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The analysis of Tsunami evacuation route based on geographic information system: a case study in the coast of Lampung Bay

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Abstract. The most fundamental issues for local people who are potentially at risk to tsunami threat are awareness and preparedness. The aim of this paper is to define the effectiveness of tsunami evacuation routes toward tsunami hazard along the coast of Lampung bay. The parameter applied in this study were elevation and slope created based on Aster GDEM while the coastline distance was made based on vector map and tsunami inundation obtained by Hills and Mader equation. In addition, the road network was derived from Development Planning Agency at Sub-National Level. AHP process was applied in determining the weight of the parameter by using pair-wise comparison via five normalized matrix iteration. Thus, there are five vulnerability classes that were classified. Weighted overlay through spatial analysis in geographic information system (GIS) was used in this study in order to make the final tsunami vulnerability map. The Network Analysis through Closest Facility Analysis in GIS was used to create the effective evacuation route and to point out 34 effective evacuation locations that could be reached by the people before the tsunami strikes. The results presented in this paper could eventually facilitate the improvement in the basic data for city planning related to evacuation process and management strategy during disaster.

1. Background of the study

There is a total of 110 tsunami happened over Indonesia. Among 110 tsunamis occurred, there were 100 tsunamis caused by earthquakes, nine tsunamis were caused by volcanic eruptions and a tsunami by caused by landslide [1]. Tsunamis caused by earthquake is a leading factor for a tsunami to occur in Indonesia. The centre of earthquakes is closely associated with the subduction zones and that caused the path of the earthquakes which occurred often go along the subduction zones [2]. Bandar Lampung, which located in Lampung province, is situated close to the Sunda strait subduction zones. It has very high level of seismicity because of the movement of the plates by the zone. There is a total of five vulnerabilities zones in Lampung, one of it is located Bandar Lampung which is the third zone (Zone

III). Based on the previous studies conducted by BPPT researchers toward the tsunami disaster especially in the Sunda Strait, [3]. Bandar Lampung is considered as one of the tsunami disaster vulnerability zones since the south coast of Bandar Lampung is a bay, which makes it prone to both tsunamis and earthquakes as well as floods and environmental damages on a very dense settlements along the coast.

In order to decrease the impact of the tsunami disaster, a sequence of attempts could be done which including the uses of alternative methods that are more acceptable for the local people. Reducing the risk of casualties and developing plans can be done through the mapping of coastal areas that are safe from the impact of tsunami which will later be used as an evacuation point location. The data then could be used in order to determine the evacuation routes hence minimizing the fatality impact from the disaster of tsunami.

The impact of the Tsunami is not only affecting the human and infrastructures but also the quantity of water absorption and the nature of the soil that would change due to the excessive water infiltration [4]. Consequently, there would be landslides in hill areas around the coast. In addition to that, the nature of soils in loam sandy areas which have excessive water infiltration or strong water flow would most likely change. Therefore, this paper will emphasize to human safety not only due to the tsunamis but other secondary factors.

There are a number of studies on tsunamis and mitigation in Lampung that have been carried out by Alhamidi and Pakpahan [5] that discussed on the coastal resilience of Lampung based along the coastline, Jokowinarno [6] discussed tsunami mitigation, Dewi and Armijon [7] investigated the composing of tsunami hazard map and Nurhasanah [8] is regarding on the tsunami evacuation route simulation. Whereas in this study the researcher conducted several other points of view in obtaining an effective tsunami evacuation route for Bandar Lampung people.

The uses of remote sensing application and geographic information system (GIS) manage to construct the possible evacuation route as well as the distribution of damaged area caused by tsunami disaster and able to evaluate the vulnerability of the zones. GIS with the spatial multi-criteria examination can really help in making a need to identify the basic leadership procedure utilizing the geo-reference information. Additionally, the preferences of the decision maker's concerning with a parameter assessment, analysis of spatial multi-criteria needed all the data from the criterion attribution and the geographical references [9-10]. Some prior works have investigated tsunami hazard using multi-scenario approach [11], the application of GIS technique for tsunami mapping and overlaying by using official land-use map [12] and also analysing the vulnerability by using remote sensing data and integrated analysis which utilizing the GIS towards the physical built-up infrastructure or buildings. There were also studies done in order to identifying the inundation of the surrounding area based on the configuration and the biggest recorded tsunami disaster concerning to the vulnerability of the buildings and human [13-14].

The aims of this study are to draw the tsunami vulnerability areas, to evaluate its impact by designing the possible tsunami inundation area and to make the evacuation routes by utilizing GIS. Elevation, slope, coastline distance and inundation are the main factors that influence the vulnerability. The Analytical Hierarchy Process for estimating weights of the parameters was applied in this study. Evacuation routes were created with network analysis processing through GIS.

2. Research method

2.1. Data

The elevation data applied in this study was collected from The ASTER Global Digital Elevation Model (ASTER-GDEM) version 2. The Ministry of Economy, Trade, and Industry (METI) of Japan and the United States National Aeronautics and Space Administration (NASA) are the ones who developed and made the Advanced Space-borne Thermal Emission and Reflection Radiometer (ASTER) GDEM as a collaborative accessible available inclusively for the public. ASTER-GDEM acquired the data via a space-borne observing optical device. The ASTER-GDEM covers the whole Earth surface at high resolution. In order to enhance global digital elevation resolution and elevation accuracy, the version 2 of the ASTER-GDEM was used. It was also used to advance algorithm and reprocessing a total of 1.5 million scene data including additional 250,000 scenes acquired after the previous release. The data were then producing a 1 arc per second posted grid or approximately 30 m at the equator.

Tsunami's vulnerability, especially for evacuation route, was analysed in this study. In addition, a tsunami heights and inundation information from the 1883 tsunami that was reported in the report book were also used during the research [15]. The steps of analysis started from data collection, proceeded with surface analysis of DEM data, vector data processing, inundation processing, continued with AHP process, raster overlay processing through GIS approach and ended with network analysis processing with road network data as in Figure 3 and by using GIS approach as in Figure 1.

2.2. Study Area

The research area was set up in four districts in Bandar Lampung City, namely Teluk Betung Timur districts, Teluk Betung Selatan districts, Bumi Waras districts and Panjang districts (Figure 2.). The four districts are several districts that have a dense population and were directly affected by the tsunami due to the eruption of Mount Krakatau in 1883. Since all four sub-districts are located not too far away from the Rakata, it makes them prone to tsunami disasters.

2.3. Spatial Analysis

2.3.1. Elevation

One of the primary data set needed for the sample to create vulnerability and tsunami inundation is elevation of data. A digital elevation model was created by using elevation map in order to derive a set of parameters that can show the physical vulnerability using data taken from ASTER GDEM version 2.0. This data was downloaded from ASTER-GDEM website *(https://gdex.cr.usgs.gov/gdex/).*

The elevation is classified into five vulnerability categories based on the height of the surface. It shows that low elevation, measured in meters, of the surface will have high tsunami vulnerability wave, as shown in Table 1. Vulnerability mapping based on elevation data showed that most of the coastal area is in the rather high-class vulnerability as shown in Figure 4.

2.3.2. Slope

Slope is the maximum change rate in z-value from each cell of the image. Slope map was made using the third-order finite difference method and ASTER-GDEM version 2.0. The slope percentages ranges vary from zero to almost infinity. A flat surface is considered as 0%, meanwhile as the surface becomes more vertical the slope percentage becomes increasingly higher. The slope map was categorized into five categories according to the value of tsunami vulnerability as described in Table 1. The vulnerability map on Figure 5 was made by applying the slope classification based on tsunami vulnerability class through reclassify process. Based on the information above, the urban areas are considered as the high vulnerability areas.

2.3.3. Coastline Distance

Dividing areas into five classes of vulnerability was done by using multi-buffering from the calculation of the distance from the coastline to the ground calculation of the distance from coastline to the land by using multi-buffering was done to divide areas into. The possibility range of the tsunami reaching the ground was used to determine the buffering distance. The distance is depending on the historical report of the maximum tsunami height in the area of study and it is expressed by the following equation (1) [11,16].

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$$logX_{max} = log100 + \frac{4}{3} log\ (\frac{Y_o}{10}) \tag{1}$$

Based on the equation above, it shows that X_{max} provides the maximum reach of the tsunami over land, and while Y_o is the tsunami height at the coast. The buffering distance was determined based on the range of possible tsunami flows flowing towards inland. The score of the X_{max} in this study was based on the history of tsunami occurred in Lampung which happened on August 27th, 1883. A tsunami occurred in the Sunda Strait with a maximum height of 30 meters above sea level and had the height on the coastlines high as 4 meters on the southern coast of Sumatra where Lampung Province is located (based on the Soloviev and Go catalogue) [15]. We used coastline distance in vector map of Lampung through GIS processing to generate vulnerability map based on coastline distance (Figure 6).

2.3.4. Inundation
Arcgis 10.6 software with the Raster calculator functions was used as the simulation of tsunami. Hills, and Mader [17] had formulated an equation to calculate the tsunami run up as in equation (2):

$$X_{max} = (Hs)^{1.33} n^{-2} k[cos\, S] \tag{2}$$

Based on the equation above, we can know that X_{max} is maximum inundation (m), Hs is the maximum tsunami run-up (m), k is constants which correspond to 0.06 for most tsunami cases, whereas Manning coefficient of land covers is represented by n and the slope of land is represented by S. We applied X_{max} in vector map of Lampung through GIS process in order to generate the vulnerability map based on inundation as in Figure 7.

Table 1. Vulnerability class based on elevation data [18]

Elevation (m)	Slope (%)	Coastline Proximity (m)	Inundation (m)	Vulnerability (class)
<5	0 – 2	0 – 65	0 – 30	High
5 – 10	2 – 6	65 – 164	30 – 75	Slightly high
10 – 15	6 – 13	164 – 282	75 – 128	Medium
15 – 20	13 – 20	282 – 413	128 – 188	Slightly low
>20	>20	>413	>188	Low

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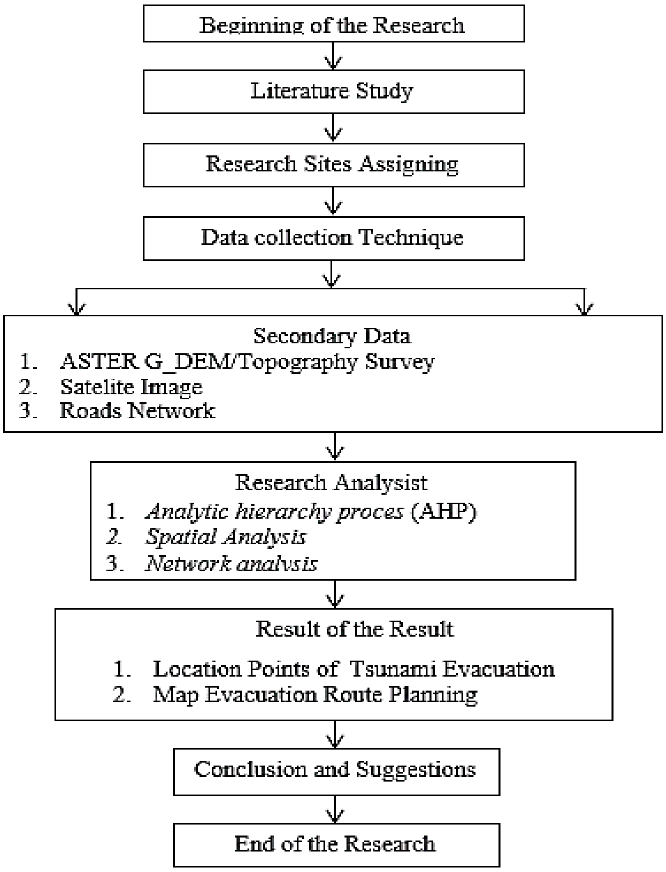

Figure 1. Research flow chart

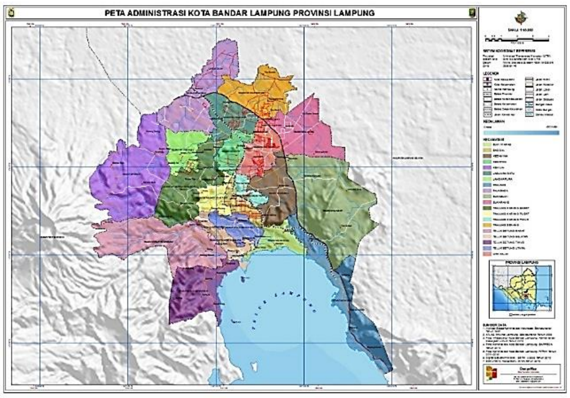

Figure 2. Map of study

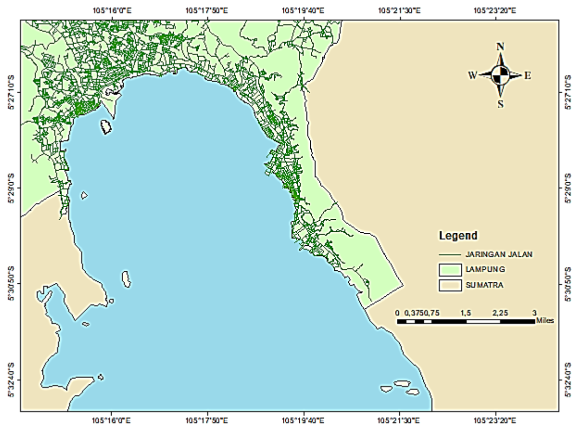

Figure 3. Map of roads network

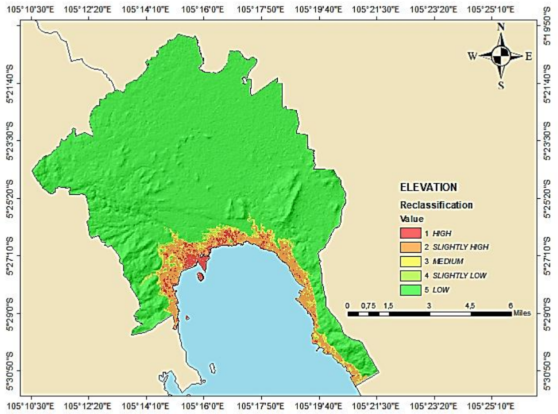

Figure 4. Tsunami vulnerability map based on the parameter of Elevation

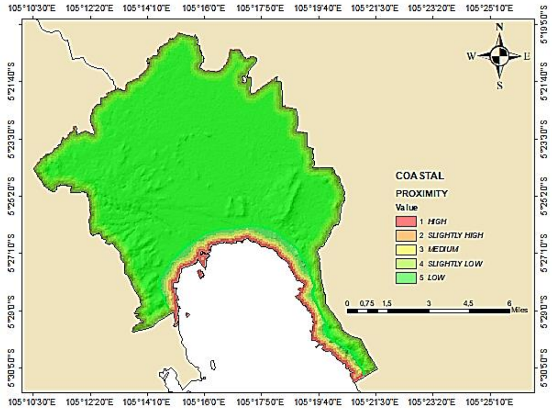

Figure 5. Tsunami vulnerability map based on the parameter of Coastline Proximity

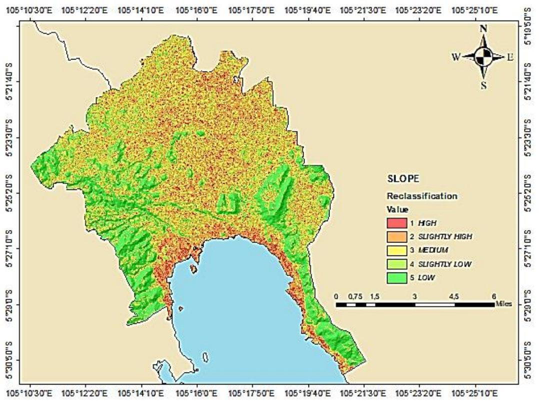

Figure 6. Tsunami vulnerability map based on the parameter of Slope

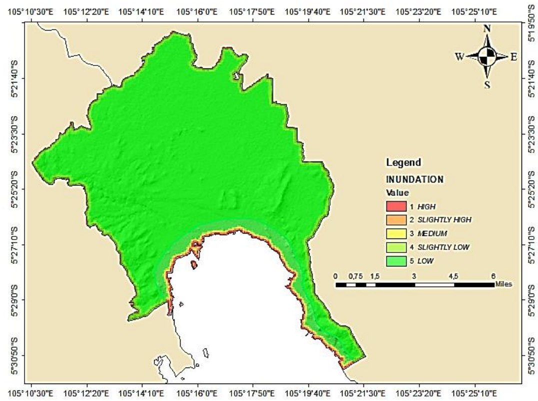

Figure 7. Tsunami vulnerability map based on the parameter of Slope

3. Results and Analysis

3.1. Analytical Hierarchy Process (AHP)

Based on research conducted by [16-18], they provide tsunami vulnerability parameters based on elevation, slope and coastline distance. As for the inundation, parameter determination is based on research conducted by [17]. All parameters in grid cells were then classified into five classes of vulnerability. For the vulnerability categories the following numbers of 1, 2, 3, 4, and 5 were used. They represent low, slightly low, medium, slightly high and high vulnerability. The whole parameter of tsunami vulnerability was overlaid by using weighting and scoring system. Scoring was designed to assess the limiting factor was scored in order to asses on each parameter, while the class of tsunami vulnerability was determined by weighting based on the dominant influence of these parameters.

AHP was applied in assigning weights to each of the parameters. By applying pair-wise comparisons, AHP assisted in making a scaled set of preferences and explaining the significance of each parameter relatively to other parameter [13-15]. In addition, AHP also enable the researchers in evaluating the vulnerability related to the natural hazard. A series of number from 1 until 9 as shown in Table 2 were used in comparison scale to make pair-wise comparison matrix. These numbers rely on the relative importance of each parameter. Meanwhile the relative weights of each parameter will be calculated through pair-wise comparison as shown in Figure 8.

Prior to the spatial analysis, the consistency level computation was required. Consistency Ratio (CR) is a procedure to determine the index of consistency. It shows that the probability of the matrix findings was randomly calculated [20]. In the other word, AHP allows inconsistency using the consistency ratio computation. The tolerable consistency ratio is less than or equal to 10 percent [21-22]. CR is the ratio between the consistency index (CI) and random consistency index (RI), it can be expressed using equation (3) and equation (4).

$$CR = \frac{CI}{RI} \tag{3}$$

$$CI = \frac{\lambda_{max} - n}{n - 1} \tag{4}$$

Based on the formula above, λ_{max} represents the largest eigenvalue, and N the size of comparison matrix. λ_{max} is computed from the sum of all parameters which later then multiplied by its eigenvector. RI is based on the random consistency index ($RI = 0.09$ for four parameters).

Pair - wise comparison matrix

	Elevation	Slope	Coastial Proximity	Inundation
Elevation	1,00	2,00	3,00	0,33
Slope	0,50	1,00	2,00	0,25
Coastial Proximity	0,33	0,50	1,00	0,20
Inundation	3,00	4,00	5,00	1,00
	4,83	7,50	11,00	1,78

Normalized matrix

Elevation	0,2069	0,2667	0,2727	0,1869
Slope	0,1034	0,1333	0,1818	0,1402
Coastial Proximity	0,0690	0,0667	0,0909	0,1121
Inundation	0,6207	0,5333	0,4545	0,5607

5th iteration

$$\begin{pmatrix} 0{,}2101 & 0{,}2101 & 0{,}2101 & 0{,}2101 \\ 0{,}1355 & 0{,}1355 & 0{,}1355 & 0{,}1355 \\ 0{,}0949 & 0{,}0949 & 0{,}0949 & 0{,}0949 \\ 0{,}5595 & 0{,}5595 & 0{,}5595 & 0{,}5595 \end{pmatrix} \begin{pmatrix} 21{,}01\% \\ 13{,}55\% \\ 9{,}49\% \\ \mathbf{55{,}95\%} \end{pmatrix}$$

Figure 8. Pair-wise comparison and normalized matrix

Table 2. Nine-point comparison scale [21]

Intensity of importance	Definition
1	Equal importance
3	Weak importance of one over another
5	Essential or strong importance
7	Demonstrated importance
9	Absolute importance
2, 4, 6, 8	Intermediate value between the two adjacent judgments

From the above data, as shown in Figure 8, it indicates that CI was 0.0244, while CR was 2.7% and it also shows that normalized matrix was computed from the pair-wise comparison in five iterations. The pair-wise comparison explains that elevation is the most significant factor and followed by slope, coastline distance, and vegetation density.

3.2. Spatial Analysis for Vulnerability Mapping

The maps parameter was created after applying the weighted overlay using spatial analyst in GIS. The weighted overlay device was used to resolve multi criteria issues [10,23]. It is a procedure in order to apply a common scale of values to diverse input parameters which have different values in establishing an integrated analysis. A series of numbers from 1 (low vulnerability) up to 5 (high vulnerability) were applied to represent the vulnerability categories. The vulnerability categories as displayed in Table 1 was made by using the subtraction from the maximum and minimum values and then divided by the number of the categories. Afterwards, the tsunami's vulnerability in five categories could be mapped (Figure 9).

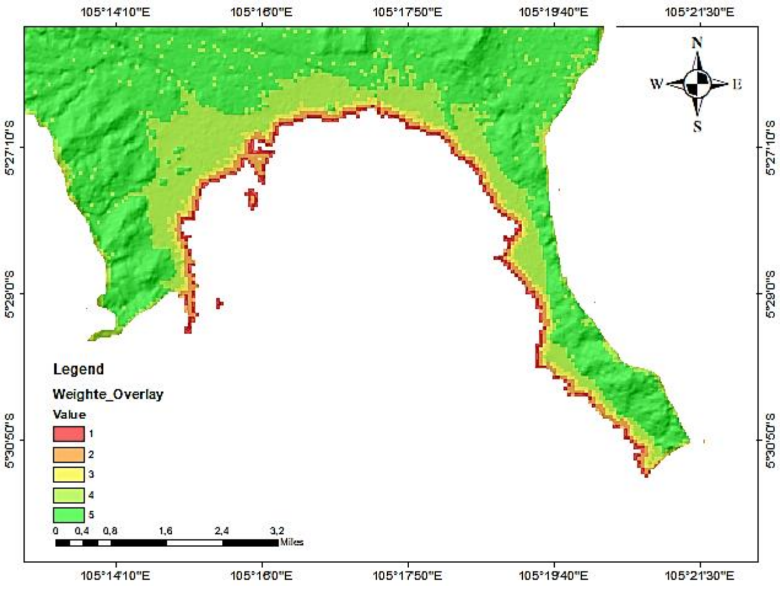

Figure 9. Tsunami vulnerability map

3.3. Network Analysis

Network analysis is carried out using a map of the Bandar Lampung city roads network and using ArcGIS 10.6. Closet Facility Analysis is used as a method for which facility is closer to a point. Like Route Analysis, the determination of facilities can be derived based on distance or travel time. The following are some of the processes and results of the network facility closet analysis in ArcGIS 10.6:

3.3.1. Evacuation Point selection

The analysis was done by considering the distance perpendicular to the coastline where the distance must exceed 516 meters, have a good height and slope, and have a fairly wide location if possible. The determination of these points was done with the help of Google Maps, Google Earth, Peta Tsunami vulnerability and road network maps. The location of evacuation points must also be able to serve all regions (Figure 10).

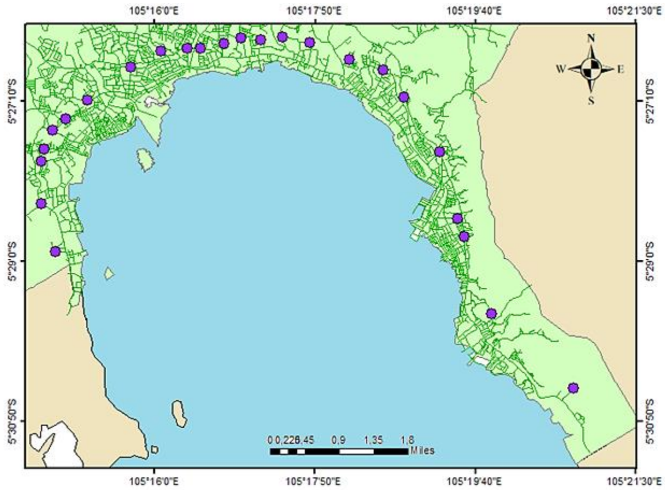

Figure 10. Evacuation point map

3.3.2. The Selection of Incident Points

Incident Points mean the point that is in the tsunami hazard zone and is directly proportional to the level of population density at that point. The position of this point is obtained from the interpretation of satellite images that have been taken previously, and it is a sample point for determining tsunami evacuation routes in Bandar Lampung City (Figure 11). From these points a tsunami evacuation route is assigned to the nearest evacuation point.

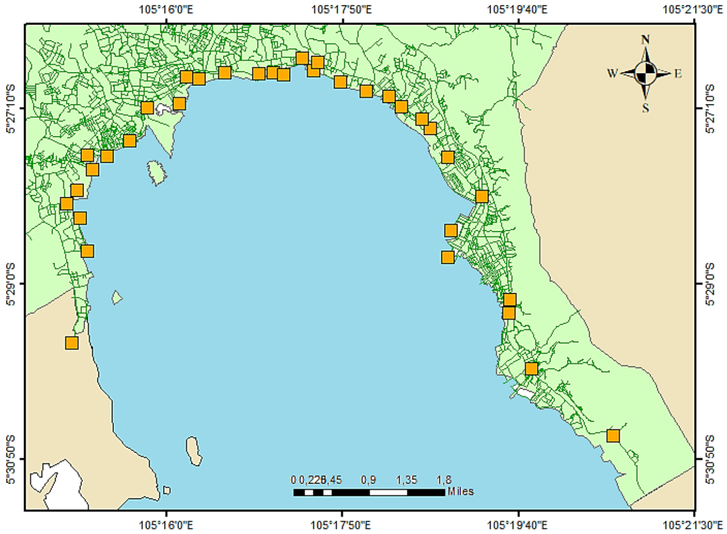

Figure 11. Incident point map

3.3.3. Making Evacuation Routes

In the network analysis, as much as 24 points were assigned to be used as evacuation points and 34 event points were used for the initial reference of movement. After determining these points, there were 34 evacuation routes and 24 evacuation points (Figure 12).

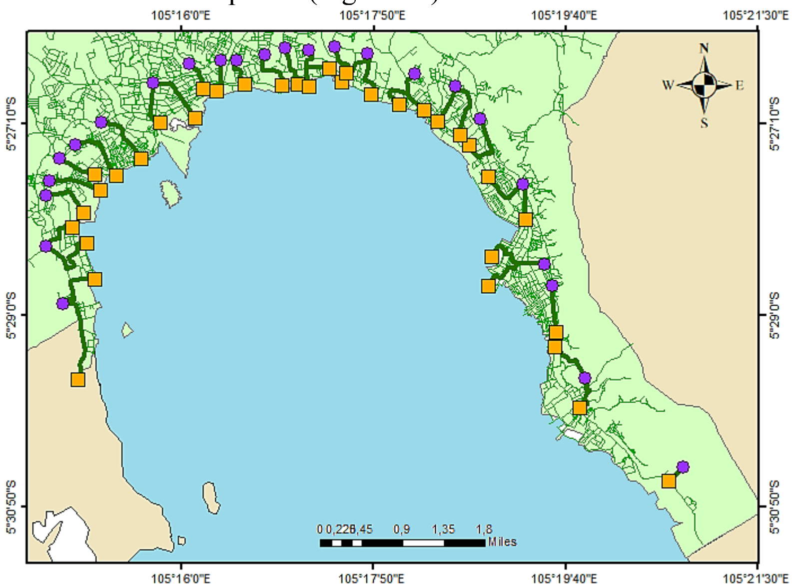

Figure 12. Evacuation Route Map

4.0 Conclusion

Based on the AHP analysis that has been done, the results obtained are as follows: the highest inundation level of influence in this study is scoring 2 for Elevation, scoring 3 for Slope and scoring 4 for Coastline. Spatial Analysis could be made into maps that can be used in determining evacuation points which are assisted with satellite images in the form of Google Earth and Google Maps. In this study as many as 24 evacuation points and 34 evacuation routes were obtained. Each of these routes is the closest route to the evacuation points which is the safest point of the tsunami with a run-up height of 5 meters. The evacuation route also has a height and slope that is suitable for the evacuation.

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References

[1] Arief M D 2011 Study of coastal line change using landsat data satellite in Kendal District *J.Remote Sensing* **8** 71-80
[2] Naryanto H S 2008 Analysis of potential earthquake and tsunami in West Coast Region Lampung in relation to mitigation and regional planning *J. Science and Technology of Indonesia* **10** 71-77
[3] Naryanto H S 2003 Mitigation of the south coast region of bandar lampung against the tsunami *J. Alami: J. Water, Land, Environment, and Disaster Mitigation* **8** 24-32
[4] Lusmeilia A 2018 Pengaruh Variasi Waktu Pemeraman dan Perendaman Sampe Tanah Terhadap Nilai Daya Dukungnya *Prosiding Semnas SINTA FT UNILA* **1** 219-14.
[5] Alhamidi, V H Pakpahan and J.E.S Simanjuntak 2018 Analysis of tsunami disaster resilience in Bandar Lampung bay coastal zone *IOP Conference Series: Earth and Environmental Science* **158**
[6] Jokowinarno D 2011 Mitigasi bencan tsunami di wilayah pesisir Lampung *Jurnal Rekayasa* **15** 1
[7] Dewi C, Armijon and Romi F 2014 Analisa Pembuatan Peta Zona Rawan Bencan Tsunami Pada Daerah Pesisir studi lokasi pesisir Kota Bandar Lampung *Proseding Seminar Bisnis dan Teknologi* 2407-6171
[8] Nurhasanah A, Yulfriwini and Susilowati 2016 ACE 3-039 Pola Pemetaan Jalur Evakuasi Tsunami Pesisir Kota Bandar Lampung Prosiding *Seminar ACE Padang* 445-52
[9] Carver S J 1991 Integrating Multi-Criteria Evaluation with Geographical Information Systems *Intl. J. Geo-Information System* **5** 3 321-39
[10] P. Jankowski 1995 Integrating Geographical Information Systems and Multiple Criteria Decision-Making Methods *Intl. J. of Geo-Information System* **9** 3 251-73
[11] Strunz G, Post J, Zosseder K, Wegscheider S, Muck M, Riedlinger T, Mehl H, Dech S, Birkmann J, Gebert N, Harjono H, Anwar H Z, Sumaryono, Khomarudin R M and Muhari A 2011 Tsunami Risk Assessment in Indonesia *Natural Hazards and Earth System Sciences* **11** 1 67-82
[12] Sinaga T P T, Adhi N, Lee Y W and Yongcheol S 2011 gis mapping of tsunami vulnerability; case study of the Jembrana Regency in Bali, Indonesia *KSCE J. Civil Eng* **15** 3 537- 43
[13] Papathoma M and Dominey-Howes D 2003 Tsunami Vulnerability Assessment and Its Implications for Coastal Hazard Analysis and Disaster Management Planning, Gulf of Corinth, Greece *J. Natural Hazards and Earth System Sciences* **3** 6 733-47
[14] Papathoma M, Dominey-Howes D, Zong Y and Smith D 2003 Assessing Tsunami Vulnerability, an Example from Herakleio, Crete *J. Natural Hazards and Earth System Sciences* **3** 5 377-89
[15] Soloviev S L and Go Ch N 1974 A catalogue of tsunamis on the western shore of the Pacific Ocean
[16] Bretschneider C L and Wybro P G 1976 Tsunami Inundation Prediction *Proceedings of the 15th ASCE Conference on Coastal Engineering* 1006-24.
[17] Hills J G and Mader C L 1997 Tsunami Produced by the Impacts of Small Asteroids *Annals of the New York Academy of Sciences* 381-94

[18] Iida K 1963 Magnitude, Energy and Generation Mechanisms of Tsunamis and a Catalogue of Earthquakes Associated with Tsunamis *Proc Tsunami Meeting at the 10th Pacific Science Congress* 7-18
[19] Van Zuidam R A 1983 Guide to Geomorphologic-Aerial Photographic Interpretation and Mapping **6**
[20] Saaty T L 1977 A Scaling Method for Priorities in Hierarchical Structures *J. Math. Psy.* **15** 3 234-81.
[21] Saaty T L 2003 Decision Making with the AHP; Why Is the Principle Eigenvector Necessary *Eu. J. Operational Research* **145** 1 85-91
[22] Saaty T L 1980 The Analytic Hierarchy Process, Planning, Priority Setting, Resource Allocation
[23] Carver S J 1991 Integrating multicriteria evaluation with geographical information systems *Intl. J. Geographical Information Systems*. **5** 3 321-39