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Research Article

Investigating a Conservation Area Based on Tsunami Hazard Mapping in Landuse Planning of Sand Dune Parangtritis Area, Yogyakarta, Indonesia

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Abstract: The Southern part of Java Island is highly risked from natural disaster, particulary tsunami. In this research, we investigated a conservation area of the southern part of Yogyakarta (Bantul Regency), Indonesia, namely Parangtritis. Sand dune in Parangtritis is a natural barrier for tsunami threat. Material loss caused by tsunami can be reduced by identifying natural barrier of sand dune through tsunami hazard zones. We propose a method to investigate changes of sand dune condition by simulating the tsunami inundation hazard impact and implementing a remote sensing application. A water depth of tsunami model scenario was used to estimate the tsunami inundation zone. The tsunami modeling used Shuttle Radar Topography Mission (SRTM) data to build Digital Elevation Model (DEM) data. Topographical map and ALOS imagery were used to analyze land coverage. Based on our simulation, the tsunami tends to surge toward the southeast direction with 30 m of elevation. Material loss due to tsunami is catastrophic; hence more extensive sand dune conservation area is required. This research provides a tsunami hazard map and a sand dune conservation map based on our simulation. In future, our research might be used as a guideline for development of policy to develop and to protect sand dune conservation area.

Keywords: Coastal area, Disaster mitigation, Land use, Tsunami hazards map.

1. INTRODUCTION

Indonesia is one of the most vulnerable areas from natural disaster because it is located nearby the zone where three main tectonic plates collide. Java Island is highly risked by a tsunami disaster due to its tectonic setting. The catalog for tsunamis in the Indian Ocean recorded that the movement of Sunda arc area generated 80 % of the tsunamis with various scale of movements [1]. This island is located in the outer arc of the volcanic belt, which is the same situation with Aceh. In the year of 2006, tsunami hazard occurred in coastal area of West Java, which then removed across the coastal of Java island to the east of Java in southern coastal part. The tsunami affected all coastal part of the southern Java island area. In this case, the tsunami may be caused by subduction zone of Indian Plate and Eurasian Plate in the sea of the southern part of Yogyakarta, Indonesia [2].

The risk of great disasters is originated from various earthquakes in the coastal part of West Java [4]. On December 22, 2018, the western coastal area of Java was hit by a tsunami. The tsunami caused massive damages in Banten province. The disaster was generated by a volcanic eruption of Krakatau volcano [5]. The tsunami killed more than 426 people with 14,059 people were reported injured and 24 people were missing. The disaster caused

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damages to settlement, public facilities, rural and farm areas.

Although tsunami is infrequent disaster, it has been recorded as a catastrophic disaster that causes a big number of victims and wide hazard impact zone. The largest tsunami disaster was generated by Krakatau Volcano eruption in 1883. The tsunami had 38 m of maximum surges height penetrating 2.5 km in Sumatra and Java. A strong earthquake caused another big tsunami in 2004. It was registered as an enormous earthquake in Indonesia since 1990. The hazard created 30 m surges of tsunami penetrating 4 km inland and destructing all the building the surged passed. Table 1 represents the tsunamis record in Indonesia.

On the other hand, the coastal area in Indonesia can be categorized into short term, medium term and long term area [3]. The classification is based on different kinds of natural hazards, land uplift of subsidence, and rise and fall of seal level. The sand dune in the southern part of Yogyakarta, Indonesia is is expressed as the unique sand dune coastal area in the South East region of Asia. The sand deposits here consist of beach sand and sand dune.

Parangtritis beach is located at the southern part of Java coastal and near from the subduction area. The beach straightly faces the plate of Eurasian and Indo-Australian. The beach is sandy gray with a view of hills in the East and North and a view of barchan type sand dune in the western part. These conditions make the area Parangtritis become a very popular tourism spot. Since Parangtritis is mostly a flat area and consists of built up area, Parangtritis is highly vulnerable to the impact of any tsunami. Parangtritis as a research area is described in Fig. 1.

Establishment of spatial range for inundation prediction as well as for calculation of agricultural damage over a large area spatially can be derived through a combination of Geographic Information System and a remote sensing technique [4]. Development and application of satellites images technology are increasing rapidly. Precision farming can be achieved by incorporating satellite data for land-use determination in coastal area. Furthermore, the ALOS satellites are considerable in the accuracy of agriculture land classification mapping.

Implementation of remote sensing technology for disaster mapping of coastal area has progressed swiftly in the recent decade. Spatial information of coastal morphology can be produced by Landsat ETM and DEM data [6–11]. Hill shade, slope steepness, range of curvature maps are derived through digital image processing methods based on the SRTM DEM extraction of morphological traces. Tsunami analysis by delineation of coastal regions can be derived by combining earthquake data in a Geographic Information System database, Landsat ETM, and the morphological maps of coastal area. In this research, a conservation management area has been reported based on disaster mitigation

Table 1. Tsunami record in Indonesia [1]

Location	Population of Disaster Impact (people)	Magnitude Scale (Richter)	Periods
Palu	3	8	1996
Biak Island	107	8	1996
Tabuna Maliabu	34	-	1998
Banggai	4	-	2000
Nanggroe Aceh Darussalam and North Sumatera	> 200 000	9.1	2004
Nias Island	-	-	2005
South Java	665	7.7	2006

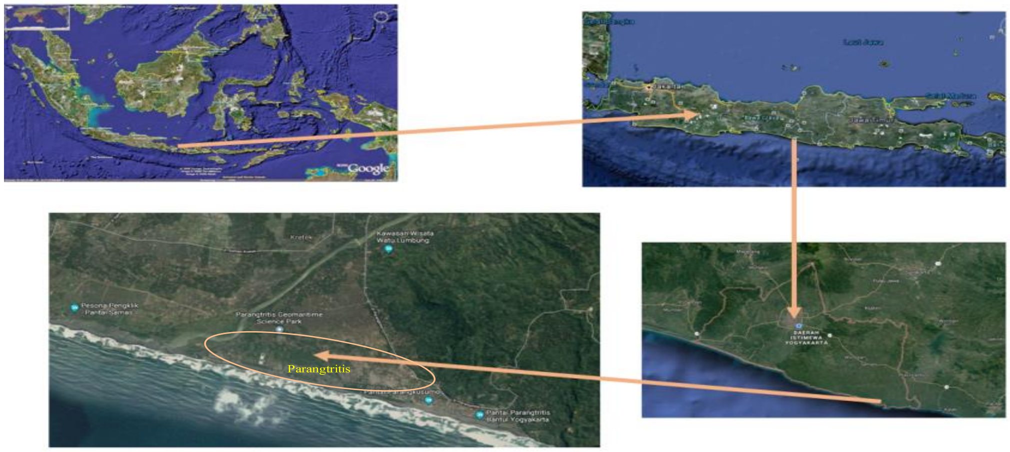

Fig. 1. Parangtritis coastal area

of tsunami inundation hazard in Parangtritis, Yogyakarta, Indonesia. This research is important as: (i) the coastal area in the southern part of Java is vulnerable from tsunami and is at risk from future tsunami occurrence [12], (ii) sand dune zones in Parangtritis are scientifically investigated; (iii) the sub district government is accomodating to create the local disaster mitigation plan for disaster risk reduction. Thus, our results will be valuable data to support the governmental programs. Furthermore, coastal land-use planning in general does not consider hazards in the coastal area.

Sand dune in Parangtritis is a natural barrier from the threat of tsunami. Various human activities, such as very intensive river tailing, affect condition of sand dune in Parangtritis. If sand river tailing activities get more intensive, the condition of sand dune exacerbates. Thus, the sand dune condition is not in optimal situation as there is not enough material supply. Furthermore, the presence of settlement area also affects the sand dune development. Many peoples in Parangtritis are not aware of protection of the sand dune area. Furthermore, there is insufficient attention of sub district government to coastal conservation by considering tsunami hazard zones. The declining function of the sand dune increases the risk of this area.

2. MATERIALS AND METHODS

Water depth scenario is used to determine tsunami inundation zone. The sand dune areas are detected based on the inundation zone. This research has not considered the hydrodynamic parameters of tsunami hazard. Furthermore, we ignore source region of tsunami and coastal configuration during inundation. In the identification of inundation zones, bathymetry of seabed is ignored because there was no information about bathymetry of the study area in detailed scale. Obtaining such data is expensive both in funds and in time. Analysis of tsunami inundation was performed under two types of scenario: direction of wave scenario (west, south, southeast and southwest direction) and wave elevation variation scenario (run-up 5 m, 10 m, 15 m, 20 m, 25 m, and 30 m). In this research, we used Geographic Information System to calculate elevation in the plain. Next, we developed an interpolation with Kriging method. The correlation of tsunami wave elevation, surface roughness coefficient, and length of land were then calculated using the following equations [13]:

$$X_{\max} = \frac{0.06 H_0^{4/3}}{n^2} \qquad (1)$$

Where:

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

H_0 : Surge vertical measurement;

n : Coefficient of roughness

Equation 2 is used to calculate the loss per 1 meter of surge height. Equation 3 is used to obtain the loss of the altitude of 1 m run-ins [14].

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

To trace the surface condition with various height, Equation 2 was converted by arriving a deciding parameter to the loss of the altitude of declination of tsunami wave is expressed by Berryman [11].

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

Where:

H_{loss} : Losing tsunami altitude

n : Coefficient of roughness

H_0 : Surge vertical measurement

S : Slope Surface

The tsunami velocity in surface area can be expressed using equation as follow:

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

u : Surge speed

g : Gravitation acceleration

h : Inundation deepness

The elevation of tsunami wave is proportional to surge speed (Equation 4). A model with various scenarios describes tsunami hazard: 5 m to 30 m of height with direction scenarios of the surges. These variations represent modeling that possibly happens on the southern part of Java island. Former field evaluation registered that the deliberated run-up elevation arranged from 1 m to 16 m around the southern part of Java coastal area in Baron and Batu karas. Since the run-up height wave scenarios is an independent factor, the additional component to solve that equation is surface roughness from the classification of landuse type. The coefficient of roughness is described in Fig. 2. Tsunami scenario model was validated using regression calculation. This method defined a model based on a set of tsunami data. Inundation area from this scenario had a linear relationship. Linear regression attempted to explain this relationship with a straight line fit to the data.

The process from DEM may produce a slope map. The slope was obtained using the topographic map from the Indonesian Geospatial Information Agency (BIG). Ilwis 3.3 software is used in raster operation. The method was correlated by mapping of sand dune conservation region with land-use regulation in Parangtritis sub district. The decision of the assessment on sand dune conservation is proposed to maximize the sand dune utility as a disaster bound. Fig. 3 shows the flowchart research design.

3. RESULTS AND DISCUSSION

3.1 Tsunami Inundation Hazard Scenario Simulation Map

Simulation of tsunami hazard mapping is conducted by supposing the multiplication of tsunami wave pixel in several considering factors, such as coefficient of surface roughness, slope, surge direction, and surge elevation scenarios. The modeling of tsunami inundation is produced depend on the coefficient of surface roughness aspects, the slope condition and inundation distance of surge per

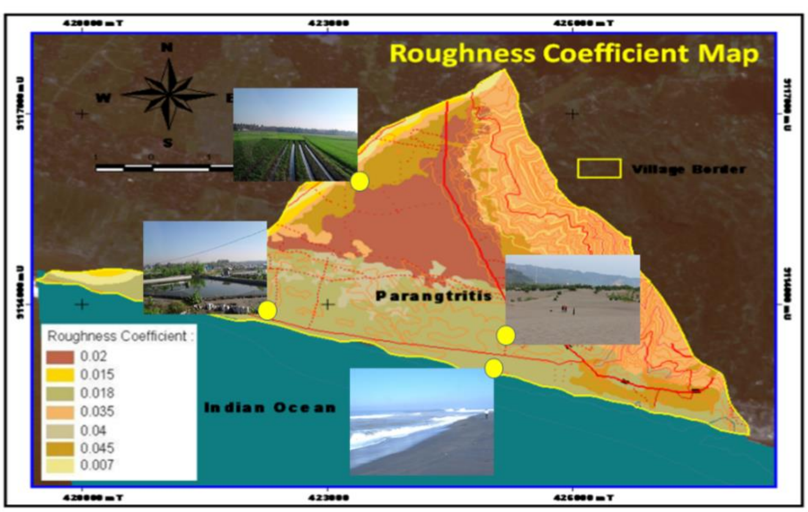

Fig. 2. Land-use roughness coefficient map

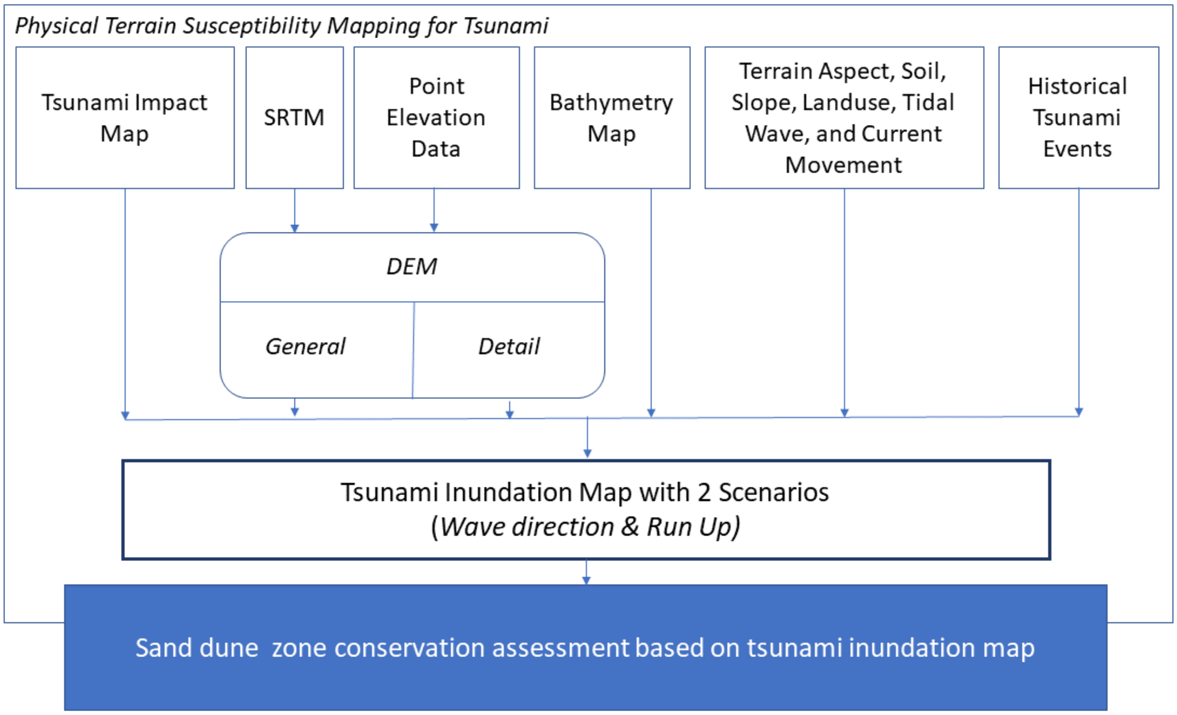

Fig. 3. Flowchart research design

meter in research area. These parameters are then used to calculate the inundation to land. The surface roughness coefficient is derived through landuse delineation. The importance of this coefficient is it would be influenced when an inundation was made in the simulation. Although this approach is considered as a simple method, the proposed method will be compelling for disaster mitigation decision maker. Fig. 4 shows diagram of roughness coefficient in Parangtritis.

The tsunami prediction modeling, sand dune current condition, and various civilized activities surrounding research area can be used to determine sand dune conservation area. The study may be used to plan appropriate conservation model based on physical and social condition. Quantitative analysis may be supported by interview or focus group discussion involving all stakeholders. Comprehensive assessment of sand dune assessment can be created due to the observed inundation

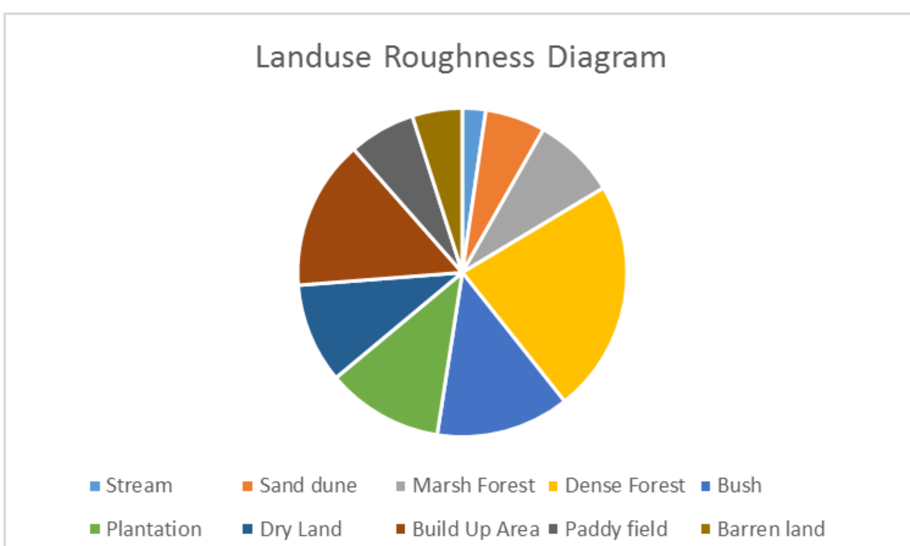

Fig. 4. Diagram of roughness coefficient [Source: Data calculation 2016]

prediction zone and the quantitative data analysis.

Entrance of tsunami surge in the stationary area of influence can be observed from tsunami inundation simulation. With the height of the surge was set to 30 m, inundation of the largest area occurred when the surge came from the south west of coast resulting 419.14 ha of inundation area. Smallest inundation area occurred if the surges came from the southeast. The tsunami surge scenario with 30 m of height would inundate wider agricultural area. If the surge came from the southern direction, an area of 3.03 ha of paddy fields was inundated. When the surge came from the south west, the inundation area was about 18.21 ha. If the tsunami model was set to 5 m of height, the whole model showed that there were no flooded fields. Tsunami inundation simulation areas are based on surface roughness coefficient, surge direction, surge height variation, and slope (slope) area of research. The parameters are then used to calculate the landward inundation.

Various approaches were done to produce tsunami inundation maps such as developing a scenario due to relief or curve, developing a model based on arithmetical method and roughness coefficient. In our case, as we were constrained by availability of the data, the developed inundation maps were based on tsunami that occurred in southern Java during 2006. Measurement was performed by investigating record of accomplishment of incident in the field and by observing residues on the ground, such as trees, house walls, etc.

The estimation method in this study considered several factors that affected the accuracy of estimation, such as: (i) the number of samples and quality at each data point, (ii) position in the deposit samples, (iii) uniform sampling that yielded better coverage than the sample of cluster model, (iv) The distance between the samples with a point or block to be estimated, and (v) Spatial continuity of the variables involved in tsunami scenarios. Fig. 5 presents inundation maps with various spatial distribution of height and direction of tsunami surge.

Analysis of sand dune coastal area is asserting, the coverage of soil, agriculture and usage by human on the study areas varies in spatio-temporal context. Furthermore, topography of the landscape changes over several years. Hence, measuring these dynamic features is important to gain deeper insight

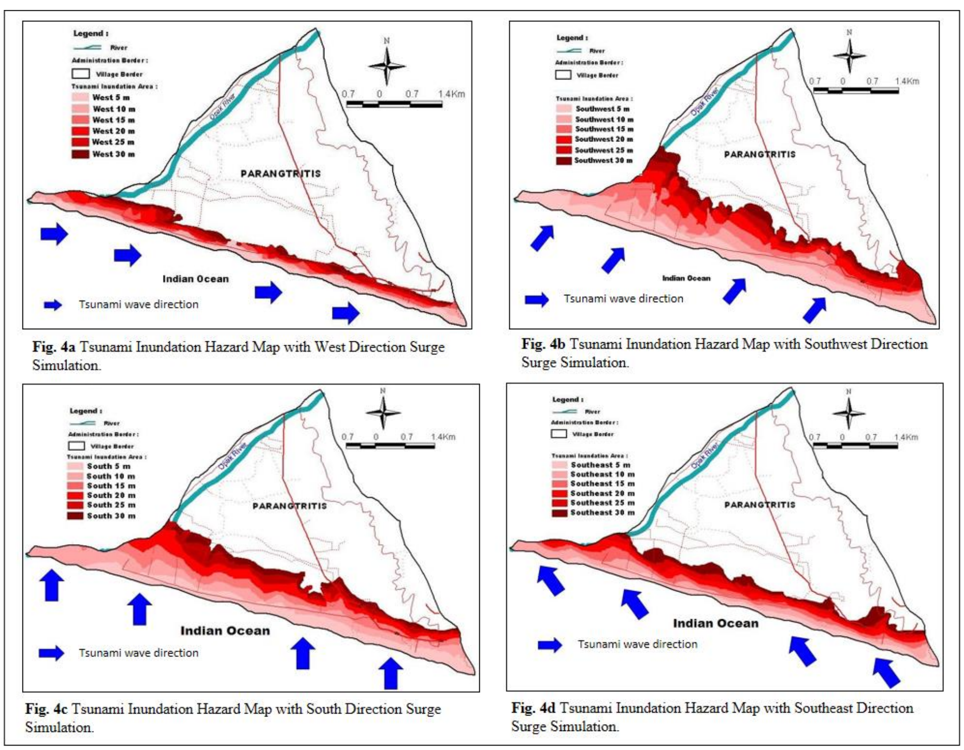

Fig. 4a Tsunami Inundation Hazard Map with West Direction Surge Simulation.

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

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

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

Fig. 5. Tsunami inundations wave scenarios

of the study areas. Given information that the average vertical height of sand dunes is 10 m, the field study of DRMs data established from 1: 25.000, it is not appropriate to be used in this study. Photogrammetric methods for aerial photographs can be used to develop detailed Digital Elevation Model (DEMs). We used DEMs of detailed contours with 0.5 m of vertical spacing. Triangulation was used to convert contours data into DEMs.

Estimation of cos (i) conducted to the more than three image period was based on a Digital Elevation Model with comparable sand dune parameters. The proposed method is also useful for estimating the sand dune morphology. However, some undesirable affixed parameter in images known as morphology effect may become apparent by the usage of the proposed method. High-resolution DEMs were used for analysis of sand dune. Estimation of coastal dune properties was conducted, such as average sand orientation, distribution and elevation. The samples of DEMs were also adapted to measure shadowing particular dune zone. We chose specific Digital Elevation Model based on type of the dune. The DEM was then moved to find the best match

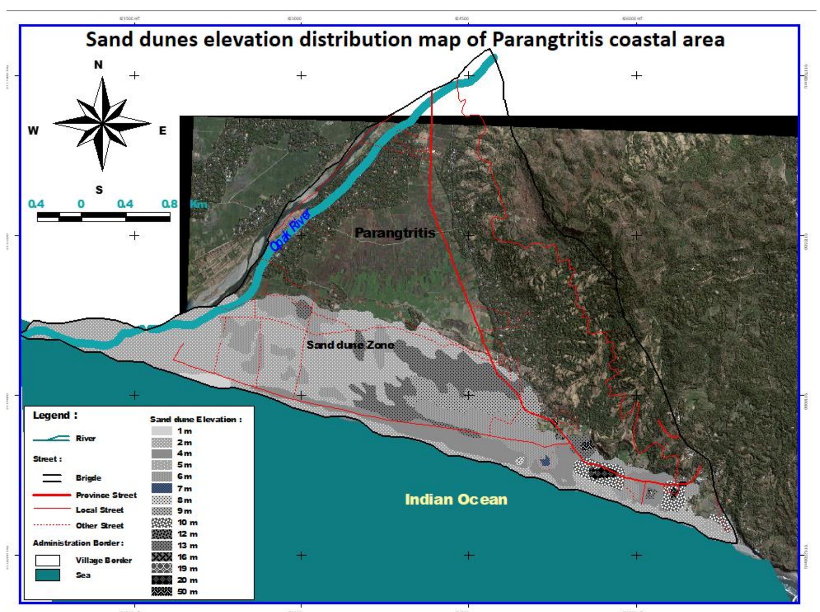

Fig. 6. Sand dune elevation map

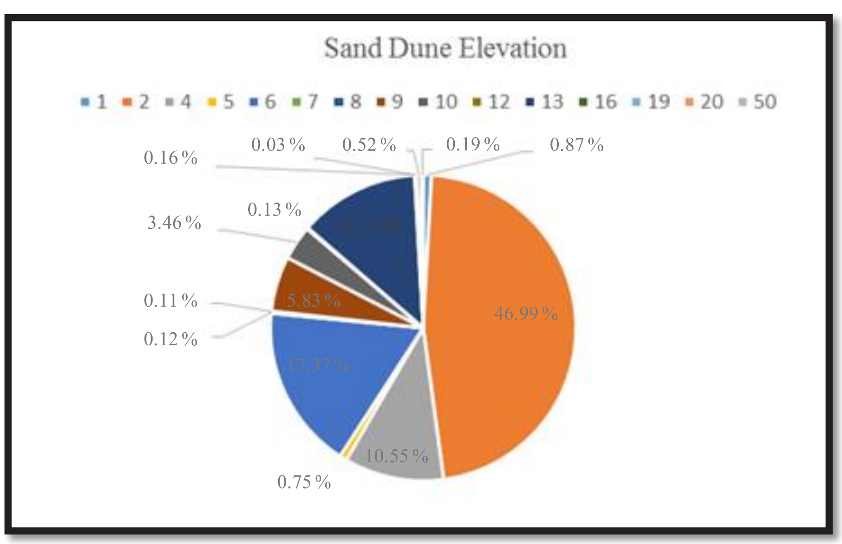

Fig. 7. Sand dune elevation zone [source: Measurement [A1] data calculation, (2016)]

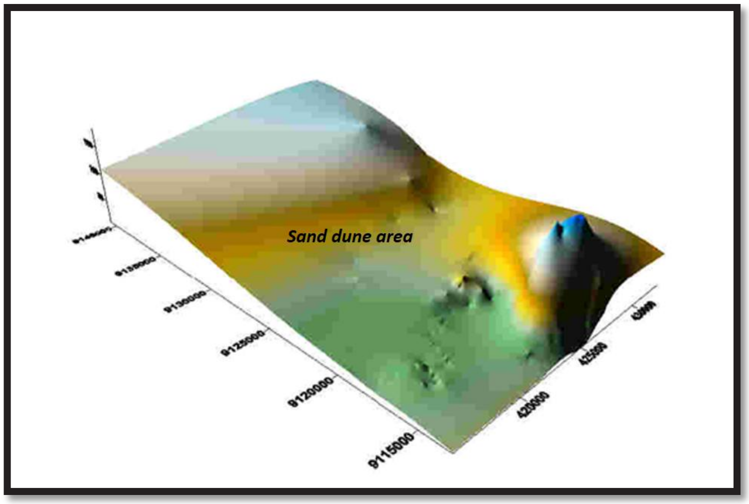

Fig. 8. 3-Dimensional of sand dune

with distribution and direction. Our approach aimed to support visual estimation. Furthermore, the proposed method is useful for study of aeolian geomorphology, by analyzing dynamic aspects of sand dunes topography in spatio-temporal context. Sand dune elevation of the study area is described in Fig. 6 and Fig. 7. Fig. 8 shows 3-Dimensional visualization of sand dune in the study area.

Kriging interpolation was used in this study. Although this interpolation was computationally demanding, this approach was appropriate for passing data to a uniform image grid. The proposed method allowed estimation of variance for each interpolated sample. The variance counted using interpolation between object coordinate and sample. Furthermore, the approximated error deviation of object area also affected the variance. Hence, this approach provided possibilities of more accurate combination. We found that region damaged by ascending mode of ALOS PALSAR image satellite produced large variation. Since only a few data were used in analysis, the rate of distance was high. Moreover, geometrical decorrelation affected the quality of the data.

Fig. 6 showed DEM of Parangtritis area. In coastal zones, the final DEM presented the estimated topography, which is the opposite of acquisition geometry (descending). On the other hand, Fig. 6 also shows that the sample of distribution was fine. Sand dune visualization using 3D image processing was adopted to estimate the wonted covering of the study area.

Fig. 9 shows that the regression equation could be interpreted correlation coefficient (R) are approaching 1 (0.999 6) that means between area inundate and inundate zone have strong correlation or the proportion from this variation inundated area in study area can be related linear with run-up elevation in shoreline. Fig. 10 shows tsunami

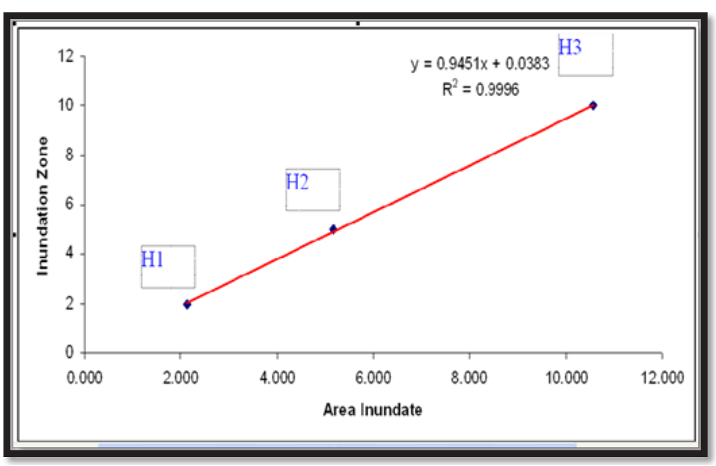

Fig. 9. Regression of comparing area and inundated zone

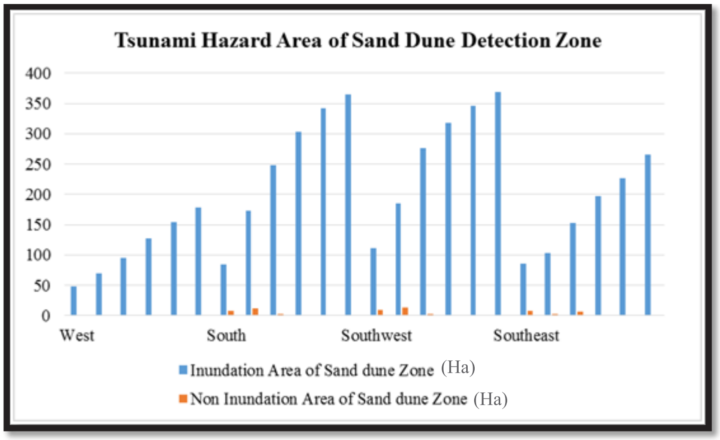

Fig. 10. Tsunami Hazard Area of Sand Dune Detection Zone [source: Data calculation [A1], (2016)

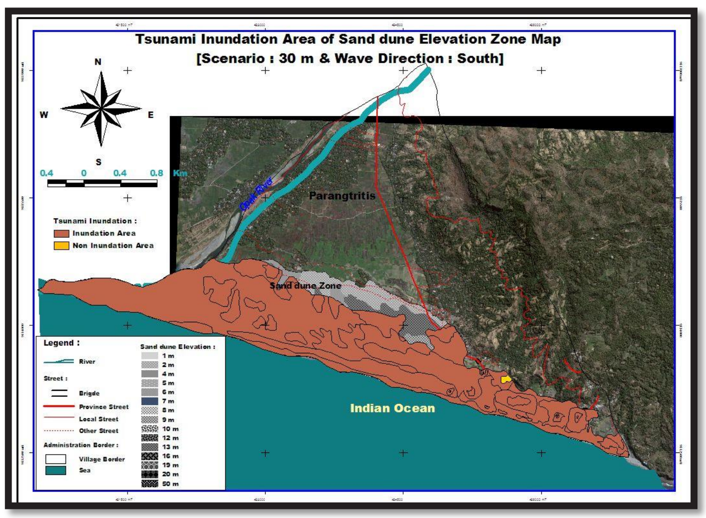

Fig. 11a. Tsunami hazard map of sand dune elevation area map with south direction surge simulation

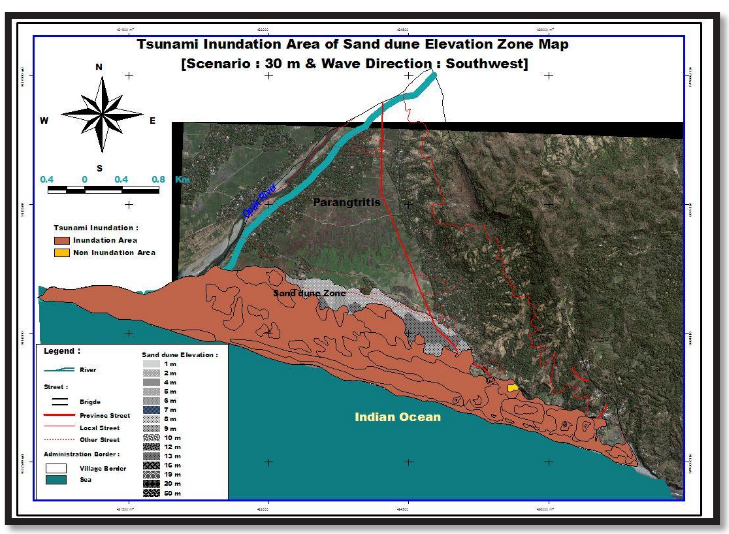

Fig. 11b. Tsunami hazard map of sand dune elevation area map with southwest direction surge simulation

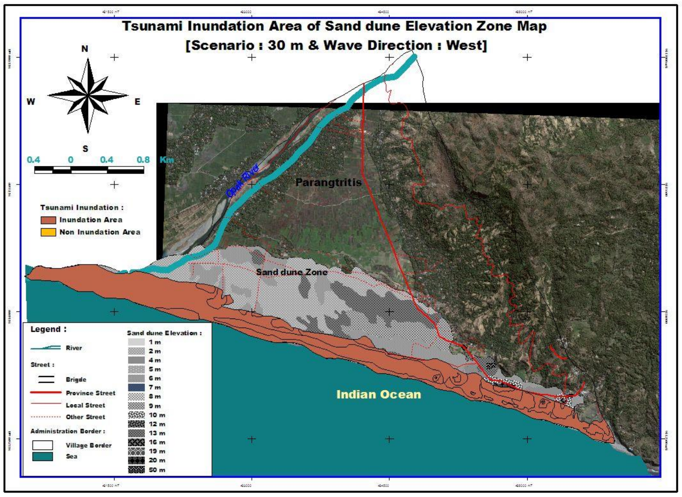

Fig. 11c. Tsunami hazard map of sand dune elevation area map with west direction surge simulation

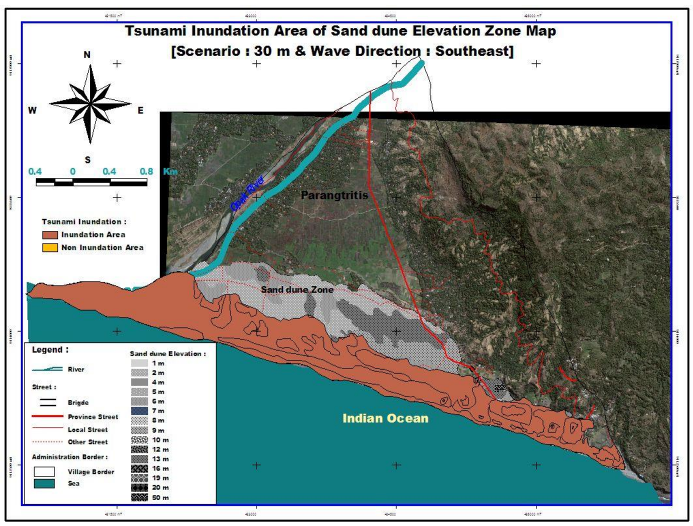

Fig. 11d. Tsunami hazard map of sand dune elevation area map with southeast direction surge simulation

inundation area of sand dune elevation zone. Fig. 11 shows tsunami hazard map of sand dune elevation area. The big impact of tsunami inundation showed in southwest direction scenario.

3.2 Sand Dunes Conservation Zone

Regent's Decree No. 4/2002 of Bantul Regency is used as a basis for spatial planning in Bantul Regency, Yogyakarta, Indonesia. To support development activities in the coastal area, the local government created meso land-use plan in Parangtritis coastal area. A 100 m to 200 m of buffer zone from the highest water line has been established to deal with land utilization in the coastal area. Moreover, the local government also has designed secure area of around 300 m from the coastal line, which was based on tsunami and high wave events. The macro plan of land-use in Parangtritis area has been divided into eight zones to develop medium to long term risk management plans (as shown in Fig. 12).

3.3 Disaster Mitigation Due to Tsunami Scenarios

The direction and the height of the tsunami surge, and the roughness and the slope of the area affect the distribution of inundation. For instance, an inundation area with 20 m tsunami height has 129.25 ha of area (west surge entrance); 337.96 ha of area (southwest surge entrance); 319.13 ha of

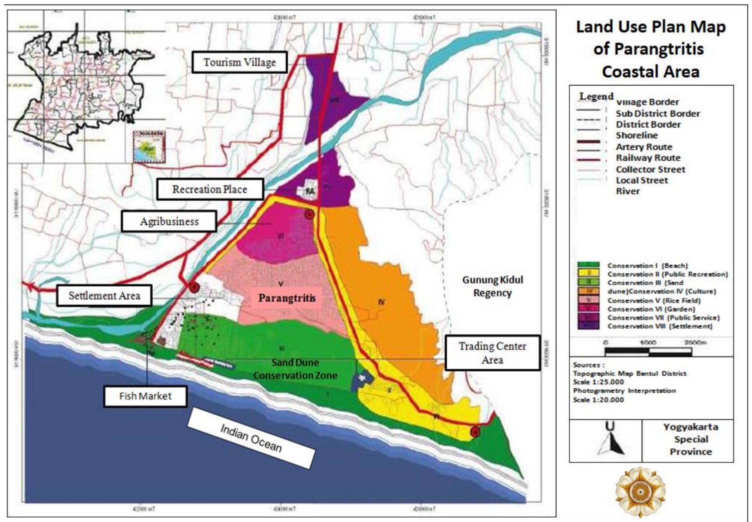

Fig. 12. Land-use plan map

area (south surge entrance); and 197.97 ha (south east surge entrance). To deal with these inundation areas, local government of Bantul Regency has established several early warning systems in coastal areas, in which probability of tsunami occurrence is high. Those completed systems consist of six public addresses, one receiver, one tower, and one amplifier. All of them are connected with a repeater. The repeater is installed in a higher place while actively distributing information to Bantul Regency government. Another advantage of these systems is their ability to inform types of earthquake that can trigger a tsunami. To prevent bigger impact of tsunami hazard, the Bantul regency management have formulated several safety points in hazard area.

4. CONCLUSIONS

Although tsunami is the worst disaster in coastal area, in Indonesia, especially people who live around coastal area were not much known about the big impacts. When tsunami occurs on Aceh 2004, it opened eyes of many people to the destructive tsunami effects. Even though tsunami disaster is catastrophic event that cannot be anticipated; the actuality does not indicate that coastal areas have to closed from human activities.

The negative impact of natural disasters should be minimized by finding the best mitigation effort based on scientific research. Both government and local people have to sit together, discussing standard operational procedure during tsunami occurrence. In this research, preliminary assessment of tsunami vulnerability was undertaken in the Java coastal area to guide mitigation policy and development of disaster management system. Some alternatives land-use options applicable in research area are fish trading market area and Parangtritis mangrove conservation area to accommodate future needs of urban and agricultural development. Our study can also be used to support decision making by various stakeholders.

Additionally, various stakeholders tasked with coastal zone authority to consult targeting coastal assets on Parangtritis coastal area. Finally, we recommend more detailed research that considers the occurrence of tsunami, run up model, coastal characteristics, hydrodynamic, and detailed morphology. Sand dune conservation management requires coordination between stakeholder and 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 methods should be supplemented with advanced scientific research and ecological studies to advices agricultural technique of Parangtritis coastal area.

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