Tsunami Inundation Hazard Mapping as Monitoring and Conservation Assessment in Parangtritis Coastal Area, Indonesia

インドネシアも地震の多発地帯だ。2006年の津波は多大な被害をもたらした。未来の被害を減免するためにハザード・マップを作る。

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Abstract An enormous earthquake-generated tsunami occurred in southern coastal Java on 17 July 2006. Tsunami waves reached the coastal area of West Java, Central Java, and Yogyakarta. The southern part of Java is characterized by a high potential tsunami hazard. Parangtritis is located in the southern coastal area of Bantul District, Yogyakarta Province (Java Island). This area is considered a highly vulnerable area due to tsunami. Sand dunes in the Parangtritis area function as a barrier against the threat of tsunami hazards. The problem of this research is some stakeholders did not pay attention to sand dune conservation as a barrier of tsunami hazard. To minimize loss material, it is necessary to have a barrier for minimizing tsunami impact such as sand dune which can be determined by considering tsunami hazard zones. This research is aimed at detecting the changing of actual sand dune conditions using a remote sensing application and simulate the tsunami inundation hazard impact (Scenario direction wave: southwest, southeast, south and west & elevation scenario wave: 5 m, 10 m, 15 m, 20 m, 25 m and 30 m). The inundation zone due to tsunami would be determined using the predicted water depth scenario. This study intends to identify the inundation zone of the hypothetical water-depth scenario, quantify what the impacts of the inundation of sand dunes are and also detect sand dune actual zone with topography detail scale. The final product of this research is production of a sand dune conservation management map.

Keywords Tsunami; Sand dune; Hazard map; Coastal; Conservation

Introduction

Indonesia is one of the most vulnerable areas due to natural disaster, because it is close to the collision area of the three main tectonic plates in the world. Due to tectonic setting, Jave Island is very vulnerable to tsunami disaster. According to the catalogue for tsunamis in the Indian Ocean, which includes tsunamis, 80% of the tsunamis are from the Sunda arc region, where on an average, tsunamis are generated once in three years with different scale events.[1)] This island is in the outer arc of volcanic belt, which has the same conditions as Aceh. In 2006, the tsunami happened in the southern part of West Java which shifted to the east. The effect is that the entire southern part of coastal zone in Java was affected by tsunami. The sea of the South Coast Bantul Regency has the potential to cause a tsunami, because there is a subduction zone between the Indian Plate and Eurasian Plate. This zone is a potential zone for earthquakes and tsunami.

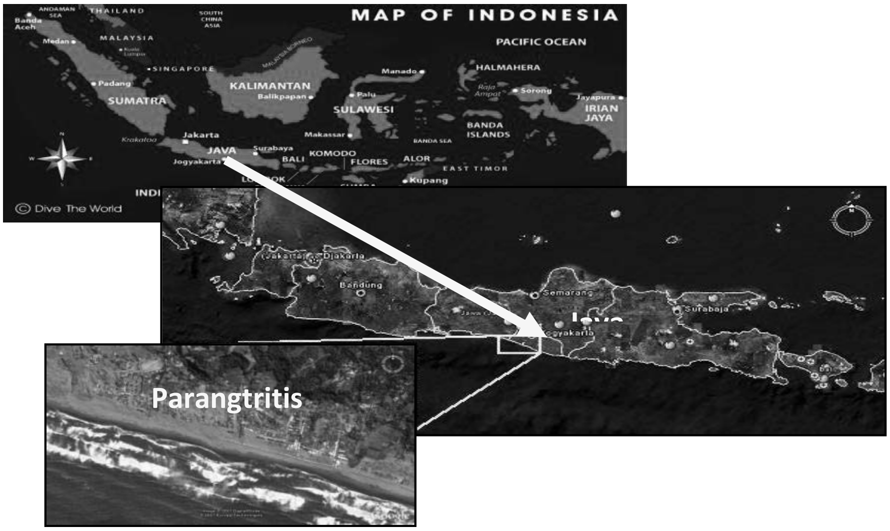

Fig. 1 Parangtritis Coastal Area

Although an infrequent disaster, tsunamis have been recorded as destructive disasters that caused great losses of life and extensive damage. The largest tsunami disaster was caused by the Krakatau Volcano in 1883, in which waves of 38 meters in height and a 2.5 kilometer trough inland was recorded on both Java and Sumatra islands. The second one occurred in 2004 caused by a huge earthquake (9.1 on the Richter scale) and was recorded as the biggest earthquake since 1900. This earthquake generated tsunami waves more than 30 meters in height and traveling 4 kilometers inland, destructing all the buildings and houses.

Coastal areas are dynamic and constantly changing.[2] Change in the coast of Indonesia consists of short-term, medium-term and long-term changes that can be seen as various kind of natural hazards, gradual or intermittent advance or retreat shoreline and those such as land uplift of subsidence or sea level rise and fall. The southern part of the coastal zone of Parangtritis has an unique sand dune phenomena. Sand dunes in this area are considered to be the only sand dune in Southeast Asia. Sand deposits in Parangtritis consists of beach sand and sand dune.

The Parangtritis area directly faces the Indian Ocean. The beach is sandy gray and has a view of the hills in the East and North and sand dune in the western part are of barchan type. These conditions make the area around Parangtritis a very popular tourist spot which is crowded during the holidays, especially the school holidays. Moreover, Parangtritis is one of the most important tourist attractions because this beach provides a beautiful panorama and also because it is a sacred place. These activities make Parangtritis highly vulnerable to the impact of the tsunami when we consider that there are many buildings in the coastal area only a few meters from the coastline and the area is relatively flat.

The Parangtritis area is located on the South Coast of the Java subduction zone directly facing the Indo-Australian Plate and Eurasian Plate. Based on a review of the literature, the threat of natural disasters that may lead to disaster with strength and great damage originate from earthquakes generated in the second subduction zone plate located in the Southern part of Java. On 17 July 2006 a tsunami occurred in the southern coastal area of Java. Heavy damage occurred in Pangandaran, one of the most preferred areas for tourism in Java. The Indonesian Ministry of Health reported that more than 600 people died, more than 60 were missing, and more than 9200 required treatment as a result of the disaster.[3] The

Table 1 Tsunami Record Indonesia

Year	Magnitude	Victims (Dead/Injured)	Location
1883	Volcano	36000	Krakatau
1961	-	2/6	NTT, Flores Tengah
1964	-	110/479	Sumatera
1965	7.5	71 Dead	Maluku, Seram, dan Sanana
1967	5.8	58/100	Tinambung (South Sulawesi)
1968	7.4	392 Dead	Tambo (Center Sulawesi)
1969	6.9	64/97	Majene (South Sulawesi)
1977	-	316 Dead	NTB and P. Sumbawa
1977	8	2/25	NTT, Flores, and P. Atauro
1979	-	27/200	NTB, Sumbawa, Bali, and Lombok
1982	-	13/400	NTT, Larantuka
1987	-	83/108	NTT, East Flores, and P. Pantar
1989	-	7 Dead	NTT and P. Alor
1992	7.5	1952/2126	NTT, Flores, P. Babi
1994	7.8	38/400	Banyuwangi (East Java)
1996	8	3/63	Palu (Center Sulawesi)
1996	8	107 Dead	P. Biak (Irian Jaya)
1998	-	34 Dead	Tabuna Maliabu (Maluku)
2000	-	4 Dead	Banggai, Center Sulawesi
2004	9.1	> 200000	NAD and Nort Sumatera
2005	-	-	P. Nias
2006	7.7	665	South Java

*Source: Diposaptono & Budiman,2006[1)]

tsunami was triggered by a 7.7 earthquake located 220 km from Java Island. This tsunami caused damage to infrastructure, land use and agricultural area including paddy field.

A remotely sensed approach in combination with the Geographic Information System (GIS) might be more useful for establishing the spatial extent of potential hazard inundation as well as to calculate the spatial agricultural damage over large areas.[4)] Nowadays, the technology of the satellites images is increasing rapidly in terms of the technology development and technology application. As an example, data acquired by satellite sensors for land use determination, especially at coastal agricultural land use, is becoming an increasingly important source of information for precision farming. A hyperspectral sensor such as IKONOS has dramatically increased spatial, spectral, and temporal frequencies that make them appealing to applications in precision agriculture and non-agriculture land.

However, due to the large synoptic view provided and reasonable spatial resolution, the Landsat and ALOS satellites are also of equal importance in precision farming. Remote Sensing Approaches for coastal morphology have developed rapidly in the last 2 years. Based on the Landsat ETM and DEM data derived by SRTM, ASTER and ALOS of the coastal area produced spatial information in order to represent the coastal morphology.[5)] Digital Image Processing methods used to produce hill shade, slope, minimum and maximum curvature maps based on SRTM DEM contribute to the detection of morphologic traces. These maps combined with Landsat ETM and seismo-tectonic data in a GIS database allow the delineation of coastal regions can be useful for tsunami analysis.

This paper reports the results of an assessment of the impact of tsunami inundation for a coastal segment of Parangtritis-Bantul, south of the Java coastal area in Yogyakarta Province, Indonesia. This study has been undertaken for three reasons: (1) The south of Java coastal area is one of the most vulnerable areas due to tsunami and has been identified as an area at risk of future tsunami occurrence[6)]: (2) This research will detect sand dune zones in Parangtritis; (3) The local government is willing to formulate a local action plan for disaster risk reduction, and our results would provide valuable data to support the governmental program. Furthermore, to our knowledge, coastal land-use planning in general fails to consider the potential role of the extreme hazards facing the coastal area.

Sand dunes in Parangtritis area have a function such as a barrier to the threat of tsunami hazard.

Nowadays, the sand dune condition in Parangtritis is not ideal as a result of human activities in surrounding Parangtritis area such as sand being affected by very intensive river tailing. As a result, sand dune material supply is insufficient to make an ideal sand dune in Parangtritis. Furthermore, the presence of settlement area affects the sand dune development. Many people in Parangtritis do not pay enough attention to protecting the sand dune area. If sand river tailing activity increases, it can cause sand dune condition to deteriorate. The problem raised in this research is the lack of awareness of local government towards the sand dune conservation. The functional decline of sand dunes increases the risks in this area.

Methodology

The inundation zone due to tsunami would be determined using the predicted water depth scenario. This study intends to identify the inundation zone of the hypothetical water depth scenario and detect sand dune areas. Unfortunately, we exclude the physical mechanisms or hydrodynamic characteristics of tsunami during generation, propagation, or inundation. Moreover, we do not consider factors such as tsunami source region and coastal configuration during inundation. Due to the lack of data and information pertaining to the detailed scale of the bathymetry on the study area and taking into consideration that obtaining such data could be time consuming and very expensive, this study also ignores the bathymetry of the seabed for identification of the inundation zone. The formulation of tsunami inundation wave simulation is as follows.

The relationship between the height of the tsunami, the coefficient of roughness, and distance towards land was formulated as follows:

$$X_{max} = \frac{0.66H_0^{4/3}}{n^2} \qquad (1)$$

Where:

X_{max} : Maximum distance the tsunami travels on land from the shoreline;

H_0 : Height of waves at the shoreline;

n : Roughness coefficient (0.015 to 0.07)

Calculating the loss per 1 m wave height can be done with the derivative of equation 2 thus obtained to lose altitude to 1 m of the run-ins as shown in equation 3. Berryman.[7)]

$$\frac{dH}{dX} = \frac{12Sn^2}{H_0^{2/3}} \qquad (2)$$

To follow the condition of the surface which has a surface height variation, equation 2 is modified by entering a determining factor as to lose altitude slopes of the tsunami as shown in the following equation formulated by Berryman.

$$H_{loss} = \left(\frac{16.7n^2}{H_0^{1/3}}\right) + 0.5\sin S \qquad (3)$$

Where:

Hloss : Losing altitude for the 1 m distance tsunami propagation

n : Roughness coefficient

H_0: Initial height of the tsunami on the coastline

S : Surface of slope

The correlation between the speed of the tsunami on the mainland can be formulated as shown in the following equation:

$$u = \sqrt{2gh} \qquad (4)$$

Where:

u : Wave velocity

g : Gravitation velocity

h : Depth of inundation

Equation 4 shows that the velocity is proportional to the height of the tsunami inundation. The tsunami in the Parangtritis area is simulated by making a model with several scenarios; 5 m, 10 m, 15 m, 20 m, 25 m and 30 m with different direction wave (West, South and Southwest wave direction). Those variations were to represent the scenarios that are possible on the south coast of Java, on field measurement reported that along the south coast of

Java between Batukaras and Baron the measured run up heights (RU) ranged from less than 1 m to 15.7 m. Since run up elevation is an independent variable, the additional data to solve that equation are slope and roughness coefficient from land use map. The surface roughness coefficient can be shown in Table 2.

The process from DEM can generate a slope map as below. The slope obtained by topographic map from the National Coordinating Agency for Surveys and Mapping in Indonesia (Bakosurtanal). The operation used is raster operation by using Ilwis 3.3 software. Sand dune conservation zone mapping will be correlated with coastal regulation zone in the Parangtritis coastal area. Determination of the conservation zone has purpose to optimize sand dune function as a barrier against tsunami inundation hazard. Figure 2 shows flowchart research design.

Table 2 Land use Roughness Coefficient

No	Landuse	Roughness Coefficient
1	River	0.007
2	Sand dune	0.018
3	Swamp forest	0.025
4	Dense forest	0.070
5	Bush	0.040
6	Plantation	0.035
7	Dry land	0.030
8	Built-up area	0.045
9	Rice field	0.020
10	Barren land	0.015

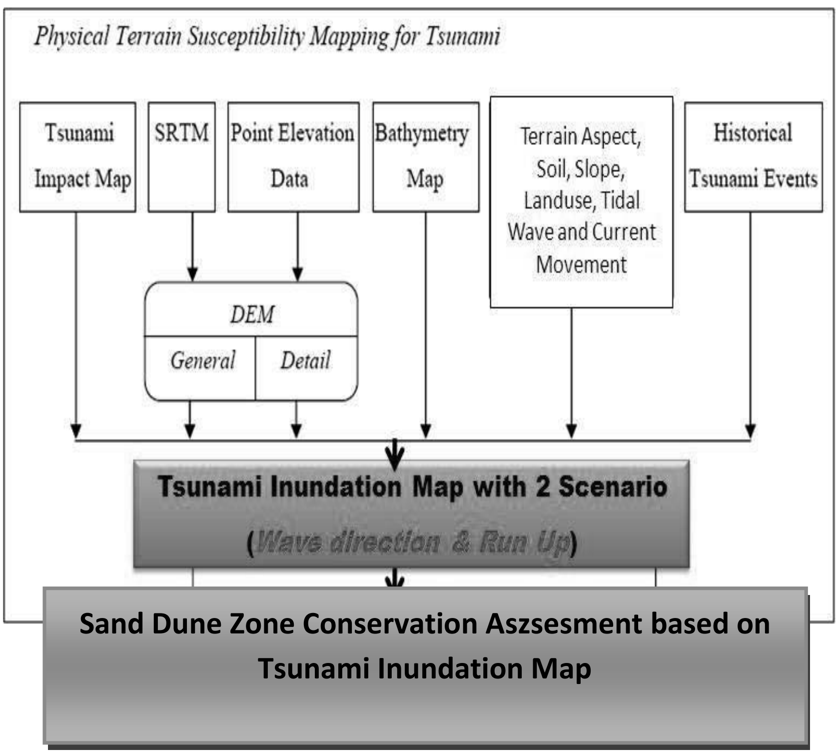

Fig. 2 Flowchart Research Design

Results

Tsunami Inundation Hazard Scenario Simulation Map

Tsunami inundation hazard map is simulated by calculating the propagation of inundation per pixel by considering the slope, surface roughness coefficient, wave direction and wave height variations. Inundation models are generated based o n roughness coefficient parameter, the wave per meter of inundation distance and slope in study area. These parameters are then used to calculate inundation of land. Delineations of land use are used to determine surface roughness coefficient. This roughness coefficient is important because consequently influencing when inundation was done in this simulation. This method is therefore considered as a simple method. However, this would make the methodology attractive for local authorities and coastal manager to use.

Application simulation of tsunami inundation, sand dune actual condition and human activity (sand river mining) in arround research area can be used to determine sand dune conservation. Simulation is carried out in this research area. It can be used for planning of conservation models based on physical and social conditions which have impact on sand dune development. Qualitative data such as interview data can be used to support the quantitative data and analyzing interview data to get information from every stakeholder. After that, sand dune conservation assessment can be made based on tsunami inundation areas and quantitative-qualitative data (questionnaire & interview) analysis. Figure 3 shows roughness coefficient in Parangtritis.

Based on inundation simulation results of the tsunami on the mainland, the direction of arrival of waves in the stagnant area of influence can be seen. At the height of the waves, 30 meters inundated the most extensive area occurs when the wave comes from the southwest or at an angle almost perpendicular to the coastline with inundation area is 419,144 hectares. Area inundated by the smallest occurs if the incoming waves come from the southeast. The tsunami wave scenario of 30 meters would inundate the broader agricultural area. If the waves come from the south, it will inundate an area of 3,038 hectares of rice fields. The most extensive inundation occurs when the wave came from the southwest, that is, 18,209 hectares. When the tsunami comes with run up scenario 5 meters then the whole model shows that no fields are flooded. Tsunami inundation simulation areas are based on surface roughness coefficient, wave direction, wave height variation, and slope area of research. The parameters are then used to calculate the landward inundation. Propagation calculations per pixel that pass through the use of certain land and a certain slope, and the reduction in height of the tsunami can be detected.

To obtain the tsunami inundation maps, various approaches have been attempted, for example through a simple model based on contour lines or slope, based on the coefficient of surface roughness (roughness coefficient) and complex mathematical models. In this case because of the limited data available, the tsunami inundation maps are displayed using the events in the 2006 tsunami in southern Java. To further map called Map Tsunami Impacts, measurement is carried out through a search incident track record in the field and seeing the remnants of which are still left, such as a puddle on the ground, like at the beach, trees, and house walls.

The tsunami inundation hazard map is simulated by calculating the propagation of inundation per pixel by considering the slope, surface roughness coefficient, wave direction and wave height variations. This estimation methods consider factors that affect the accuracy of estimates, namely, the number of samples and quality at each data point and position in the deposit samples. Uniform sampling will yield better coverage than the sample of the cluster model, The distance between the samples with a point or block to be estimated, and spatial continuity of the variables involved in tsunami scenarios. Spatial distribution on a variety of tsunami wave height and direction is presented in Figures 4a, 4b, 4c and 4d in the tsunami inundation hazard map.

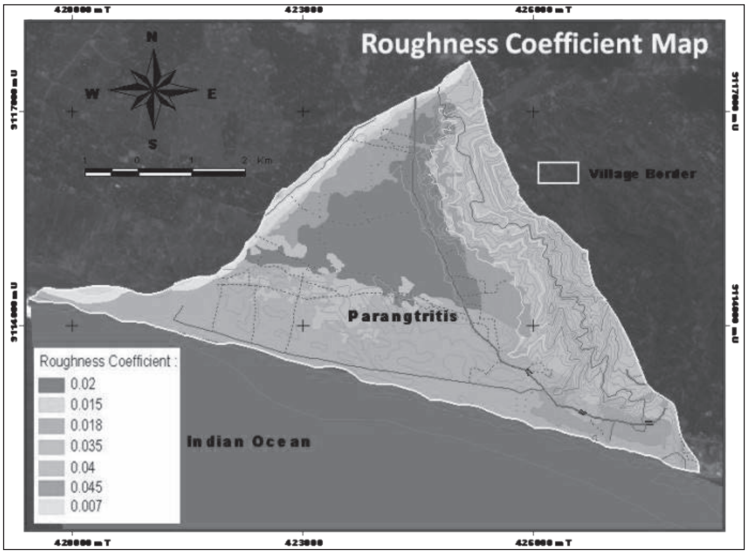

Fig. 3 Roughness Coefficient Map

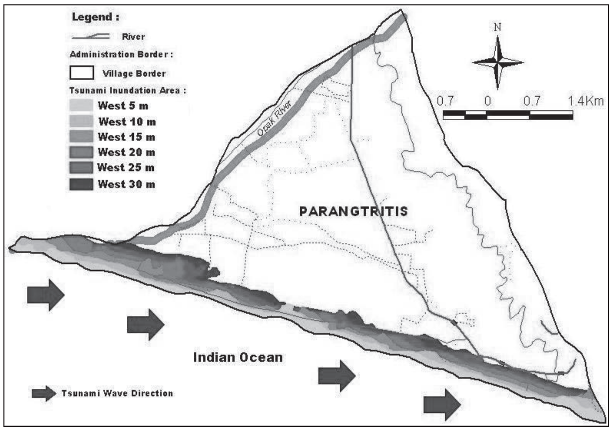

Fig. 4a Tsunami Inundation Hazard Map with West Direction Wave Simulation.

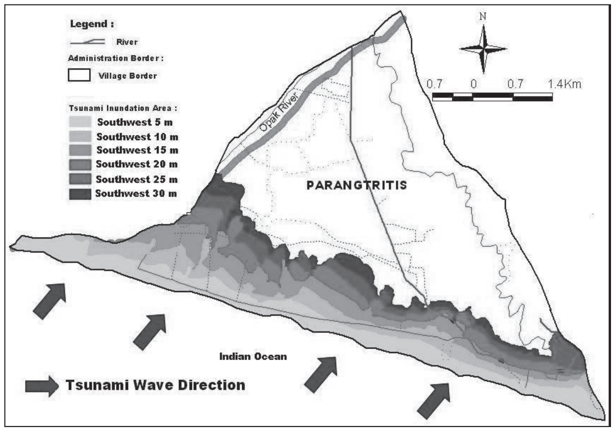

Fig. 4b Tsunami Inundation Hazard Map with Southwest Direction Wave Simulation.

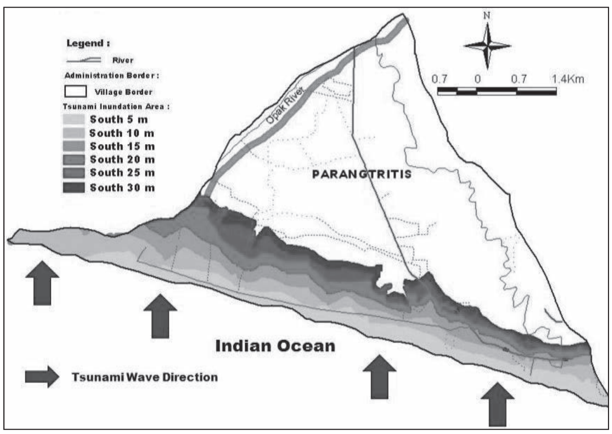

Fig. 4c Tsunami Inundation Hazard Map with South Direction Wave Simulation.

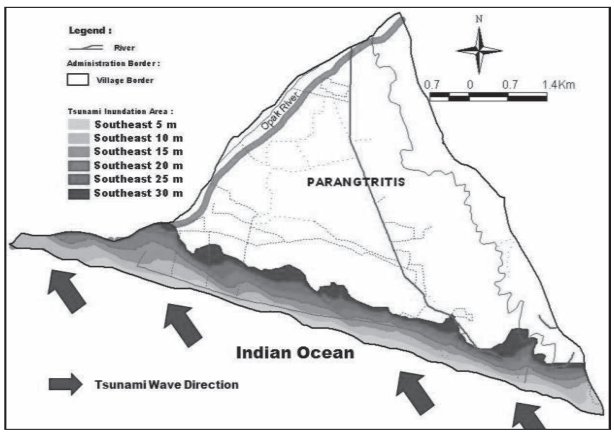

Fig. 4d Tsunami Inundation Hazard Map with Southeast Direction Wave Simulation.

Sand dune Topographic Mapping

The study of sand dune areas is challenging, as not only do the land cover (vegetation, biogenic soil crusts, human uses) vary in space and time, but also the topographic features of the landscape may change over short time spans of several years. Measuring these dynamic is essential to the understanding of these areas. As the average height of the dunes is about 10 m, the Survey of Fieldwork DRMs constructed from 1:25.000 maps is unsatisfactory, as it is based on 10 m contours. Detailed DEMs are created by photogrammetric methods for aerial photographs. The DEMs were created from detailed contours (vertical spacing of 0.5 m) that were measured photogrammetrically. The data from the contours were converted into a DEM using the triangulation method.

A DEM with similar dune characteristics is used to calculate cos(i) values for the time ofthe two images. The method proposed treats what is usually considered as unwanted additional variability in satellite images (the topographic effects) as a signal, and estimates the slope and aspect of the dune terrain. Sand dune data collecting will be used high resolution DEMs for the different dune types—barchan, parabolic, transverse, and linier. Each dune's mean length, width, spacing, orientation, and height is calculated. To apply these sample DEMs in order to predict the expected shading on a given sand dune's area, the DEM will be chosen according to the dune type and the rotated and stretched to fit the actual orientation and spacing (that can be visually estimated). The method developed offers new opportunities for studies of eolian geomorphology, adding the ability to analyze dynamic aspects of sand dunes topography in time and space. Sand dune elevation of Parangtritis is described in Fig. 5 and Table 3. Figure 6 shows 3-dimensional sand dune in Parangtritis coastal area.

As already mentioned, kriging interpolation, though computationally expensive, is a good technique for passing to a uniform image grid. In fact, it is possible to associate for each interpolated sample

Table 3 Sand Dune Elevation Zone

No	Sand Dune Elevation	Hectare (Ha)	%
1	1 m	3,675	0,87
2	2 m	197,577	46,99
3	4 m	44,351	10,55
4	5 m	3,172	0,75
5	6 m	72,992	17,37
6	7 m	0,512	0,12
7	8 m	0,445	0,11
8	9 m	24,497	5,83
9	10 m	15,286	3,64
10	12 m	0,538	0,13
11	13 m	53,56	12,74
12	16 m	0,688	0,16
13	19 m	0,136	0,03
14	20 m	2,174	0,52
15	50 m	0,809	0,19

Source : Measurement Data Calculation, 2010

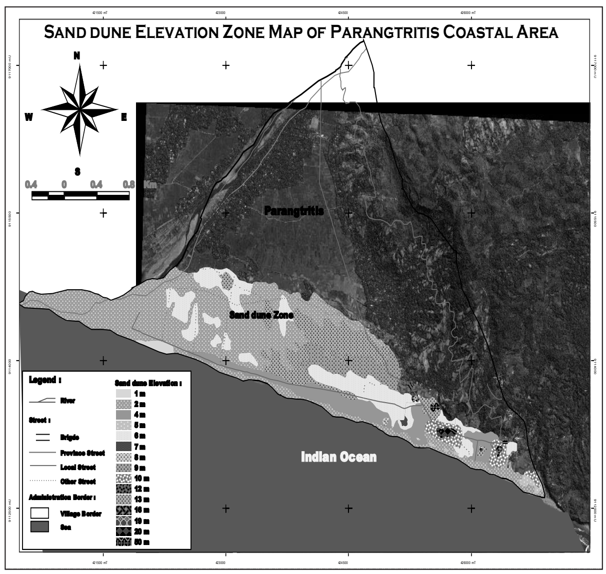

Fig. 5 Sand Dune Elevation Map.

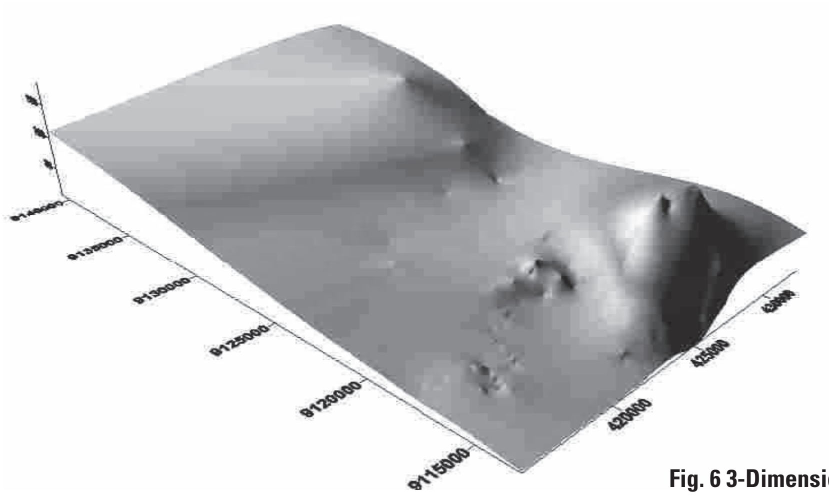

Fig. 6 3-Dimensional of Sand Dune.

an estimation of its variance (dependent on the distances between the data and the position of the cell to be interpolated and the estimated error variance on each data sample) and this makes a more accurate combination possible. In fact, areas affected by foreshortening in one satellite acquisition mode (e.g. ascending) give rise to high variance samples; since only a few data are available, the average distance between them will be large and usually they are strongly affected by geometrical decorrelation.

Figure 6 showed Digital Elevation Model of Parangtritis area. In these areas the final DEM will resemble the topography estimated from data relative to the opposite acquisition geometry (descending), where the spatial sampling (for areas not in shadow) will be good and the geometrical decorrelation lower.

Discussion

Sand Dune Detecting Condition Based on Tsunami Inundation Map

Inundation area from this scenario has linear regression relationship. Linear regression attempts to explain this relationship with a straight line fit to the data. Regression analysis is the statistical method for defining an algorithm that describes a set of data. The advantage of regression is that it finds a pattern or trend in the data. The disadvantage of regression analysis is that the pattern may not be useful or valid. Following figure show the result of linear regression of the inundation zone and area inundated within the study area.

Figure 7 shows that the regression equation could be interpreted in a way that the correlation coefficient (R) approaches 1 (0.9996), that means between area inundate and inundate zone have strongly correlation or the proportion from this variations inundated area in study area can be related to the linier with run up elevation in shoreline. Table 4 shows tsunami inundation area of sand dune elevation zone.

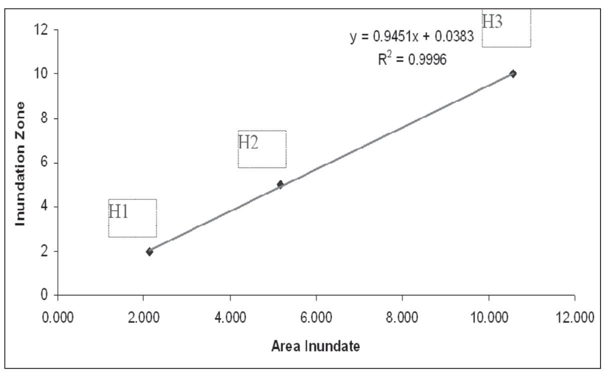

Fig. 7 Linier Regression Result of Comparing Area and Inundate Zone.

Table 4 Tsunami Inundation Area of Sand Dune Elevation Zone

Tsunami Inundation Scenarios (Height & Direction of Wave)		Inundation Area of Sand dune Zone (Ha)	Non- Inundation Area of Sand dune Zone (Ha)
West	5 m	47,719	0,446
	10 m	70,232	0,030
	15 m	95,246	0,030
	20 m	126,921	0
	25 m	154,087	0
	30 m	178,280	0
South	5 m	83,911	8,327
	10 m	173,444	11,704
	15 m	247,954	2,859
	20 m	302,544	0,683
	25 m	341,43	0,809
	30 m	365,402	0,809
Southwest	5 m	111,310	9,512
	10 m	184,659	12,839
	15 m	276,742	2,739
	20 m	318,561	0,803
	25 m	346,437	0,809
	30 m	369,138	0,809
Southeast	5 m	85,654	8,327
	10 m	103,235	2,916
	15 m	153,249	6,265
	20 m	197,121	0
	25 m	227,272	0
	30 m	266,041	0

Source: Data Calculation, 2010

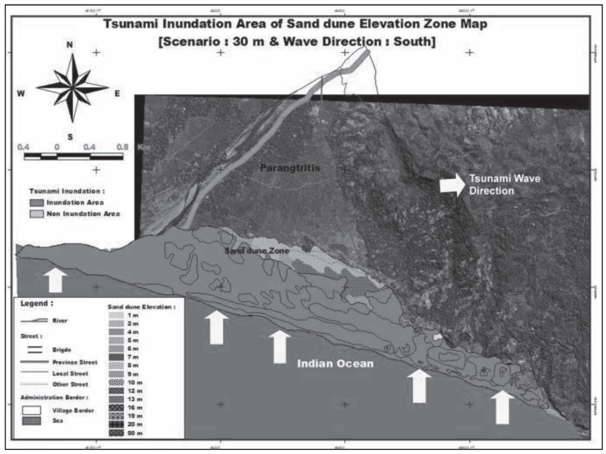

Fig. 8a Tsunami Inundation Area of Sand Dune Zone Map with South Direction Wave Simulation.

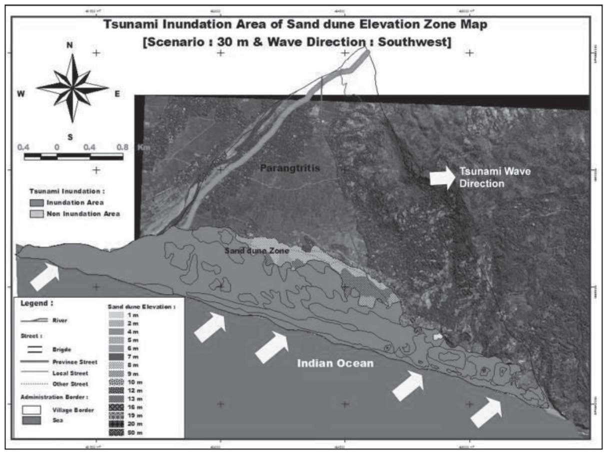

Fig. 8b Tsunami Inundation Area of Sand Dune Zone Map with Southwest Direction Wave Simulation.

Figures 8a, 8b, 8c and 8d show tsunami inundation area of sand dune elevation zone. The big impact of tsunami inundation showed in southwest direction scenario.

Sand Dune Conservation Zone

Spatial planning in Bantul Regency has been regulated by Regent's Decree No. 4/2002 concerning Spatial Planning. Regarding the development activities in the coastal area, the Government of Bantul Regency has established a semi-detailed plan and a detailed plan known as "Rencana Detail Tata Ruang Kawasan Pantai Selatan Kabupaten Bantul" or RDTRK Pantai Selatan and "Rencana Teknis Tata Ruang Obyek Wisata Kawasan Parangtritis" or RTOW Kawasan Parangtritis, respectively. Concerning land utilization in coastal area, the buffer zone of 100-200 meters from the highest high water line has

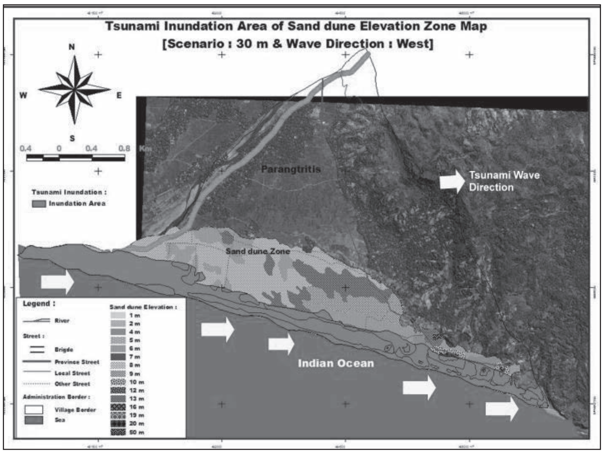

Fig. 8c Tsunami Inundation Area of Sand Dune Zone Map with West Direction Wave Simulation.

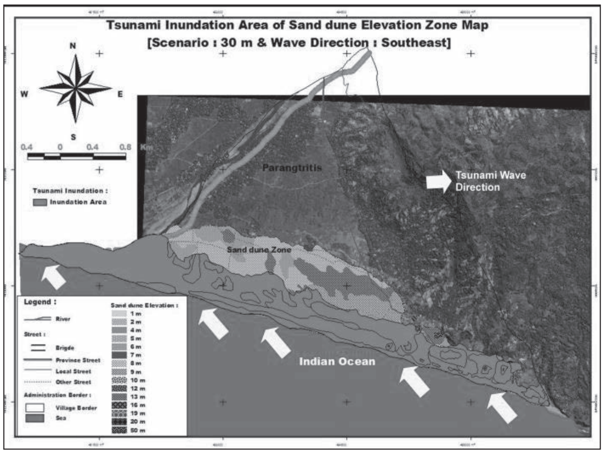

Fig. 8d Tsunami Inundation Area of Sand Dune Zone Map with Southeast Direction Wave Simulation.

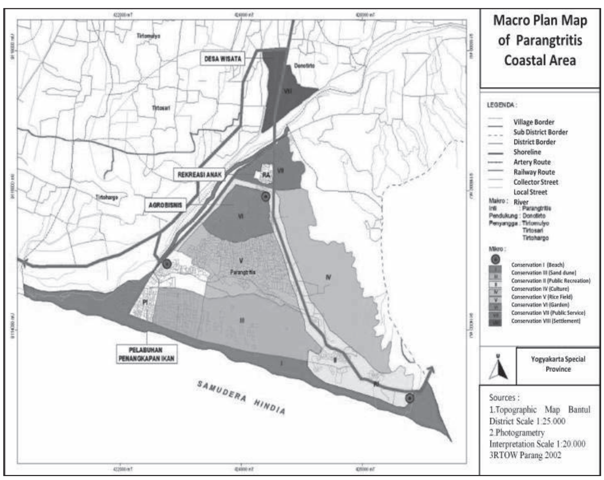

Fig. 9 Micro Plan Map of Parangtritis

been established. Futher, based on tsunami and high wave events, Bantul local government established another buffer zone approximately 300 m from the highest high water.

Detailed spatial planning concerning Parangtritis is the Regent's Decree about Technical Plan of Parangtritis Tourism Resort Development. Based on this decree, Parangtritis has been divided into 8 zones (Fig. 9) in which each of it has been assigned for special allotment, as follows:

Zone 1 : Beach Preservation
Zone 2 : Public Recreation
Zone 3 : Dune Preservation
Zone 4 : Cultural Preservation
Zone 5 : Rice Field Preservation
Zone 6 : Orchard (Fruit) Preservation
Zone 7 : Public Facility
Zone 8 : Settlement

Disaster Mitigation Based on Tsunami Inundation Hazard Scenario Simulation Map

Distribution of inundation depends on the direction of the tsunami wave coming, wave height, surface roughness, and slope. Tsunami inundation zone for 20 meters scenario has 129.250 hectares (west wave direction); 337.960 hectares (southwest wave direction); 319.125 hectares (south wave direction); and 197.976 hectares (southeast wave direction). Tsunami inundation zone for 20 meters scenario has 129.250 hectares (west wave direction); 337.960 hectares (southwest wave direction); 319.125 hectares (south wave direction); and 197.976 hectares (southeast wave direction).

Bantul local government in cooperation with Yogyakarta Central Government has installed siren systems in the Parangtritis area which is an area vulnerable to tsunami. Those completed systems are: 6 public address systems, 1 tower, 1 amplifier and 1 receiver. This system is installed in 8 different

Fig. 10 Tsunami Mitigation in Parangtritis.

locations connected to a repeater which is placed in hill then correlate with the active system in headquarters of the local government Bantul. This system is based on radio analogue technology with FM wave. The other advantages of this system beside sounding a siren for evacuation are that it also gives information about what the kind of earthquake can trigger a tsunami. Bantul local government have organized the commercial place for local people in higher place and safe from tsunami and have also figure out tsunami drill to face tsunami hazard.

Conclusions

Although the tsunami is the worst disaster in coastal area, in Indonesia, especially people who live along coastal area, not much was known about the big impacts. When the tsunami occurred on Aceh in 2004, it opened the eyes of the people to the destructive and dangerous impact of a tsunami. Tsunami are a natural phenomenon which cannot be prevented; however, this does not imply that no one should live in coastal areas. It is very important to maximize the mitigation effort in order to minimize the negative impact from the natural disaster. Both government and local people have to sit down together, discuss what the standard operation procedure should be when a tsunami occurs, and how it could be done and whether the government could provide a nearby evacuation zone. The southern coastal area of Central Java is frequently affected by tsunami. We undertake a preliminary tsunami vulnerability assessment in a part of the coastal segment in southern coastal area of Central Java as a support for the disaster management system.

The result of our study may have important implications for many different stakeholders. In addition, it would seem appropriate that those agencies tasked with coastal zone management ought to consider focusing their resources in the Parangtritis coastal area. In particular, agricultural land and non-agricultural land appears to be at significant risk in terms of the impact of a future tsunami event. Finally, recommendations include (1) further research that considers the occurrence of tsunami, run-up model, coastal characteristics, hydrodynamic and detail coastal geomorphology; (2) detailed land-use mapping in order to identify the impact of the tsunami inundation and to calculate the detail potential loss in comprehensive approach. Furthermore, the result also suggests that integration of GIS and satellite image is a suitable method for detecting damage caused by tsunami inundation. In terms of risk management, there are many ways to address risk and hazard issues as describe in Coastal Planning and Management. They consist of 1) Event protection (hard or soft engineering), 2) Damage prevention (avoidance, mitigation), 3) Loss Distribution (transfer) and 4) Risk Acceptance (do nothing). The role of spatial planning for disaster management consists of:

Keeping areas free of development

Spatial planning has the instruments at hand to keep free those areas of future development that are (1) Prone to hazards (e.g. flood-prone areas, avalanche-prone areas), (2) that will be needed to lower the effects of a hazardous event (e.g. retention areas) and (3) that will be needed to guarantee the effectiveness of response activities (e.g. escape lanes, gathering points etc.).

Differentiated decision on land use
Besides keeping certain areas free from development, spatial planning may also decide on land-use type according to the intensity and frequency of the existing hazard (e.g. agricultural use of a moderately hazardous flood area might be allowed whereas residential use may be forbidden).
Recommendations in legally binding land use or zoning plans
Although recommendations about certain construction requirements belong to the area of building permissions, some recommendations can already be made on the level of land use or zoning plans (e.g. minimum elevation height of buildings above floor level, prohibition of basements, prohibition of oil heating, type of roof).
Influence on hazard intensity and frequency (hazard potential) by spatial planning
Spatial planning can also contribute to a reduction of the hazard potential, e.g. protection or extent of river flood retention areas, protective forest etc.

Sand dune conservation management requires coordination between stakeholders and the local community. Many local communities are aware of the importance of the coastal sand dunes and have their traditional methods of dune conservation and restoration, as in the case of Southern part of Parangtritis Village. It is necessary to revive these traditional practices as they are locally tested and successful strategies. These need to be supplemented with advanced scientific research and ecological studies to suggest suitable species as vegetation cover, plantation techniques and method of site selection, which would effectively serve restore dunes. In cases where destruction of the dune system has passed a stage where simple methods such as removal of stress factors and protection may not reverse the damage, restoration efforts may be necessary. Dune restoration efforts not only help in dune formation, but also help in bringing back floral and faunal diversity, which previously existed in the healthy system.

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