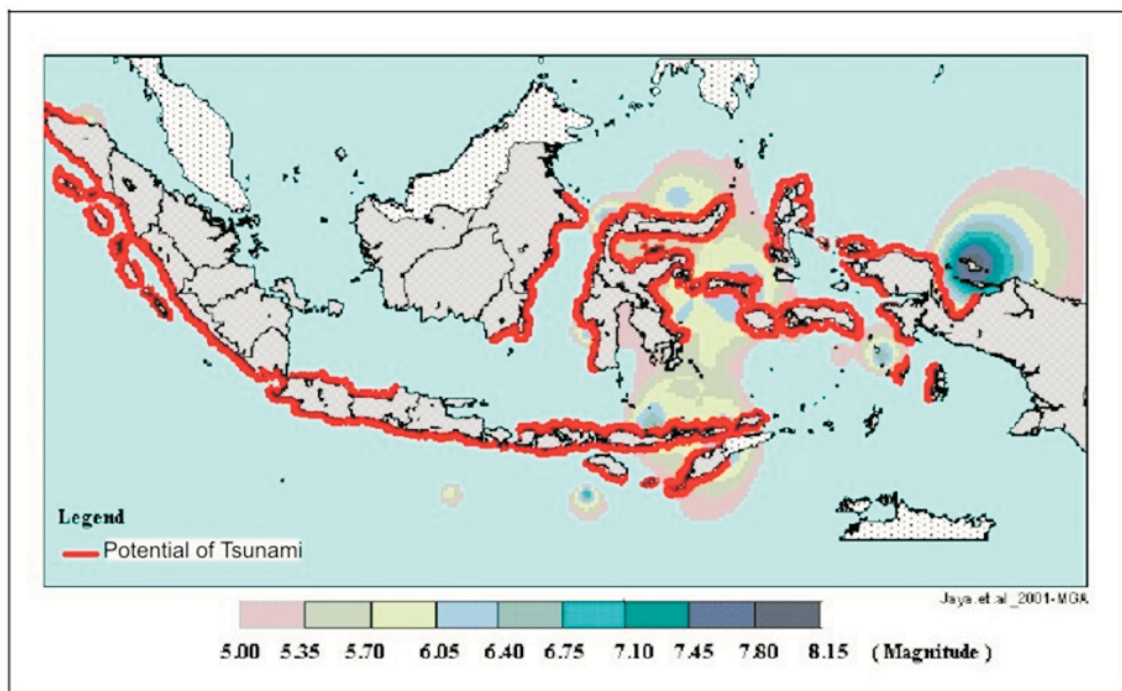


Fig. 2. Map showing coastal lines (red color) which are vulnerable to tsunami (<http://serc.carleton.edu>, 2005).

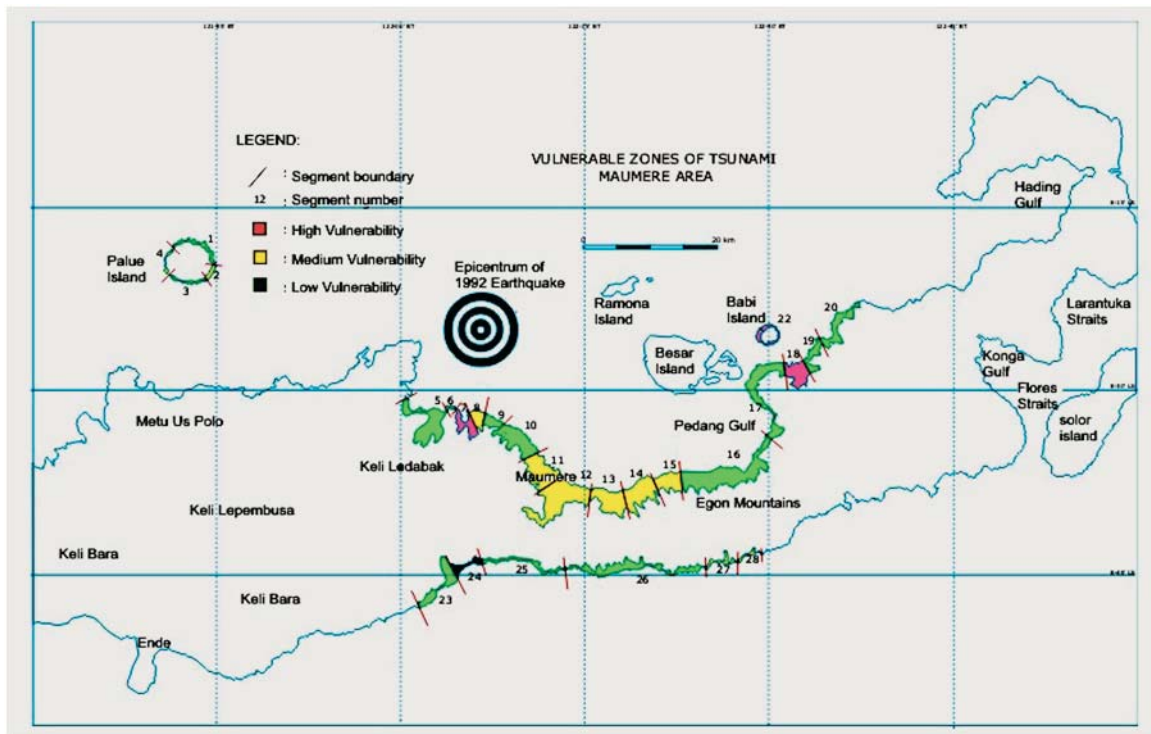


Fig. 3. Segments of coastal line and tsunami vulnerability of Maumere and surrounding area, Flores.

Table 2. Classification of Tsunami impact intensiveness

Class	Died (% of total population)	Injuries (% of total population)	Material lost (billions Rp)	Houses damaged (number)	Infrastructure damage (% of total existing)	Impact Seriousness Index
High	>25	>25	= 50	=1500	= 75	3
Medium	15 - 25	20 - 25	25 - 50	250 - 1500	50 - 75	2
Low	2 - 15	5 - 20	2- 25	50 - 250	25 - 50	1
Safe	0 - 2	0 - 5	= 5	= 50	= 5	0

13.30 pm local time. The disaster destructed Maumere, the capital city of Sikka region and Larantuka of east Flores region, were influenced by back arc tectonic activity along the north of East Nusa Tenggara islands. The tsunami killed 2080 people and damaged infrastructure of Sikka region (Satlak, 1994). Infrastructures destructed included houses, offices, schools, and many others. Thousands lost their houses and jobs.

According to the Board of Meteorology and Geophysics (BMG) of Kupang (2007), the earthquake source was located under the seafloor, on the coordinate of $8,42^\circ$ at south latitude and $122,10^\circ$ east longitude, at 36 km depth and 30 km distance from northern Maumere, with magnitude of 6,8 Richter scale; and 7,5 Richter scale. The earthquake then generated tsunami. The tsunami attacked about 300 m into the land area, with almost 10 m high wave. Wave height in the harbour was 4 meters (Kupang, 2007). The tsunami also beat the Babi island, north of Maumere (850 people died), Pamana island north of Flores, Kalautoa island of Selayar region, and south Sulawesi province

(killed 20 people, and damaged some buildings).

Results and Discussion

Indonesia belongs to a country with the longest shorelines and most potential of tsunami disaster on the world. According to Rahardjo (2005) coastal line configuration determines how serious the damage was caused by tsunami. Submarine geomorphology and bathymetry influence how strong and high the tsunami wave is coming to the beach. The morphology of the shores of Maumere, as like any other coastal area, there will be high potential when the coast has a gulf or fjords. Factors influencing the shape are lithology, geomorphology, and geologic structures of the area. Despite those geologic factors, exodynamic processes such as abrasion and coastal sedimentation also play important role. Curve of coast lines belong to fractal geometry. Ranges of fractal dimensions (D) of the coastal lines can be grouped into four, i.e. $D = 1 - 1,05$, $D = 1,05 - 1,1$, $D = 1,1 - 1,15$, and $D = 1,15 - 1,2$, (Table 1, Fig. 3).

Coast with fractal dimension > 1 is usually displaying fiord and embayment morphology, there is intensive sedimentation, and influenced by the existence of active faults. Comparing the values of fractal dimension of the coastal lines in the study area and the impact of tsunami in the past time, there is a positive correlation of fractal dimension value and the impact intensiveness (Table 2). The higher the fractal dimension of the coastal lines, the more serious the damage of the area, including the number of people died. Based on its intensiveness, tsunami impact on coastal lines correlated to their fractal dimension can be indexed as 0, 1, 2, and 3, and classified into four classes, e.g. safe, low, medium, and high (Table 3). There

is positive correlation between value of fractal dimension and the seriousness of tsunami impact. Impacts of tsunami Maumere 12 December 1992 were listed in the Table 3, while Figure 4 shows the correlation of fractal dimension of coastal lines in the study area and tsunami impact intensiveness.

Conclusion

1. Due to the tectonic setting of Indonesia, most of the southern coastal lines, which are facing the subduction zone of Indo-Australia plate and close to some transform faults have high potential for tsunami

Table 3. Fractal dimensions and Tsunami impacts.

Name of district	Fractal dimension	Number of human victims	Amount of Lost (billions Rp)	Infrastructure damages
Alok	1.04	1503	76.31	193.17
Maumere	1.17	918	59.35	190.14
Nita	1.02 – 1.09	174	48.42	249.21
Lela	1	93	9.45	174.13
Paga	1	35	7.07	149.56
Kewapante	1.01	109	11.05	239.14
Bola	1.02	51	5.4	185.96
Talibura	1.05 – 1.09	139	12.67	180.49
Palue	1.02	18	2.57	88.89
Waigete	1.02	8	5.79	152.12
Legebai	1	43	8.56	144.42

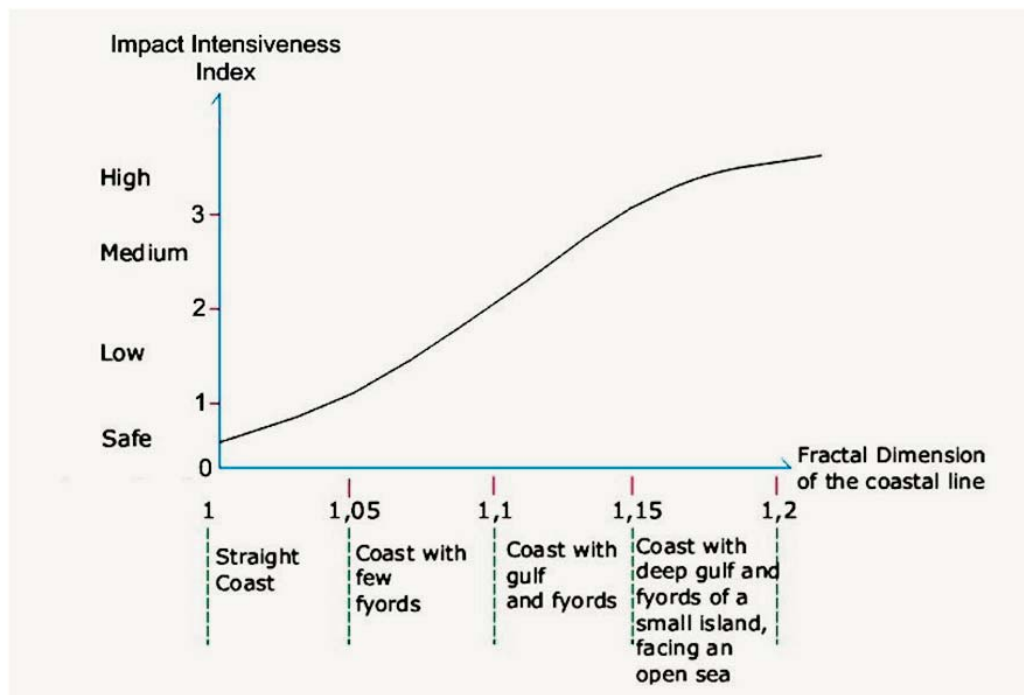


Fig. 4. Correlation of coastal line fractal dimension and tsunami impact intensiveness, Maumere, Flores

2. Tsunami destroyed Maumere and surrounding area in 1992, which was caused by back arc transformal fault movement triggered by the subduction activity of Indo-Australia plate beneath Eurasia plate.
3. Based on tsunami impact intensiveness and its fractal dimension, coastal lines in the study area can be classified into “safe” with fractal dimension 1 – 1.05, “low” with fractal dimension 1.05 – 1.1, “medium” with fractal dimension 1.1 – 1.15, and “high” with fractal dimension > 1.2
4. There is a positive correlation between the fractal dimension value of the coastal lines geometry and impact intensiveness of tsunami in Maumere area. Higher the fractal dimensions of the coastal line geometry, the more serious is damage to the area by tsunami.

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