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MAPPING TSUNAMI VULNERABILITY FOR MATARAM CITY IN LOMBOK ISLAND – INDONESIA: A PHYSICAL AND SOCIOECONOMIC ASSESSMENT

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Abstrak

Letak kedekatan lokasi geografis dengan lempeng tektonik *Eurasian* dan *Indo-Australian* membawa konsekuensi logis terhadap tingginya resiko kebencanaan, terutama gempa dan tsunami, bagi Indonesia. Kota Mataram yang merupakan ibukota Provinsi Nusa Tenggara Barat merupakan salah satu wilayah yang perlu mendapatkan perhatian khusus terhadap resiko bencana tsunami. Sebagai langkah awal, identifikasi lokasi yang paling rentan terhadap resiko bencana tsunami perlu dilakukan dengan memadukan aspek-aspek fisik, sosial dan ekonomi. Penelitian ini bertujuan mengidentifikasikan lokasi paling rentan terhadap resiko bencana tsunami di Kota Mataram dengan menggunakan analisa sistem informasi geografis (*GIS*). Penilaian dilakukan dengan mengembangkan Indeks Gabungan (*Composite Index*) berupa *Total Vulnerability Index* (*TVI*) yang merupakan kombinasi Indeks Kerentanan Fisik/ *Physical Vulnerability Index* (*PVI*), Indeks Kerentanan Sosial/ *Social Vulnerability Index* (*SVI*) dan Indeks Kerentanan Ekonomi/ *Economic Vulnerability Index* (*EVI*). Hasil analisis berhasil menemukenali bahwa Kota Tua Ampenan merupakan wilayah di Kota Mataram dengan nilai indeks gabungan tertinggi yang mencerminkan tingkat kerentanan yang paling tinggi.

Kata Kunci: Mataram, Tsunami, Vulnerability, GIS, Composite Index.

1. INTRODUCTION

Human settlements are concentrated in the coastal area, being vulnerable to specific hazards such as tsunami, coastal flooding and coastal-related diseases (Adger, Hughes, Folke, Carpenter, & Rockström, 2005). Due to the proximity of Indonesia to Indian Ocean, which is a convergent boundary between Eurasian and Indo-Australian plates, Indonesia is very vulnerable to undersea earthquakes. In 2004, the collision between these two tectonic plates was responsible for earthquake-induced tsunami which resulted in, at least, 150,000 fatalities (Indonesian National Disaster Management Authority, 2014). According to National Geophysical Data Center (2014), more than 300 significant earthquakes were recorded in Indonesia during 1629 – 2013. Meanwhile, three significant earthquakes occurred in Lombok Island where one of the earthquakes resulted in tsunami in 1856 (Hamzah, Puspito, & Imamura, 2000; Rynn, 2002). In 2013, an earthquake hit the area surrounding Mataram and destroyed more than 5,000 houses (National Geophysical Data Center, 2014). Fortunately, the last earthquake did not result in a tsunami event.

Recent studies and initiatives have been done due to the increasing awareness to reduce the impact of tsunami in Mataram. Mueck (2013) has been able to generate a map of tsunami hazard for Mataram based on the estimated time arrival with three scenarios of earthquake magnitude. The finding for this inundation model suggests that tsunami is possible to happen with the minimal height of 0.5 meters and a severe destruction is likely to occur within 500-meter proximity to the coastline. Further, the recent model by the Alfred Wegener Institute has produced a map of the level of destruction based on tsunami propagation wave (Rakowsky et al., 2013). In urban planning, initiatives have been started by the local government by putting the agenda of tsunami

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mitigation in their strategic plans and statutory frameworks (Local Government of Mataram, 2011). Further, the local government also considers developing an inventory map for historical and potential tsunami hazards for Lombok Island (Mueck, 2013). Tsunami evacuation paths and procedures were also established to reduce the severity of the impacts such as a map by Oswald, Astini, and Herman (2013). In addition, Sudiartha and Santoso (2011) propose a new model of integrated tsunami early warning system for all areas in Mataram. Currently, several tsunami buoys have been installed and broadband seismic networks have been upgraded since 2004 to support the early warning system (Bautista, 2007). These are the rising concern about the impact of tsunami in Mataram. However, these studies and initiatives have not addressed the degree of vulnerability for each district in Mataram in terms of physical and socioeconomic conditions. Therefore, this project is intended to fill this gap by assessing the physical and socioeconomic conditions to determine the level of vulnerability.

Mataram is the capital of West Nusa Tenggara Province. The status of the city as a capital city brings a question about the impact of destruction in a case of tsunami. Not just the impact would be in the local context but the severity would expand to a regional and national scale. As the impact of tsunami which occurred in Indonesia in the past was very detrimental, the level of vulnerability should be investigated in order to understand what action and priority should be taken in order to reduce the risk. Previous studies throughout the globe consider that the vulnerability to disaster is not only composed by physical aspects but also socioeconomic aspects, such as Clark et al. (1998); Cutter, Boruff, and Shirley (2003); Eddy (2011) and Papathoma, Dominey-Howes, Zong, and Smith (2003). This is based on the notion that the level of vulnerability to disaster is not only influenced by physical environment. Rather, the socioeconomic conditions will also contribute to the degree of vulnerability of a place (Cutter, 1996). The severity is not just on the day of the event but also in the reconstruction phase and recovery process. Therefore, this project questions "which area in Mataram is the most vulnerable to tsunami in terms of physical and socioeconomic aspects?"

This project aims to understand the level of vulnerability to tsunami in Mataram City, assessing physical and socioeconomic conditions which compose the level of vulnerability. In order to do so, consecutive analyses using GIS were conducted in order to develop a composite index of vulnerability. The composite index is a Total Vulnerability Index (TVI) composed by three components of vulnerability index, including 1) Physical Vulnerability Index (PVI); 2) Social Vulnerability Index (SVI); and 3) Economic Vulnerability Index (EVI). The finding suggests that, within 6 districts in Mataram, Ampenan District is the most vulnerable area. More than 90% area of this district is categorised as having high to very high level of vulnerability. Interestingly, Sekarbela District, which is located in the coastline, is likely to be the least vulnerable as more than 50% area of this district achieves the level of vulnerability from very low to low. Ultimately, this project can be beneficial for planning, program evaluation, community development and foundation for future studies

2. MATERIALS AND METHODS

Geographical Setting. Mataram City is located in the Lombok Island and geographically ranging from 8°33' – 8°38' South Latitude and 116°04' – 116°10 East Longitude. This city is about 1,058 kilometres from Jakarta, the Capital of Indonesia. Physically, the city is located on a low land area with the elevation of 0-73 meter with the slope of 0-2%, 2-15% and 15-40% formed by alluvium sediment. The overview of Mataram in the national and regional context can be seen in Figure 1.

Mataram City is delimited by West Lombok Region and Lombok Strait. The city is divided into 6 (six) districts including Ampenan, Selaparang, Cakranegara, Mataram, Sekarbela and Sandubaya (see Figure 2). The vast majority people living in Mataram work on non-agricultural sector. The spatial structure of the City is designated as spaces for several activities including built areas and protected areas. The built areas comprise settlements, government districts, trade areas, industrial areas, tourism areas and agricultural zones. Meanwhile, the protected areas include water conservation areas, cultural heritages, disaster-zoned areas and public open spaces.

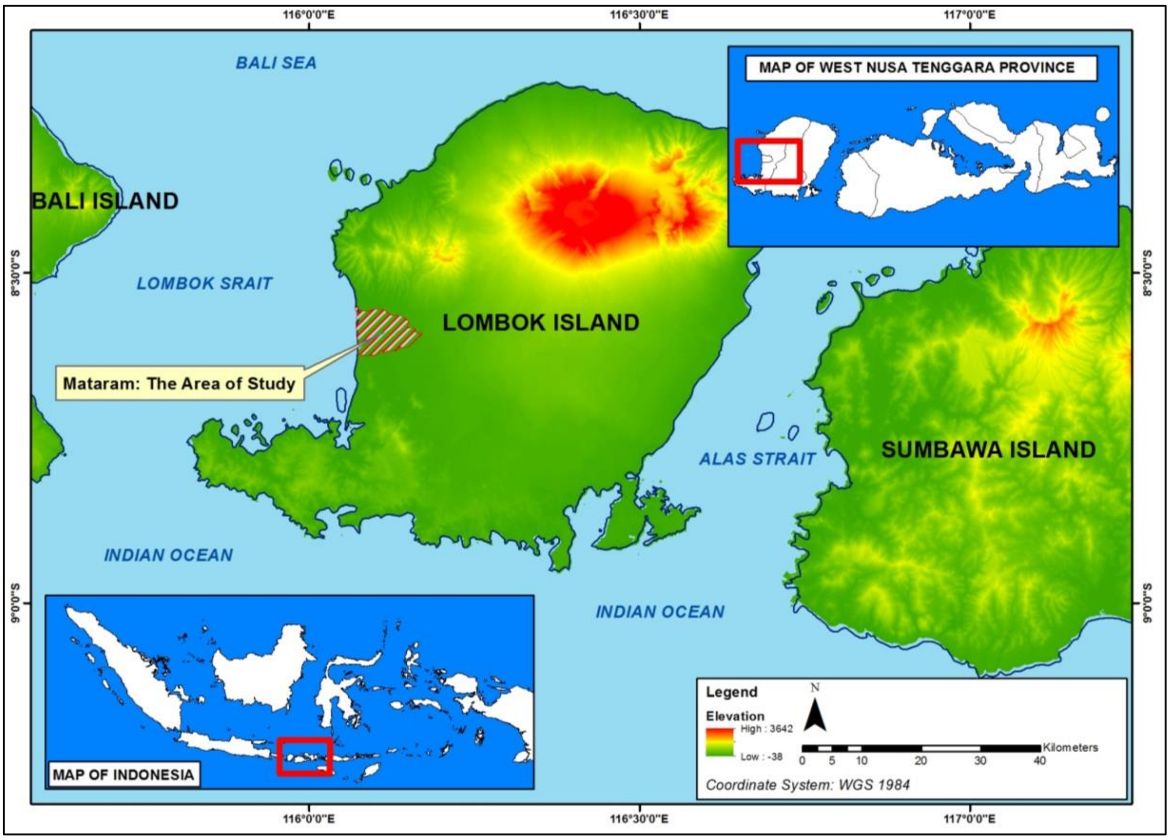

Figure 1. Mataram in the National and Regional Context

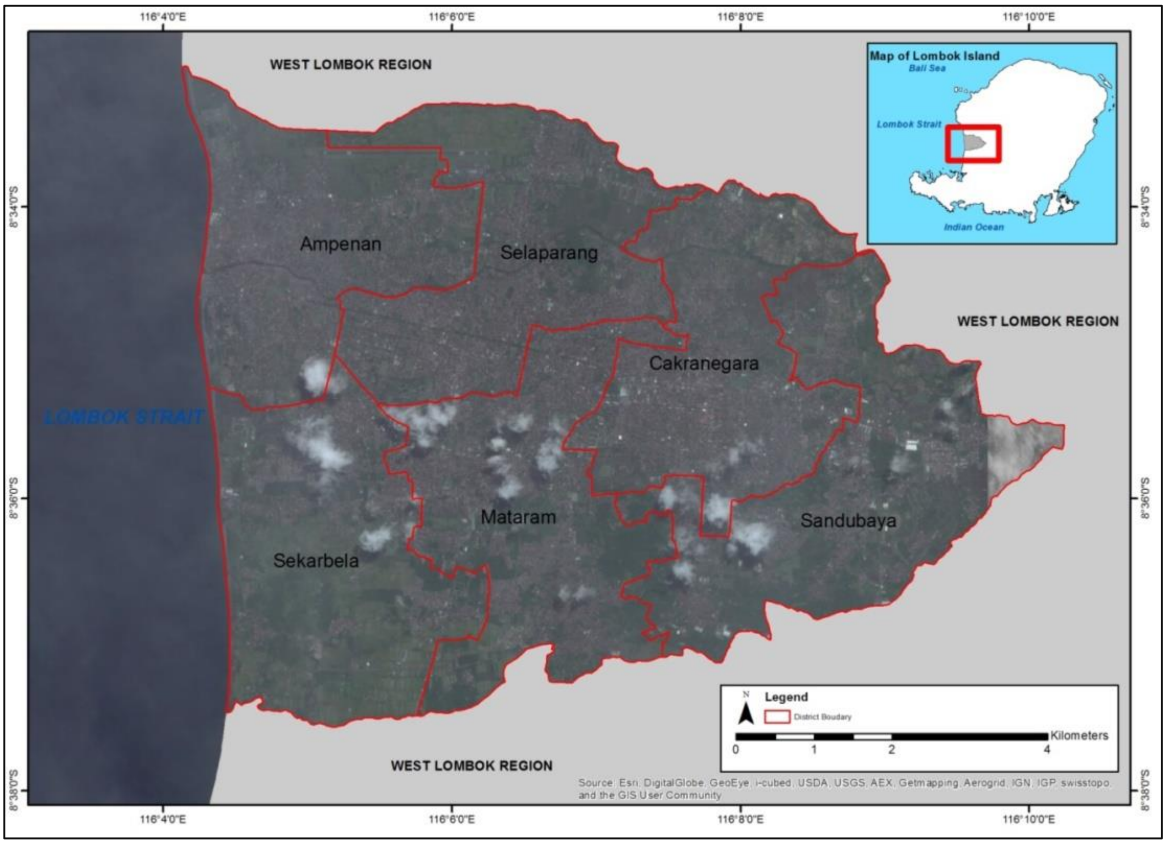

Figure 2. Administrative Boundaries of Mataram

The Framework of Vulnerability to Tsunami. In this project, the assessment of the level of vulnerability combined physical characteristics and socioeconomic conditions in order to develop a composite index of vulnerability. The composite index of vulnerability was developed based on the several frameworks developed by previous works and studies. Table 1 summarizes the variable involved in this project as derived from physical, social and economic aspects inlfluencing the level of vulnerability to tsunami.

Data Requirements. This project required spatial and textual data to construct the composite index of vulnerability based on the physical and socioeconomic aspects as summarized in the table 1. Further, table 2 details the data required in the project, the source and a brief description of the metadata. Some data are available online but some them are unavailable online. Therefore, the unavailable data should be obtained by directly contacting the respective agency.

Physical Aspects

Topographic Elevation. Topographic elevation is a primary variable to assess the vulnerability of tsunami in a region (Eddy, 2011; Najihah, Hairunnisa, & Masiri, 2014; Sinaga, Nugroho, Lee, & Suh, 2011). In this project, DEM from SRTM Data with 90m resolution were used to extract the elevation data. The 90m grid were downscaled to 30m grid using bilinear interpolation as this method is able to provide the most reliable result (Grohman, Kroenung, & Strebeck, 2006). The elevation data were reclassified into five categories according to the work by Najihah et al. (2014) and Sinaga et al. (2011). Following that, each cell of raster was assigned a value depending on the level of vulnerability as mentioned in Sinaga et al. (2011) and Najihah et al. (2014). Table 3 summarizes the score of vulnerability to tsunami based on the elevation data. Meanwhile Figure 3 depicts the vulnerability of Mataram City in terms of elevation.

Slope. The impact of tsunami can be severe on a low land area with relatively flat slope (Eddy, 2011; Sinaga et al., 2011). This is because the run off can easily flow without having substantial disturbance from topographic variations. In this project, a slope map was created from SRTM Data using the algorithm by Burrough and McDonell (1998) in the ArcGIS 10.2 package. After the slope map was created, the slope map was then reclassified into five levels of vulnerability as shown in the Table 4. The classes of vulnerability was adopted from the work by Sinaga et al. (2011). Each cell in the raster data was then assigned a value representing the level of vulnerability. Figure 4 depicts the vulnerability class of Mataram to tsunami based on the slope classification.

Land Use. Land use is one of important factors which contribute for the degree of severity in tsunami and other hazardous events. Some studies such as Papathoma et al. (2003), Papadopoulos and Dermentzopoulos (1998) and Najihah et al. (2014) take account this variable to assess the degree of vulnerability to tsunami. This project adopts the work by Najihah et al. (2014) to determine the level of vulnerability based on the type of landuse as defined in Table 5. However, the modification was required as the classification by National Land Agency of the Republic of Indonesia (2013a) does not fit the criteria as outlined by Najihah et al. (2014).

The modification of land-use classification includes changing the criteria of high density urban areas and low-density urban areas into planned and unplanned urban areas. The reason for this modification is that the classification of unplanned/planned settlements in Mataram considers the density of settlements (National Land Agency of the Republic of Indonesia, 2014). The low density settlement is taken into account to classify the settlement as planned settlements while the unplanned settlements seem to be high-density. Other than that, the planned settlements are more likely to have less degree of vulnerability (Edwards, Gustafsson, & Näslund-Landenmark, 2003). Therefore, this technique may replace the criteria as outlined by Najihah et al. (2014). In this project, the 26 classification of original land use data obtained from the National Land Agency as depicted in Figure 5 were reclassified into five major categories which reflect the degree of vulnerability. All vector data were converted into raster data and were then reclassified following the classes as presented in Table 5. After that, each cell value was given a value which represents the degree of vulnerability.

Distance from the Coastline. Distance from the coastline is definitely the main feature influencing the degree of destruction in the tsunami event. In general, it can be concluded that the degree of

Table 1
Variables Used in the Project Drawn from Some Previous Studies.

Nature	Variable	Previous Study
Physical Aspects	Topographic Elevation	Najihah et al. (2014); Sinaga et al. (2011)
	Slope	Sinaga et al. (2011)
	Type of Landuse	Najihah et al. (2014); Papadopoulos and Dermentzopoulos (1998); Papathoma et al. (2003)
	Distance from the Coastline	Najihah et al. (2014); Sinaga et al. (2011)
Social Aspects	The number of population	Eddy (2011); Papathoma et al. (2003)
	The number of women	Eddy (2011)
	The number of children and elderly	Clark et al. (1998); Cutter et al. (2003); Eddy (2011)
	The number of people living with disability	Cutter et al. (2003); Eddy (2011)
Economic Aspect	The number of people living with poverty	Clark et al. (1998); Eddy (2011)
	The number of People dependent of fishery sector	Agung (2012); Eddy (2011)

Table 2
Data Requirement, Type of Data and Source

No	Data	Type of Data	Source and Metadata
1	Digital Elevation Model	3 arc-second SRTM with 90m resolution for global coverage.	U.S. Geological Survey (USGS). Coordinate System for this dataset is Geographic Coordinate System WGS 1984.
2	Land Use Data	Vector Data Surveyed in 2013	The data are obtained from National Land Agency of the Republic of Indonesia (*BPN RI*). This is the latest updated database of land use system in Mataram. The accuracy of this data is 100m by the interpretation of high resolution image combined with cadastral survey conducted in 2013. The coordinate system for this dataset is WGS 1984 UTM Zone 50.
3	Administrative Boundaries and Coastal Line.	Vector Data 2010	The data are obtained from Indonesian Spatial Bureau (*Bakosurtanal*) for Coastal Line and the Local Government of Mataram for Adminisrative Boundaries as re-surveyed by National Land Agency. This is the latest administrative delimitation for Mataram with the scale of 1:10,000. The coordinate system for these maps is Geographic Coordinate System WGS 1984 for Coastal Line and DGN 1995 Indonesia TM-3^{o} Zone 50.1 for the Administrative Boundaries.

No	Data	Type of Data	Source and Metadata
4	The number of Female for each district in Mataram	Tabular - Census Data 2010	Indonesian Central Bureau of Statistics - *BPS*
4	The number of Children for each district in Mataram	Tabular - Census Data 2010	Indonesian Central Bureau of Statistics - *BPS*
5	The number of Elderly for each district in Mataram	Tabular - Census Data 2010	Indonesian Central Bureau of Statistics - *BPS*
6	The number of people with disability for each district in Mataram	Tabular - Census Data 2010	Indonesian Central Bureau of Statistics - *BPS*
7	The number of people living in poverty for each district in Mataram	Indonesian Poverty Database 2010 by District	National Planning Agency of Republic of Indonesia – *Bappenas*
8	The number of people working in fishery for each district in Mataram.	Tabular - Census Data Compiled in 2010 and adjusted in 2013	Indonesian Central Bureau of Statistics - *BPS*

Table 3
Vulnerability Score Based on Elevation

Range of elevation	Description	Vulnerability Score
<5 m	Very High	5
5 – 10 m	High	4
10 – 15	Medium	3
15 – 20	Low	2
>20	Very Low	1

Source: Najihah et al. (2014) and Sinaga et al. (2011)

Table 4
Vulnerability Score Based on Slope

Range of slope	Description	Vulnerability Score
0 – 2%	Very High	5
2 – 6%	High	4
6 – 13%	Medium	3
13 – 20%	Low	2
>20%	Very Low	1

Source: Sinaga et al. (2011)

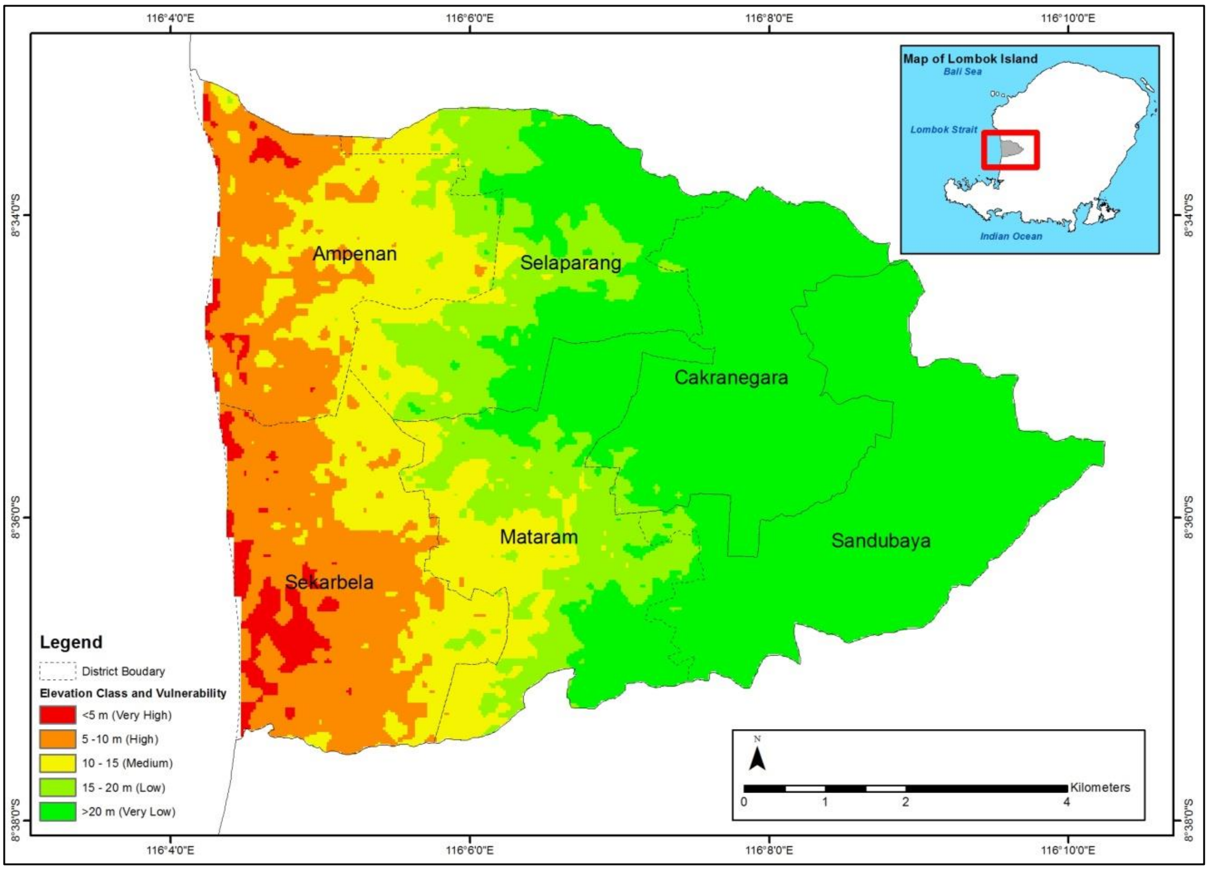

Figure 3. The Level of Vulnerability Based on Topographic Elevation.

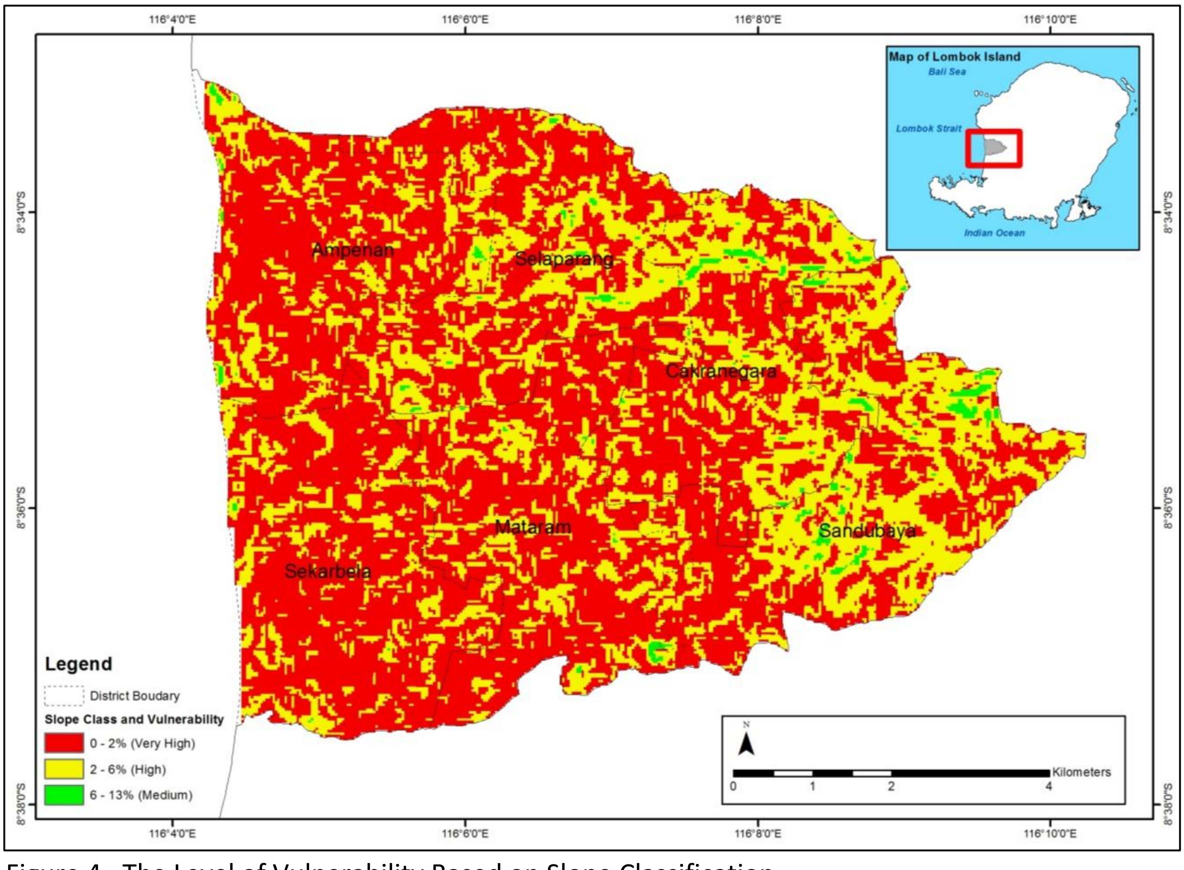

Figure 4. The Level of Vulnerability Based on Slope Classification.

Table 5
Vulnerability Score Based on Land Use Type

Land use type	Description	Vulnerability Score
Unplanned Urban Areas	Very High	5
Planned Urban Areas	High	4
Agriculture and Aquaculture	Medium	3
Water Bodies	Low	2
Forest, Mangrove and Inactive Urban Spaces	Very Low	1

Adopted from: Najihah et al. (2014)

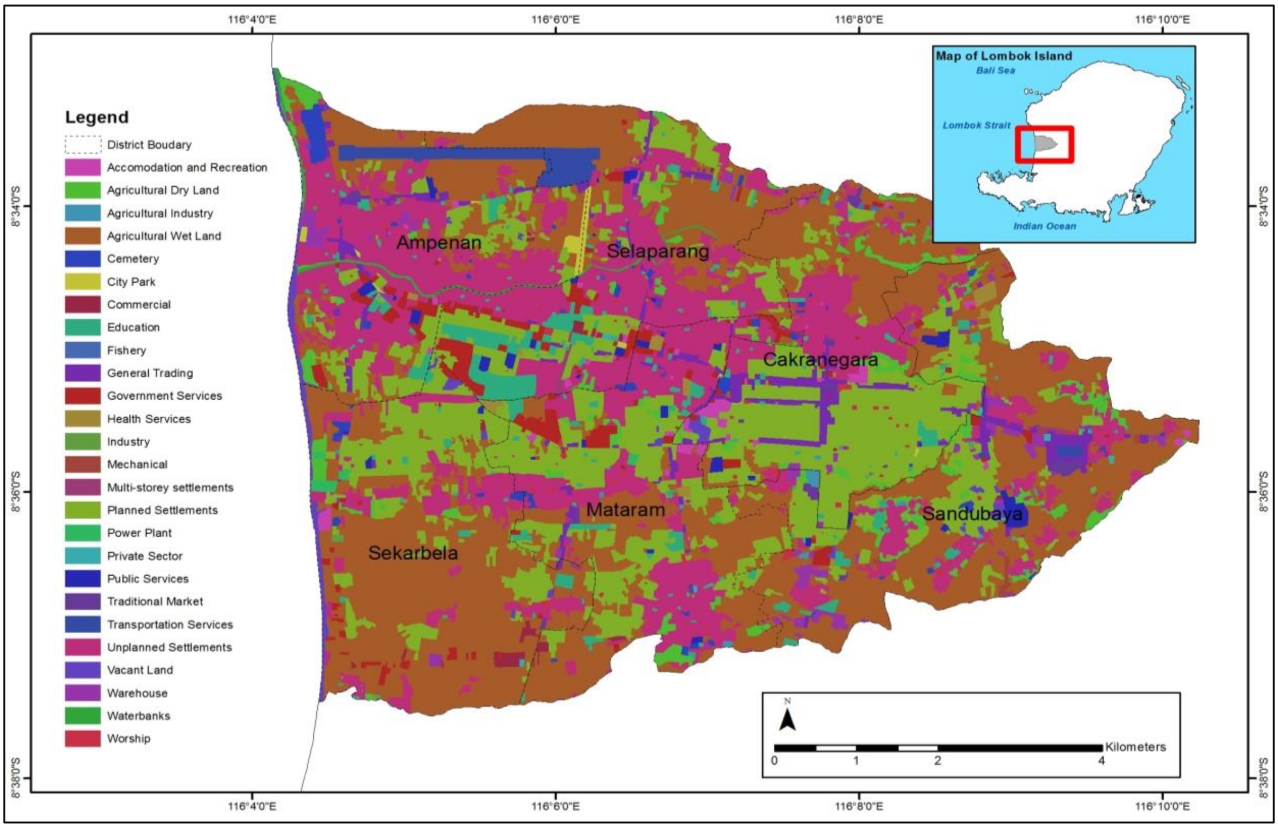

Figure 5. Original Land Use Classification 2013 by National Land Agency of the Republic of Indonesia (2013a).

vulnerability decreases as the proximity to the coast increases. In this project, the classification of vulnerability based on coastal proximity is based on a method developed by Bretschneider and Wybro (1976). This method is also adopted in the study by Eddy (2011) and Sinaga et al. (2011).

Social Aspects. The social vulnerability was determined by calculating the proportion population, the proportion of female, the proportion of children and elderly and the proportion of disabled people for each district to the total population of each variable in the city scale. There are several reasons to draw the variable. First, a large population in each district makes difficulty in the evacuation process (Papathoma et al., 2003). Second, the victim of female exceeded the male victim in the last Indian tsunami as female tend to stay at home and to save their children without considering their safety (Eddy, 2011). Third, the group of children and elderly may have difficulty and need assistance during the disaster event (Clark et al., 1998; Cutter et al., 2003). Fourth, disabled people often have the issue of mobility when disasters occur (Cutter et al., 2003).

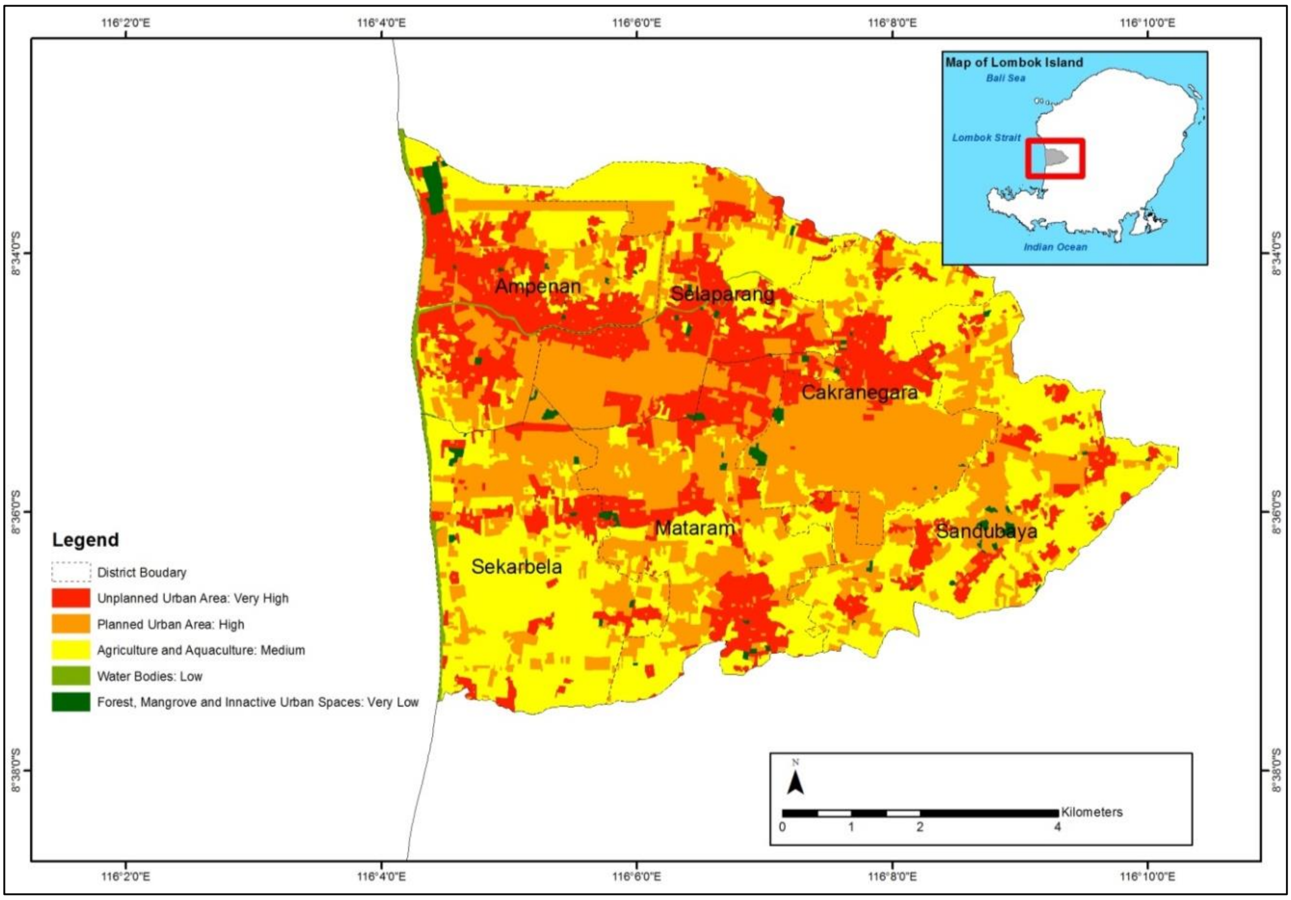

Figure 6. The Level of Vulnerability Based on Land Use Classification

Following the work and formula by Eddy (2011), the proportion of each criteria was first calculated. After that, the formula for social assessment as outlined by Eddy (2011) was applied in order to maintain the scale of every criterion. In this method, the district which has the highset population for each variable will have a score of 1.00 as the highset social vulnerability score. Table 7 details the score of social vulnerability for each social factor. After each score of social vulnerability was calculated, the score was then attributed to the administrative map through ArcGIS.

Economic Aspects. The calculation of the score of economic vulnerability also follows the framework by Eddy (2011) with the variable of people living with poverty and people working on fishery sector by district. Poor people may have less capacity to build houses which can be used for shelters, less capacity to access health services and limited access to resources (Clark et al., 1998). Meanwhile, people working in the fishery sector seem to find difficulty in the recovery phase after the tsunami event (Agung, 2012; Mills, Adhuri, Phillips, Ravikumar, & Padiyar, 2011). The score of economic vulnerability is given in Table 8. After each score of economic vulnerability was calculated, the score was then attributed to the administrative map.

Developing Composite Index of Vulnerability. The level of vulnerability in this project is basically a composite index which combines physical, social and economic aspect (Equation 1). Scores for vulnerability are already determined as previously discussed in this section. After each raster cell was assigned a score, each cell was weighted by multiplying the score and the weighting value (Table 9). Following that, all cells for each aspect were summed up to produce the physical index (PVI), the social index (SCI) and the economic index (EVI). Consecutively, all indices are combined using raster calculators to produce the total vulnerability index (TVI). This method was the most prominent method used in this project. Delaney and Van Niel (2007) explain that map algebra is the most flexible and useful tool when conducted thoroughly. The process of analysis is detailed in Figure 9.

Equation 1
TVI = PVI + SVI + EVI, where TVI: Total Vulnerability Index; PVI: Physical Vulnerability; SVI: Social Vulnerability Index; and EVI: Economic Vulnerability Index.

Geoprocessing. This project was conducted by setting several parameters in geoprocessing when conducting spatial analysis. First, UTM projected coordinate system (UTM Zone 50S) with the datum of WGS 1984 was applied to ensure the uniformity. Second, all raster conversions and raster analyses were set into the cell size of 30x30. Third, the city border (outline) was also determined as the extent of spatial processing to lock the scale. All parameters for spatial analysis were set into the same value in order to reduce errors when conducting spatial analysis.

3. RESULTS

Physical Vulnerability Index (PVI). The highest Physical Vulnerability Index (PVI) is 435 and the lowest PVI is 230. Ampenan District seems to have the highest characteristic of PVI with mean value of 345. Meanwhile, Mataram District achieved the lowest mean of PVI (315). Table 10 details the statistical characteristics of physical vulnerability for each district in Mataram whereas Figure 8 depicts the spatial distribution of PVI for Mataram.

Social Vulnerability Index (SVI). Based on the development of Social Vulnerability Index (SVI), Ampenan District achieved the highest level of SVI. Ampenan is also the most vulnerable in terms of SVI compared to other districts (Table 11). Meanwhile, Sekarbela only achieves the SVI of 66 which is the lowest SVI. Figure 10 depicts the spatial distribution of SVI for tsunami in Mataram.

Economic Vulnerability Index (EVI). The calculation process of scoring and weighting on economic aspects produced the Economic Vulnerability Index (EVI) for tsunami with the highest EVI located in Ampenan District which achieves the EVI value of 100. Meanwhile, the lowest value of EVI is achieved by Mataram District. Table 12 details EVI for each district in Mataram. Meanwhile the spatial distribution of EVI is depicted by Figure 11.

Total Vulnerability Index (TVI) for Tsunami. The raster calculator employed to combine physical and socioeconomic aspects is able to generate a grid dataset representing the Total Vulnerability Index for Tsunami (TVI) with 66,713 cells. The lowest value for this dataset is 345 located in Sekarbela and the highest value is 634 located in Ampenan. In terms of other statistical characteristics, Table 13 clearly reveals that Ampenan is the district that achieved the highest mean value for TVI whereas the lowest mean value is achieved by Mataram Districts. Figure 12 shows the spatial distribution of total vulnerability index in Mataram City.

4. DISCUSSION

The Total Vulnerability index (TVI) generated from the analysis was further classified into five classes of vulnerability using Jenk's Natural Breaks algorithm in order to create internally homogenous groups as presented in Table 14. Based on this classification, it seems that Ampenan Disrict is very vulnerable to tsunami as 99% area of very highly vulnerable area in Mataram was identified in this district. Within the district, Table 15 and Figure 13 also suggest that 70% area of Ampenan is very vulnerable. Unplanned land use is likely to determine the high level of physical vulnerability for this district. Almost 40% area of the district is dominated by unplanned urban area (National Land Agency of the Republic of Indonesia, 2013b). Further, the socioeconomic condition seemingly increases the level of vulnerability since the socioeconomic index for Ampenan is the highest compared to other districts. This means that a future investigation should be made in Ampenan District to investigate the real socioeconomic activity in this district. A further assessment with detailed socioeconomic data at a sub-district level can be done to reveal the level of vulnerability at a sub-district level.

The physical and socioeconomic condition of Ampenan has a close relationship with history and the characteristic of urban growth of Mataram. Historically, Ampenan is the embryo of Mataram City in the era of Dutch Colonialism, which established economic infrastructures in Ampenan (Jamaludin et al., 2011). Consequently, an economic agglomeration and urbanization occurred in this

Table 6
Vulnerability Score Based on the Proximity from the Coastline

Distance from coast line	Description	Vulnerability Score
< 556m	Very High	5
556 – 1,400m	High	4
1,400 – 2,404m	Medium	3
2,404 – 3,528m	Low	2
> 3,528 m	Very Low	1

Table 7
Social Vulnerability Score for Each District

District	Actual Number				Score of Vulnerability			
	Population	Women	Children and Elderly	Disabled People	Population	Number of Female	Number of Children and Elderly	Number of Disabled People
Ampenan	78,779	39,112	23,065	5,435	1.000	1.000	1.000	0.970
Cakranegara	64,087	32,451	18,773	5,396	0.814	0.830	0.814	0.963
Mataram	73,107	37,279	20,584	5,364	0.928	0.953	0.892	0.957
Sandubaya	61,093	30,630	19,195	3,337	0.775	0.783	0.832	0.595
Sekarbela	53,112	26,881	14,559	3,621	0.674	0.687	0.631	0.646
Selaparang	72,665	37,158	18,143	5,604	0.922	0.950	0.787	1.000

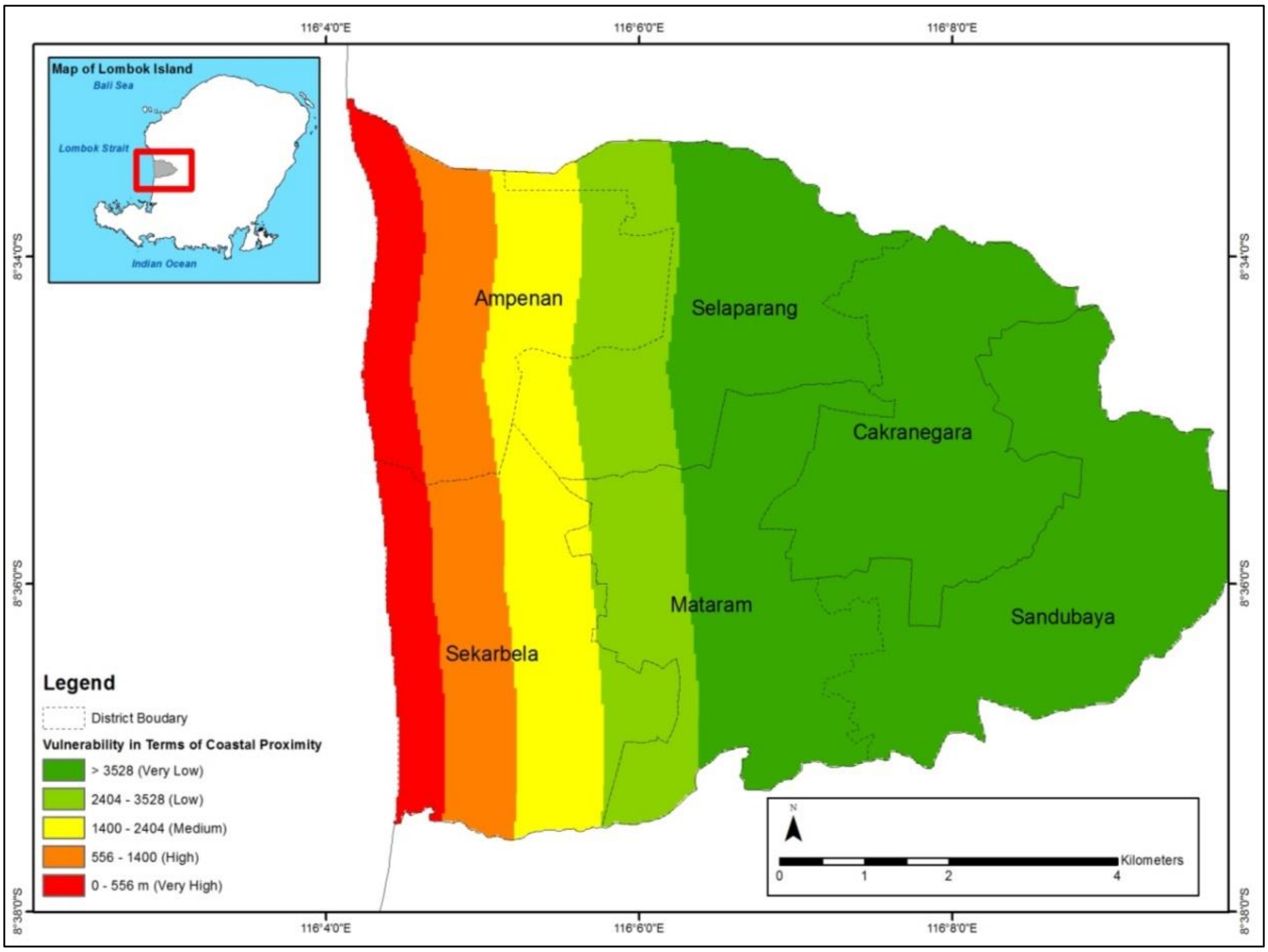

Figure 7. The Level of Vulnerability Based on the Proximity from the Coastline

Table 8
Economic Vulnerability Score for Each District

District	Number of people with poverty	Number of people in Fishery Sector	Vulnerability Score for Poverty	Vulnerability Score for Fishery Sector
Ampenan	12,158	1,123	1.00	1.00
Cakranegara	10,484	47	0.86	0.04
Mataram	8,457	36	0.70	0.03
Sandubaya	11,671	20	0.96	0.02
Sekarbela	7,717	394	0.63	0.35
Selaparang	9,691	46	0.80	0.04

Table 9
Variables, Criteria, Score of Vulnerability and Weight

Aspects	Variable	Criteria	Score of Vulnerability	Weight	Method of Weighting
Physical	Topographic elevation	<5 m	5	35	Eddy (2011)
		5 – 10 m	4		
		10 – 15	3		
		15 – 20	2		
		>20	1		
	Slope	0 – 2%	5	15	Eddy (2011)
		2 – 6%	4		
		6 – 13%	3		
		13 – 20%	2		
		>20%	1		
	Land use	Unplanned Urban Areas	5	15	Eddy (2011)
		Planned Urban Areas	4		
		Agriculture and Aquaculture	3		
		Water Bodies	2		
		Forest, Mangrove and Inactive Urban Spaces	1		
	Distance to coastline	< 556m	5	35	Eddy (2011)
		556 – 1,400m	4		
		1,400 – 2,404m	3		
		2,404 – 3,528m	2		
		> 3,528 m	1		
Social	Total population for each District	Proportion of population in each district to the city	Calculated with proportion formula	25	Eddy (2011)
	Number of female	Proportion of female in each district to the city	Calculated with proportion formula	25	Eddy (2011)
	Number of children and elderly	Proportion of children and elderly in each district to the city	Calculated with proportion formula	25	Eddy (2011)

Aspects	Variable	Criteria	Score of Vulnerability	Weight	Method of Weighting
	Number of disabled people	Proportion of Disable in each district to the city	Calculated with proportion formula	25	Eddy (2011)
Economic	Number of people living with poverty	Proportion of People with poverty in each district to the city	Calculated with proportion formula	50	Eddy (2011)
	Number of fisherman	Proportion of People with poverty in each district to the the city	Calculated with proportion formula	50	Eddy (2011)

Table 10
The Statistical Characteristic of Physical Vulnerability Index for Each District in Mataram

District	Cell Count	Min Value	Max Value	Range	Mean	Median
Ampenan	10059	245	435	190	347	345
Cakranegara	9983	250	360	110	335	330
Mataram	11268	245	395	150	319	315
Sandubaya	13081	270	360	90	330	330
Sekarbela	11718	230	430	200	327	330
Selaparang	10604	230	415	185	332	330

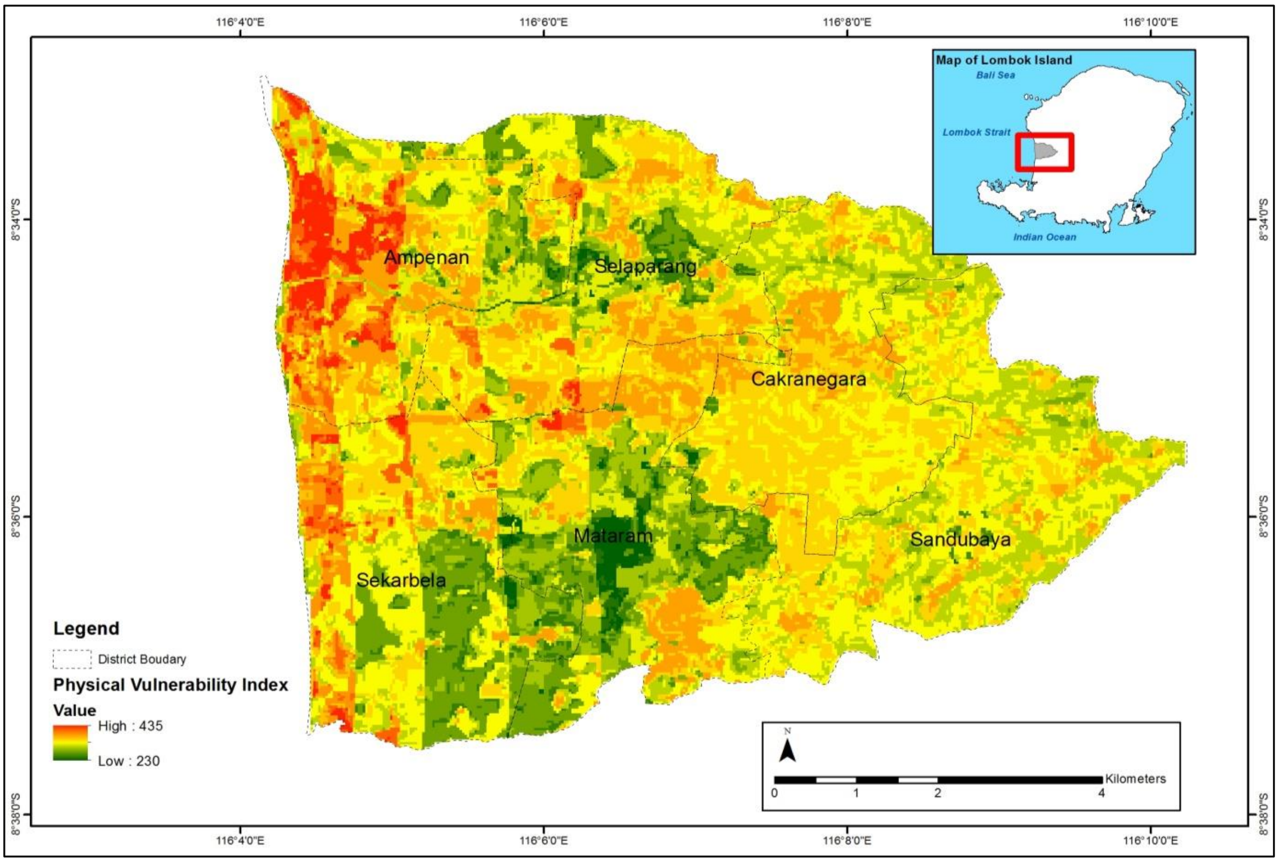

Figure 8. Map of Physical Vulnerability Index (PVI) for tsunami

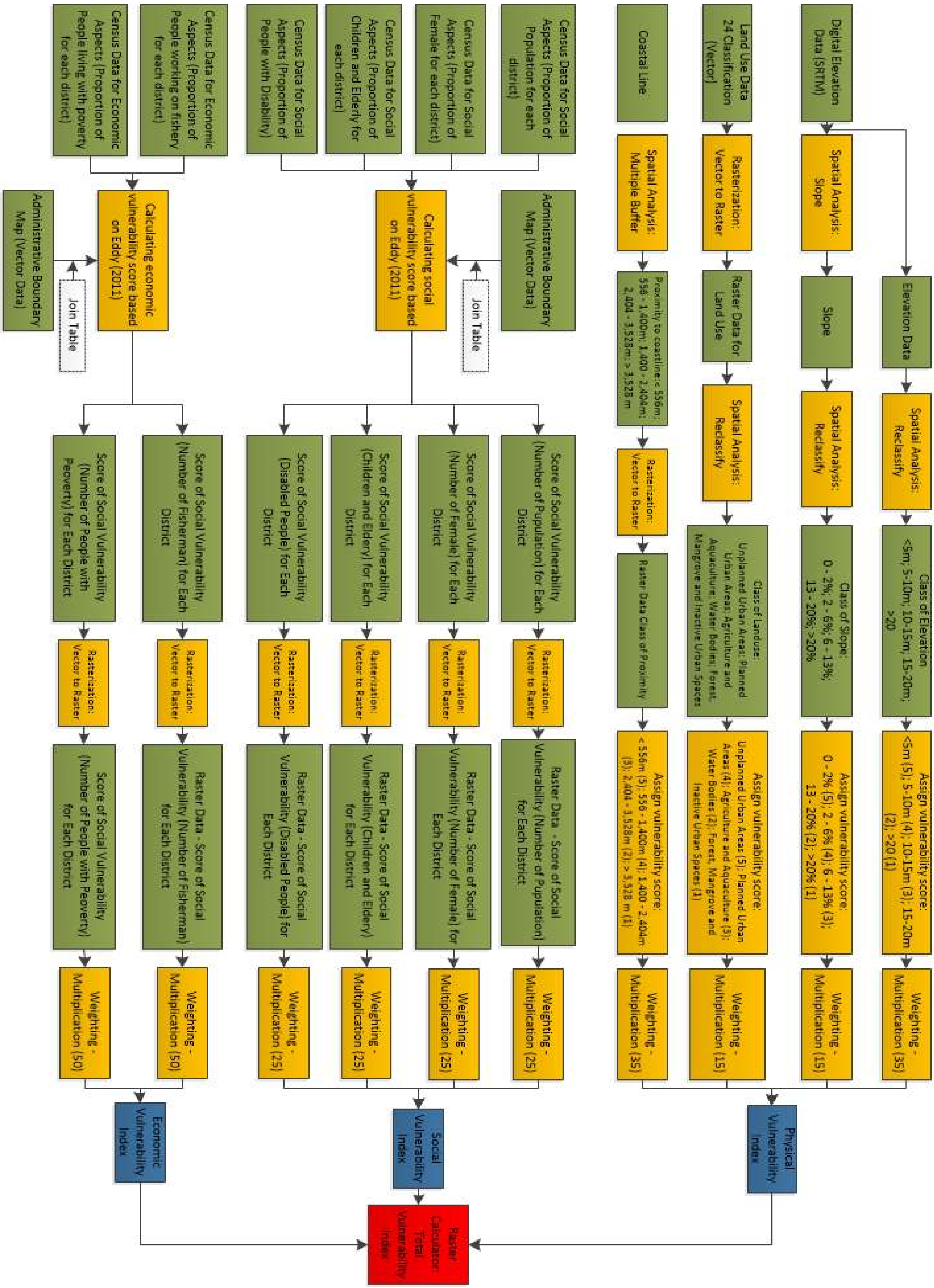

Figure 9. A Consecutive Process in Developing Vulnerability Index for Tsunami in This Project.

area. The area is now very dense with a high variation of socioeconomic conditions. As the economy grows, the area develops sporadically and the population is concentrated in this district with a high level of poverty. This seems also to make the socioeconomic vulnerability is very high in this district.

The strategy in reducing the risk of tsunami for this area should not only focus on physical conditions but also socioeconomic conditions. For instance, the physical aspects should consider the path for evacuation, the creation of evacuation facilities or any other physical aspects. Meanwhile, community development is encouraged to educate people and increase the capacity in facing unprecedented impacts of disaster. Social capital plays a large role in the level of resilience of coastal communities (Adger et al., 2005; Mathbor, 1997, 2007). Therefore, as Adger (2006) argues that the increase of social capital may improve the capacity to adapt disasters and global changes, decreasing the level of socioeconomic vulnerability may help the coastal community to prepare the tsunami disaster.

Sekarbela District, though located near to the coastline, is not as vulnerable as Ampenan District. Sekarbela achieved the lowest mean value of TVI. Table 14 suggests that more than 50% of least vulnerable area is located in this district. Furthermore, more than 70% area in this district achieved the level of vulnerability from very low to medium. This is indicative that the proximity from the coast is not important when it comes to combining socioeconomic characteristics with physical characteristics. The socioeconomic factors seemingly moderate the effect. Moreover, this district is characterised by low-density residential area. Most of land in this district is agricultural land and is not occupied by an intensive human activity. However, the recent issue for this area is an intensive development for residential areas. The built environment for residential areas increased significantly by 28% during 2008-2013 (National Land Agency of the Republic of Indonesia, 2013b). The development is mostly conducted by converting agricultural land into residential areas. It is important to note that landuse play a role in physical vulnerability. Furthermore, the rapid urban growth will also increase the population which, in turn, contributes to the level of social vulnerability. Therefore, the development of residential areas for this district should ensure the principles of disaster management in order to reduce the impact of destruction in a case of tsunami. The design of urban fabric is a key role to reduce the impact of destruction of the area. A bad land use planning will make the community more prone to disaster and reduce the ability of the community to adapt the disaster (Glavovic, Saunders, & Becker, 2010). Permitted development should ensure the optimal density and mitigation plans in order to reduce the severity of the impact (Eisner, 2005). Therefore, a good practice in urban planning will allow the community to reduce the level vulnerability.

Table 11
The Social Vulnerability Index for Each District in Mataram

District	Index for Total Population	Index for Female	Index for Children and Elderly	Index for Disability	Social Vulnerability Index (SVI) in integer value
Ampenan	25.00	25.00	25.00	24.25	99
Cakranegara	20.34	20.74	20.35	24.07	85
Mataram	23.20	23.83	22.31	23.93	93
Sandubaya	19.39	19.58	20.81	14.89	75
Sekarbela	16.85	17.18	15.78	16.15	66
Selaparang	23.06	23.75	19.67	25.00	91

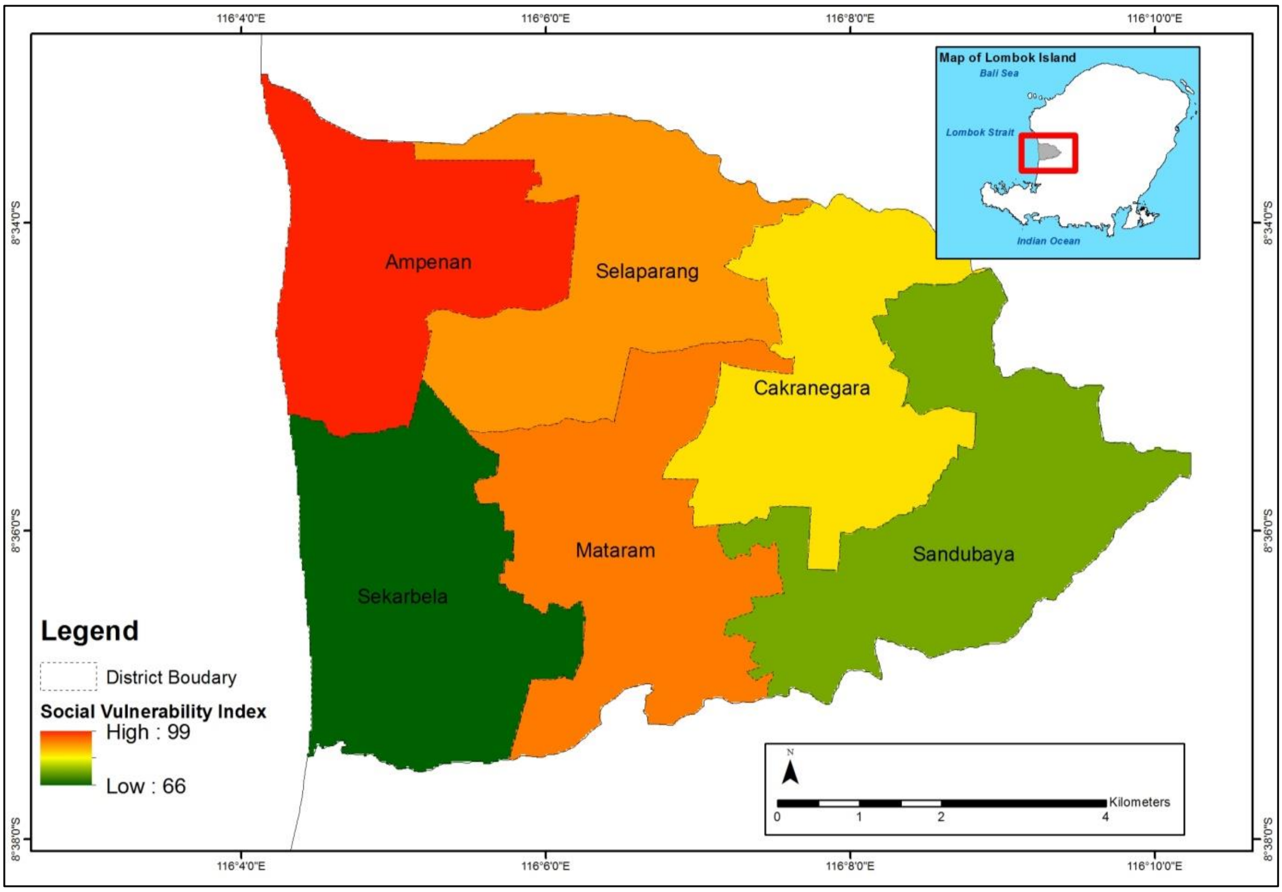

Figure 10. Map of Social Vulnerability Index for tsunami

Table 12
The Economic Vulnerability Index for Each District in Mataram

District	Index for Poverty	Index for Fishery Sector	Economic Vulnerability Index (EVI) in integer value
Ampenan	50.00	50.00	100
Cakranegara	43.12	2.09	45
Mataram	34.78	1.60	36
Sandubaya	48.00	0.89	49
Sekarbela	31.74	17.54	49
Selaparang	39.85	2.05	42

Table 13
The Total Vulnerability Index for Each District in Mataram

District	Cell Count	Min Value	Max Value	Mean	Median
Ampenan	10,059	444	634	546	544
Cakranegara	9,983	380	490	465	460
Mataram	11,268	374	524	448	444
Sandubaya	13,081	393	483	453	453
Sekarbela	11,718	345	545	443	445
Selaparang	10,604	363	548	465	463

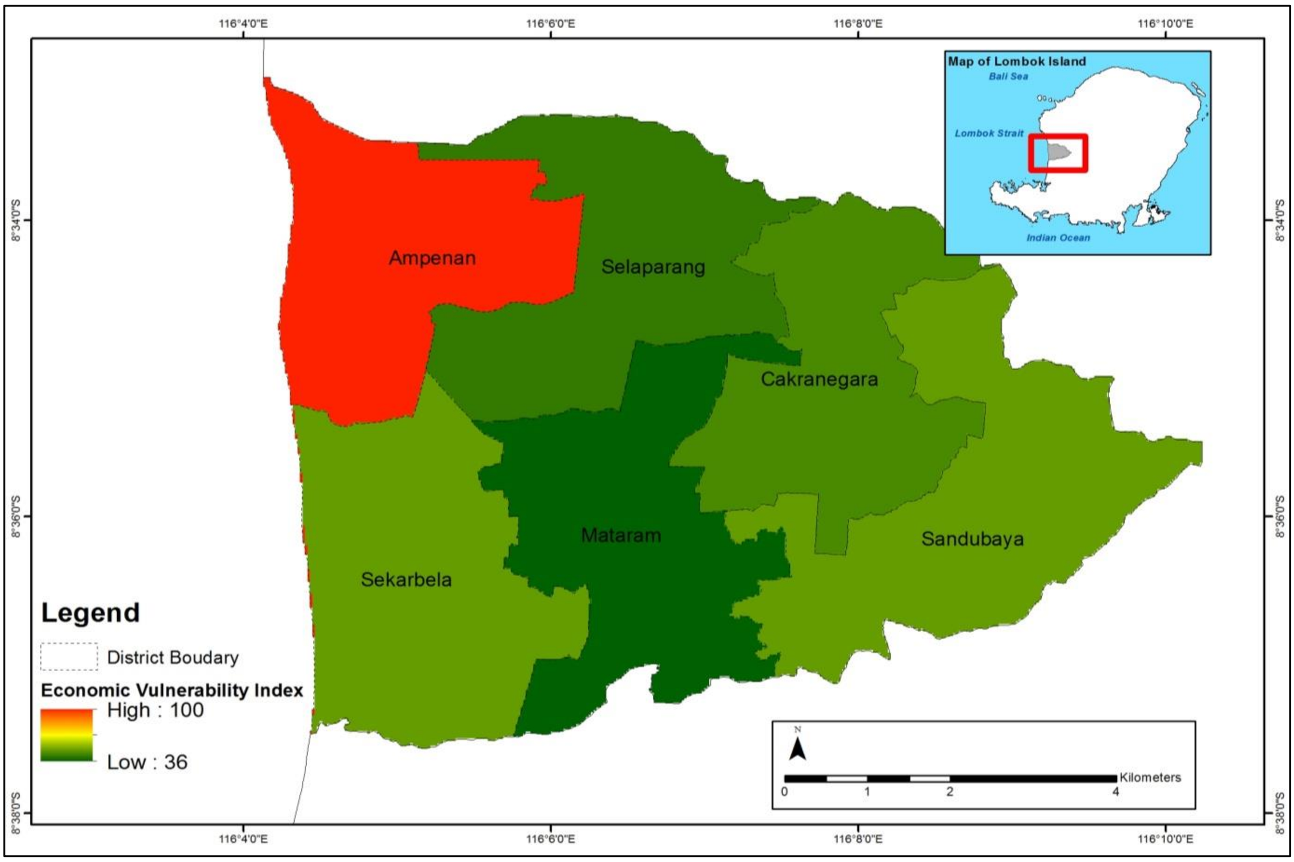

Figure 11. Map of Economic Vulnerability Index for tsunami in Mataram

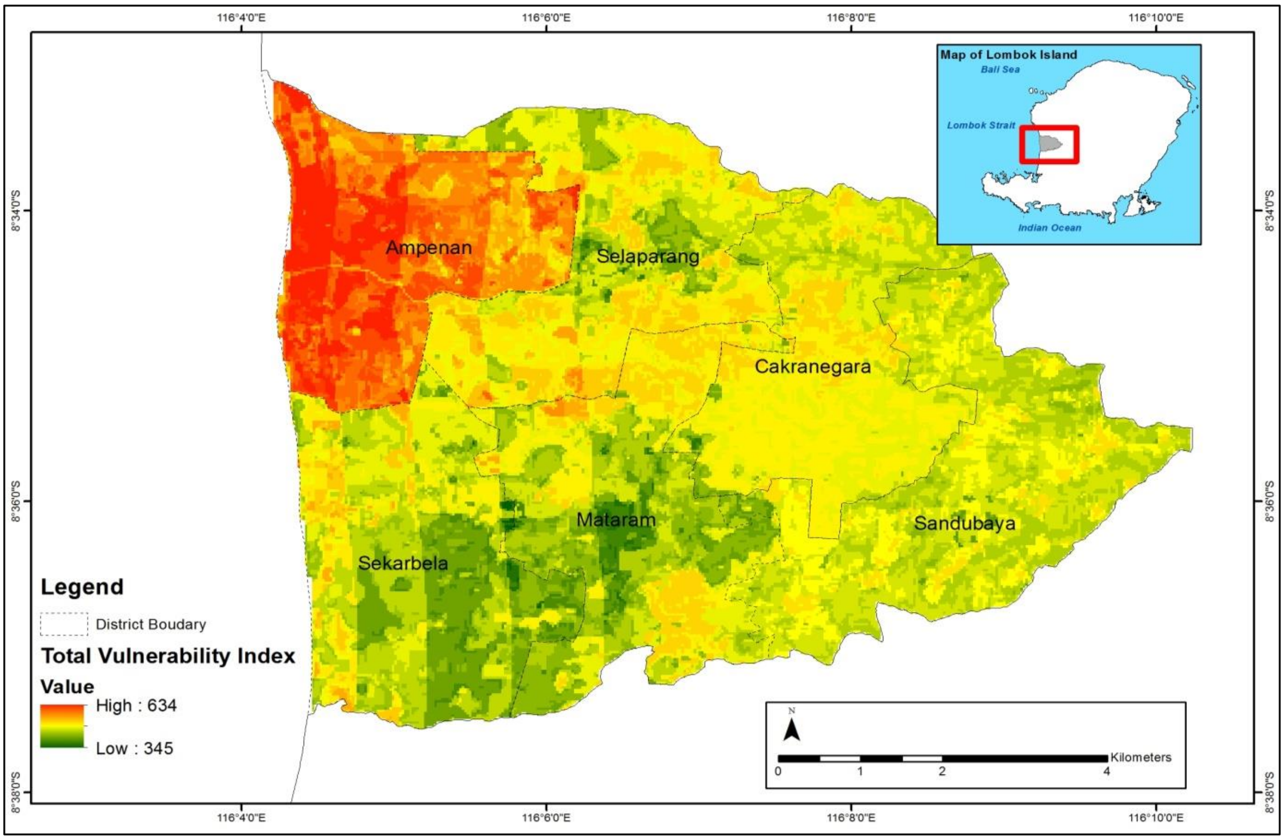

Figure 12. Map of Total Vulnerability Index for tsunami in Mataram

Table 14
The Distribution of Each Level of Vulnerability with 5 Classifications.

Level of Vulnerability	Area Distribution of Vulnerability (% of Total Class)						
	Ampenan	Cakranegara	Mataram	Sandubaya	Sekarbela	Selaparang	Total Area
Very High	99.10	-	-	-	0.10	0.80	100.00
High	25.52	11.27	21.59	9.77	8.59	23.26	100.00
Medium	0.77	25.28	12.96	28.81	11.89	20.30	100.00
Low	0.04	10.54	26.14	22.66	26.53	14.09	100.00
Very Low	0.06	2.15	25.81	4.39	58.17	9.41	100.00

Table 15
The Area for Each Level for Vulnerability in Each District

District	The Area for Each Level for Vulnerability in Each District				
	Very High	High	Medium	Low	Very Low	Total Area
Ampenan	77.10	20.63	2.17	0.06	0.03	100.0
Cakranegara	-	9.17	71.66	18.01	1.15	100.0
Mataram	-	15.58	32.57	39.61	12.25	100.0
Sandubaya	-	6.08	62.49	29.63	1.80	100.0
Sekarbela	0.06	5.96	28.74	38.67	26.56	100.0
Selaparang	0.59	17.82	54.18	22.67	4.74	100.0

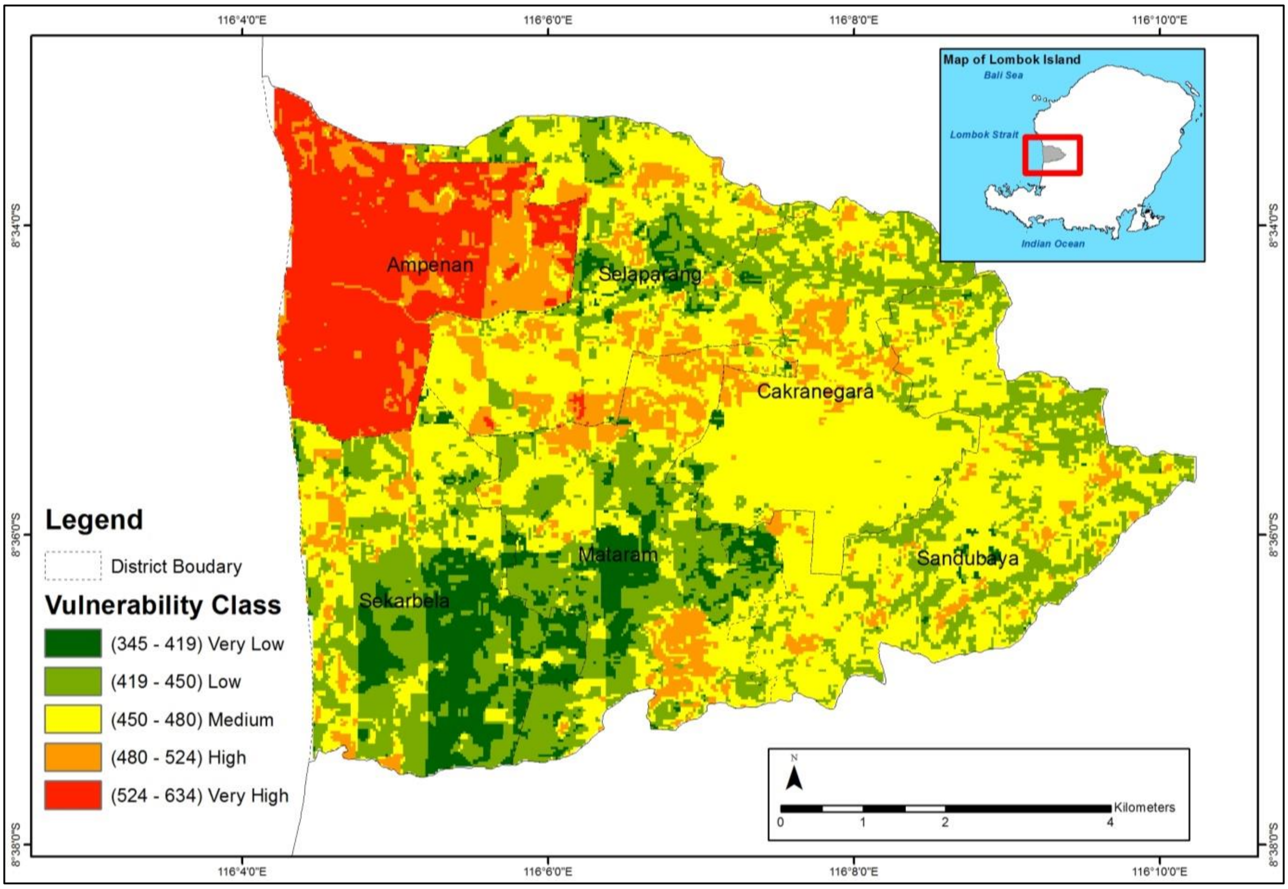

Figure 13. The Level of Vulnerability to Tsunami in Mataram Classified using Natural Breaks

5. CONCLUSIONS, LIMITATIONS AND FUTURE STUDIES

There are several conclusions which can be drawn from this project. First, within 6 (six) districts in Mataram, Ampenan District seems to have the highest level of vulnerability to tsunami. Not only this district is located in the coastal area but also the other physical condition such as land use affects the level of vulnerability. The socioeconomic condition as a result of the concentration of population also escalates the degree of vulnerability. Second, Sekarbela district is less vulnerable compared to several other districts although this district is located in the coastline. The district is now emerging as a result of rapid growth of property development. Therefore, a good practice in urban planning and design is expected to reduce the increasing level of vulnerability.

The implication of this project is to propose an integrated disaster management in Mataram City. The risk management should be integrated in urban planning frameworks. Strategic planning should be focused not only in the physical development but also in socioeconomic development. While physical development is intended to provide a tool to reduce the impact, socioeconomic intervention should be made in order to prepare the community escape from the severe situation when the disaster happens. The education to increase public awareness towards disaster is a prominent role in preparing the community coping with disaster and dealing with the recovery process in the post-disaster event. In addition, socioeconomic intervention should be made in conjunction with the attempt to increase the capacity of the community to adapt disasters and changes. Therefore, the level of vulnerability can be maintained.

There are some limitations for this project regarding the weighting method. As this project is only based on literature review, it could not consider the expert opinion related to the vulnerability of tsunami. Other than that, this project also uses the Census Data 2010 as the census is only conducted by the Central Bureau of Statistics every 10 year-period. Therefore, the census data is not able to capture the current socio-demographic characteristics.

Future studies and project are proposed to assess the risk of Mataram City towards tsunami. This can be done by integrating and combining previous studies with this project in order to determine the level of risk. For example, the integration between tsunami propagation wave from previous study and the level of vulnerability from this project can be a powerful tool to determine the level of risk so strategic options in disaster management can be taken. Further, this project, though has limitation, is good source information for the government to plan for reducing the impact. Evaluation should also be made based on this project for the plan and program which are already available.

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