

Spatial modelling for tsunami evacuation route in Parangtritis Village

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Abstract. Tsunami is a series of huge sea waves that commonly occurs because of the oceanic plate movement or tectonic activity under the sea. As a sudden hazard, the tsunami has damaged many people over the years. Parangtritis village is one of high tsunami hazard risk area in Indonesia which needs an effective tsunami risk reduction. This study aims are modelling a tsunami susceptibility map, existing assembly points evaluation, and suggesting effective evacuation routes. The susceptibility map was created using ALOS PALSAR DEM and surface roughness coefficient. The method of tsunami modelling employed inundation model developed by Berryman (2006). The results are used to determine new assembly points based on the Sentinel 2A imagery and to determine the most effective evacuation route by using network analyst. This model can be used to create detailed scale of evacuation route, but unrepresentative for assembly point that far from road network.

1. Introduction

Tsunami is a series of huge sea waves, usually occurs because the sudden move of oceanic plate causing vertical dislocations resulting in a decrease or shift that causes the mass of water above to move in response to changes in the underlying plate [4]. Some of the factors that can cause such vertical dislocations include earthquakes, volcanic eruptions, landslides, and collisions from meteors. Indonesia as a country in the subduction zone of the plate has a high potential earthquake on the seabed until the tsunami event. Tsunami wave height that ever occurred in south coast of Indonesia ranged from 0.1 to 26.2 meters [8].

The damage caused by the tsunami is influenced by the magnitude of the earthquake that occurs. Some of the periods of the tsunami incident in 1883, due to the eruption of Krakatoa volcano, caused more than 36,000 victims and a global impact on climate change [3]. Another incident in Java Island in 2006 has killed approximately 600 people and destroyed many villages on the Coast of Java Island [6]. Given the magnitude of the loss and the high potential for the tsunami in Indonesia, appropriate disaster mitigation is needed to reduce the number of the victims. The tsunami is a secondary disaster as a result of an earthquake on the seabed. After an earthquake, there is an interval of a few minutes before the tsunami wave reaches the coast. In this interval, it is possible to provide early warning and self-evacuate to a safe area. The evacuation concept is moving people from relatively harmful locations to safety area through safe evacuation routes [9]. The success of evacuation is depend on the effectively of evacuation route. The main problem in determining the effective evacuation route is selecting the fastest route. It is not a simple case because the shortest route is not always the fastest path towards the evacuation point. Topography characteristics and land use may increase the travel time so it becomes obstacle. To solve this problem we built evacuation route model based on the network analysis. In this case road is consider as a network that can be used to determine the best route, nearest facility, service area, build the cost matrix and solve the road problems. Consequently,



roads are an important variable in determining the effective routes for evacuating people and also showing the appropriate assembly point based on distance and travel time.

There are two models of evacuation method, horizontal and vertical evacuation [7]. Horizontal evacuation requires an assembly point that is far from the source of danger, while the vertical model requires the higher location only (refers to the floor in a building). Unfortunately, most of the buildings on Indonesia coast are not able to withstand the impact of tsunami waves. Therefore, the more suitable evacuation model is the horizontal model. The tsunami susceptibility model is required to determine the safe evacuation assembly point.

The main problems of making tsunami susceptibility model are the selection of representative model and the determination of wave height scenarios to illustrate the distance of tsunami waves that reach the mainland. Parangtritis Village in Bantul District was chosen as a model to determine the tsunami evacuation route in addition to its potential for a tsunami as well as having many elements at risks to the tsunami disaster (dense settlement and tourism activity). The main objective of this study is producing the most effective tsunami evacuation route recommendations based on the spatial model of the tsunami susceptibility level.

Based on the research background, then formulated three research problems, such as: a) the impact of tsunami waves determines the level of tsunami susceptibility in a coastal area, therefore the spatial model of tsunami susceptibility should be representative of the tsunami-affected landscape with the selection of certain wave height scenarios, b) the evacuation assembly points are determined based on the elevation, distance from the tsunami hazard and the vastness of the assembly point location, it is necessary to evaluate the existing evacuation points and choose the new appropriate location based on the spatial model of tsunami susceptibility, c) the main focus in determining the evacuation route is choosing the fastest route since the shortest path does not necessarily mean the fastest path to the evacuation point due to a barrier of topography and land use. Therefore, modelling is needed to determine the fastest route to reach the tsunami evacuation point.

2. Research Methods

The effective route recommendation is made with network analyst based on the evaluation of existing evacuation assembly points and then determined new evacuation points. The framework of this research is shown in figure 1. There are three data employed in this research as follows, 1) data for spatial modelling of tsunami susceptibility, 2) data to evaluate and determine the evacuation point, 3) data for the creation of the road network dataset. Details of the data and how to obtain it can be seen in the table below:

Table 1. Details of data.

| No | Types of Data | Source | Other Information |
|----|--|-------------------------------------|--|
| 1 | ALOS Imagery Data | asf.alaska.edu | Resolution of 10 meters year image and recording in 2011 |
| 2 | Sentinel 2A Imagery Data | earthexplorer.usgs.gov | Resolution of 10 meters year image and recording in July, 2017 |
| 3 | Parangtritis Village Map | Parangtritis Geomaritime Sains Park | Map published in 2016 |
| 4 | Coordinate of Tsunami Assembly Point Locations | Field survey | Data collection time is in August 2017 |

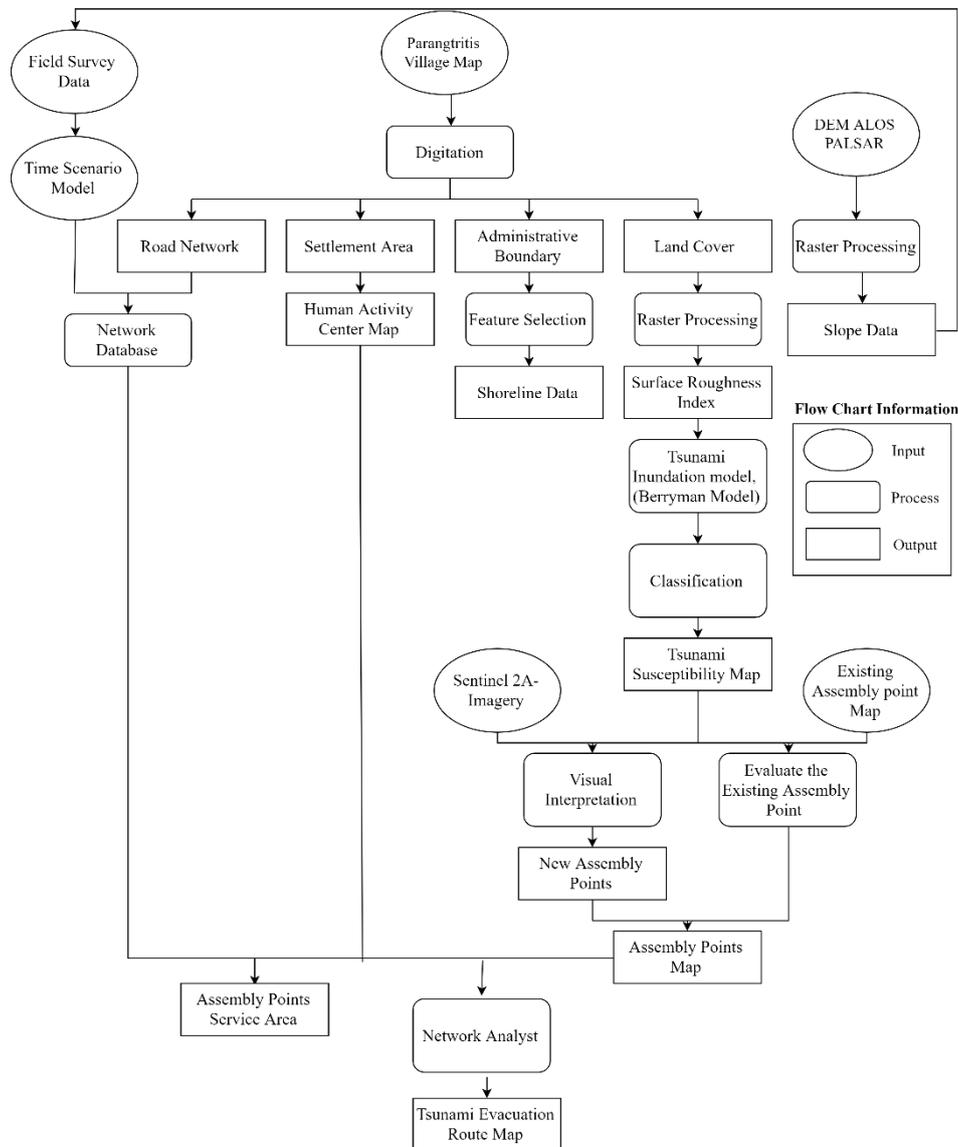


Figure 1. Framework of the research.

There are four main steps in creating network analyst model for determining the evacuation route. These steps produce three maps and it use to build the evacuation route model.

2.1. Creating spatial model for tsunami susceptibility

The tsunami spatial model is created by adopting a model developed by Berryman (2006) using coastline data, slope, and surface roughness coefficient. The tsunami wave inundation model from Berryman (2006) is a model that works by using a certain wave height scenario that starts from the coastline to the mainland then calculating the loss of wave height per one meter. The calculation considers slope, surface roughness, and elevation. The tsunami inundation model by Berryman (2006) was also adopted by BNPB (National Disaster Management Agency) to create tsunami susceptibility map through Perka BNPB No. 2 Tahun 2012.

Tsunami inundation is a maximum horizontal distance of tsunami wave that can reach the mainland [5]. Factors that strongly influence the inundation are the coastal topography, bathymetry condition,

and the earthquake magnitude. Inundation is also affected by the terrain condition which is expressed by the surface roughness coefficient and has strong relationships with the inundation distance.

The classification of tsunami susceptibility level (considering the height of wave inundation) refers to the classification of tsunami hazard map by *Perka BNPB No 2 Tahun 2012*. There are three classes of susceptibility classification: high susceptibility class refers to a region that having inundation up to 3 meters, medium susceptibility class refers to an area which has inundation between 1-3 meter and low susceptibility class refers to a region that having inundation value less than 1 meter. Tsunami inundation model in this research use 20 m wave height scenario. This wave height scenario based on the highest tsunami wave statistics data that have occurred on the southern coast of Java with a magnitude of 7.8 [9].

Tsunami susceptibility modelling data are shoreline data, land cover, and slope. The shoreline data was used as the initial calculation to calculate iterations of tsunami model inundation. The coastline was obtained from administrative boundary data of Parangtritis Village Map on a scale of 1:5,000. Land cover data was used to construct a surface roughness coefficient in a tsunami model. The land cover data was obtained from the Parangtritis Village Map on a scale of 1:5,000. Conversion from land covers data to surface roughness coefficient referred to BNPB in Risiko Bencana Indonesia [1]. Table 2 shows the conversion value from land use type to surface roughness coefficient.

Table 2. conversion value from land use type to surface roughness coefficient.

| Land use | Surface roughness coefficient |
|--------------|-------------------------------|
| Water bodies | 0.007 |
| Shrub | 0.040 |
| Forest | 0.070 |
| Plantation | 0.035 |
| Bare land | 0.015 |
| Paddy field | 0.025 |
| Settlement | 0.045 |
| Mangrove | 0.025 |
| Ponds | 0.010 |

Slope data is obtained from the geo-processing results of the DEM of ALOS PALSAR imagery. ALOS DEM data is used because it has a higher spatial resolution than other free DEM data such as SRTM or ASTER GDEM.

2.2. Mapping the evacuation point

The evacuation assembly point is an area that safe from certain disaster impacts and used as a gathering place when a disaster occurs to reduce the number of victims caused by a disaster. Evacuation assembly point data was used to build a network dataset as a destination point when composing evacuation routes. The data of the evacuation point was obtained from the map of the assembly point made by GTZ. Assembly point map then overlaid with the susceptibility of tsunami inundation model to evaluate which assembly points are really safe and does not belong to tsunami susceptibility area. In addition, the determination of the assembly point was also visually observed by sentinel 2A imagery.

2.3. Build network datasets

A network database is a set of data set needed to perform network analyst. Network datasets required some spatial and attribute data (table 3). The most important issue in making the network analyst dataset is the value of FT minutes and TF minutes. The assumption of travel time in FT minutes and

TF minutes was obtained by conducting field survey. This survey was attempting to travel by walking at slow speed on several road segments with different types of roads and terrain. A slow-track survey was used to construct the slowest evacuation movement assumptions such as elderly and children. The field survey data was arranged to create the time travel data in the network dataset (TF dan FT minutes). Also slope assumption is employed to create this network dataset.

Table 3. Network datasets data.

| Data | Types of data | Information |
|----------------|--|---|
| Spatial data | Road data | Road data refers to road distribution spatial data (attribute and geometry) in Parangtritis village. There are three classifications of roads used in this research such as other roads, local and trails. |
| | Assembly point data | The assembly point data is derived from the existing assembly point map that has been evaluated with new tsunami susceptibility map. This modelling produces new evacuation assembly point by visual interpretation of Sentinel 2A imagery. |
| | Block of human centre activity | The human activity block data is obtained from settlement blocks digitization in Parangtritis Village Map. These blocks of activity are used as the starting point assumption of the community to begin self-evacuation which is modelled as the centroid point of human activity centre block. |
| | Slope data | Slope data is derived from ALOS Palsar DEM, showing the gradient elevation changes and steepness of a location. This data was overlaid with road network to obtain the road terrain conditions. Slope data was made using slope classification according to van Zuidam (1983). |
| Attribute data | Street name The road length Oneway Road types and its terrain condition FT minutes TF minutes | |

The assumption used is the narrower and steeper the road, the travel velocity will be decreased. The velocity for each road segment is 1.2 m / s, obtained from the field survey data through walking simulation from the center of human activity point to the 1st and 3rd assembly point located in Mancingan Hamlet and Grogol 9. While for the velocity on the steep slope road is 1 m/s, assuming that steep slope would impede pedestrian velocity during evacuation. This velocity (v) value is a function of the travel time function (t) for each path length (s) by Equation (1):

$$t = \frac{s}{v} \quad (1)$$

2.4. Networks Analyst

There were two kinds of network analysis performed on this spatial modeling of evacuation route, as follows service area modelling and closest facility modelling. Service area modeling was performed on evacuation points. Service area modelling of evacuation assembly points aims to find out how far the assembly points are able to reach from the centre of human activity blocks in 50 minutes. The 50-minute assumption was taken on the average estimated time of tsunami waves on the South Coast of Java from the occurrence of earthquakes. Closest facility modelling was used to model the fastest route that can be travelled from the centre of human activity blocks toward the evacuation assembly points. Modelling the nearby facility will result in generating an evacuation route map.

3. Result and discussion

3.1. Tsunami susceptibility model

Tsunami susceptibility model was classified into three classes, high (>3 m), moderate (1-3m), and low (<1 m). The height of tsunami wave in this scenario is 20 meters based on the statistical data of maximum tsunami height that ever happened in the southern coast of Java. Based on the modelling result (Figure 2) high susceptibility class dominate the result, about 3,824,500m² affected by 3m of tsunami inundation also 252,113 m² heading to land, will affected by 3–1 m tsunami inundation.

Therefore about 34.88% of Parangtritis settlement is threatened by tsunami risk within this wave height scenario. Vertical position (elevation) really affects the modelling result beside of the land use type. The west region (Opak River and its surrounding) is classified as a high tsunami susceptibility class even though it is far away from the coastal line (figure 2).

Opak river with low elevation allows the tsunami wave to affect this region also the surface roughness coefficient of water is only 0.007 so that the wave height reduction velocity will decrease in that location. Low susceptibility class is dominant in the east region of Parangtritis village because of the hilly topographic so the tsunami wave cannot reach that location.

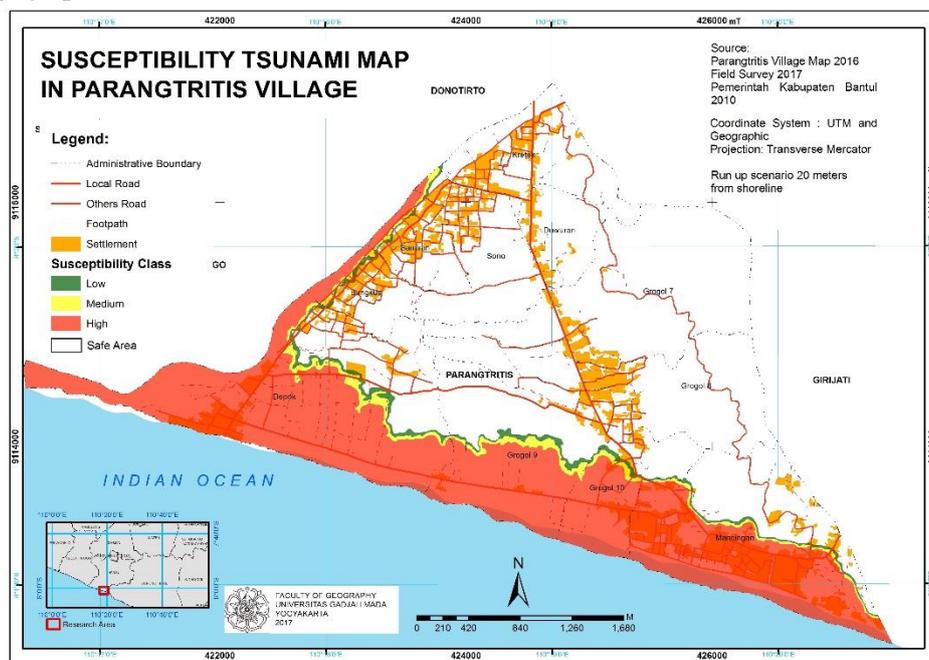


Figure 2. Tsunami susceptibility modelling result.

Area that does not belong to the high, medium and low tsunami susceptibility class is categorized as potential safe area. This area became priority in determining the evacuation assembly point. Overlay analysis of tsunami susceptibility model and land use map showed that 36.67% (of the 1,577,428.92 m²) of the settlement area in high susceptibility of tsunami inundation, while only 8.37% of other settlement area are in medium to low susceptibility of tsunami. This model shows that land use in the form of forest, garden, and mooring can reduce the tsunami hazard level because of the surface roughness coefficient is relatively high therefore it effectively reducing the wave height.

3.2. Assembly point evaluation

Overlay analysis between susceptibility map and existing evacuation point map is used to evaluate the safety of evacuation points. There are seven evacuation assembly points (temporary assembly points and fixed evacuation point) that have been mapped by the Bantul Regency Working Team. According to this analysis, there is one evacuation assembly point in the southeast which is considered to be less suitable because it is located in high level of tsunami hazard.

Another point is then added through a visual interpretation method with a sentinel 2A imagery and DEM. Finally selected a field in Kretek hamlet, with a distance 2.812.43m from the coastline and 33m above the sea surface. Those assembly points are spreading across five hamlets such as Mancingan, Grogol 10, Duwuran, Sono, and Kretek. The result of the evaluated assembly points can be seen in figure 2. The tsunami evacuation point is located in the eastern part of the Parangtritis Village due to the presence of an escarpment with hilly relief. Another assembly point is in the northern region as it is close to the settlement as a centre of human activity and relatively safe based on distance from coastline.

3.3. Network dataset and assembly point service area

A network dataset was constructed based on the field survey data and the estimation of the slowest pedestrian speed toward the evacuation assembly point. The network dataset was used to view the service area of an evacuation assembly point and determine the fastest route toward the evacuation assembly point. There are three important attribute components in network dataset creation that is FT minutes, TF minutes, and Oneway. Slope value is also an important parameter because it's employed to assume the travel velocity on each road segment.

The centre of human activity point was obtained from the settlement, tourism activities, trade, schools and other public facilities area with the assumption that those location was occupied by a lot of people. The parameter used was a 50-minutes travel time according to DLR (2010) [5]. The tsunami occurrence in Indonesia is a local tsunami where the time between earthquake event and the intermittent of tsunami waves is less than an hour. Figure 3 shows the range of assembly point service area to the centre of human activity point created using ArcGIS network analyst tools.

The evacuation assembly point was defined as facility location meanwhile the centre of human activity point as the incident point. This model represents the area of incident point that will be able to reach the facility in 50 minutes travel time. The number of evacuation assembly points (incident) that can reach the evacuation assembly point is summarized into table 4.



(a)



(b)



(c)



(d)



(e)



(f)

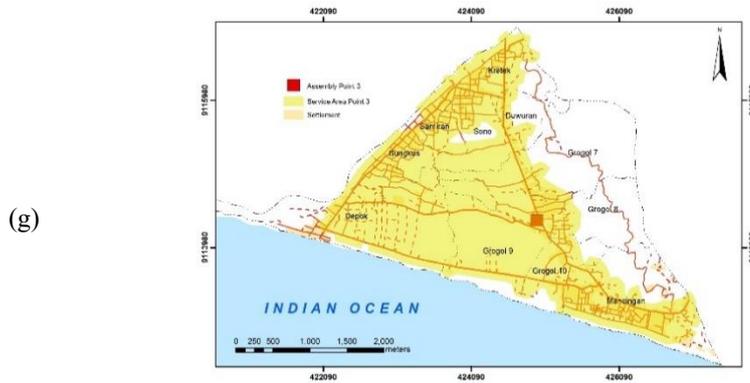


Figure 3. Service area of assembly point map (a) Assembly point 1 (hilly area) (b) Assembly point 2 (Syekh Belabelu Graveyard) (c) Assembly point 3 (Open Space area) (d) Assembly point 4 (Parangtritis Government Office) (e) Assembly point 5 (Hilly area) (f) Assembly point 6 (Field) (g) Assembly point 7 (Syeh Maulana Graveyard).

Based on table 4, it is known that the most accessible evacuation assembly point is Parangtritis Government office in Dhuwuran hamlet. The assembly point that located around the settlement may not necessarily serve many activity centers in the area. For example, the assembly point 1 (figure 3) only capable to serve 120 points of human activity centers while the assembly point 7 is able to serve 187 point of human activity centers although assembly point 1 is located around the denser settlement than assembly point 7.

Table 4. Range of assembly point service area.

| Evacuation Assembly point | Number of center human activity reached | Center of human activity location (Hamlet) |
|------------------------------------|---|---|
| 1 (hilly area) | 120 | Mancingan, Grogol 10, some area of Grogol 8 and Grogol 9 |
| 2 (Syekh Belabelu Graveyard) | 179 | Mancingan, Grogol 7, Grogol 8, Grogol 9, Grogol 10, Dhuwuran, Sono, and Depok |
| 3 (Open Space area) | 324 | Mancingan, Grogol 10, Grogol 9, Grogol 8, Grogol 7, Kretek, Dhuwuran, Sono, Samiran, Depok, and Bungkus |
| 4 (Parangtritis Government Office) | 277 | Mancingan, Grogol 10, Grogol 9, Grogol 8, Grogol 7, Kretek, Dhuwuran, Sono, Samiran, Depok, and Bungkus |
| 5 (Hilly area) | 77 | Kretek, Sono, Dhuwuran, Grogol 7 |
| 6 (Field) | 217 | Grogol 10, Grogol 9, Grogol 8, Grogol 7, Kretek, Dhuwuran, Sono, Samiran, Depok, and Bungkus |
| 7 (Syeh Maulana Graveyard) | 187 | Mancingan, Grogol 10, Grogol 9, Grogol 8, Grogol 7, Dhuwuran, Sono, and Depok. |

3.4. Evacuation Route

The final result of this research is the tsunami evacuation route map which is used as the recommendation of the evacuation route. Closest facility from network analyst tools produces the fastest route from the center of human activity point towards the evacuation assembly point. This model also provide direction, time, and distance information. Figure 4 shows the evacuation route map with seven assembly points which are represented by the black arrows.

The shortest route based on the model is 2 meters with <1 minute travel time and the longest route is 3.785 meters with 59 minutes travel time. One of the modeling routes shown in figure 5, the information obtained through this model is route, distance, time displayed in detail on each segment and its summary. The road’s name is not identified as shown in table 5, because there are so many country lane and footpath in this road network model.

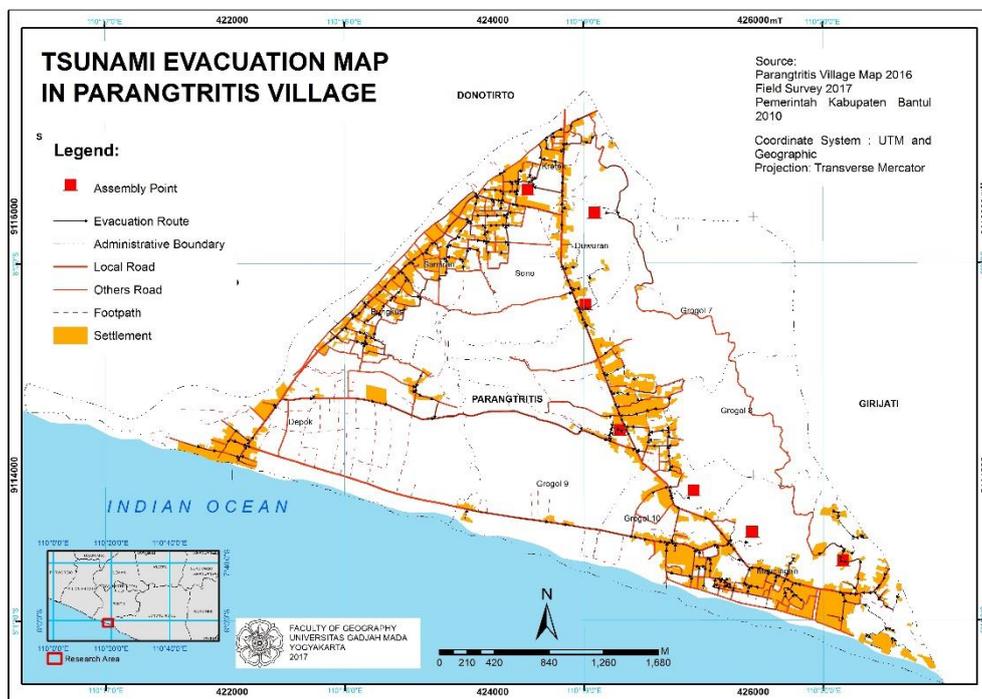


Figure 4. Evacuation route map.

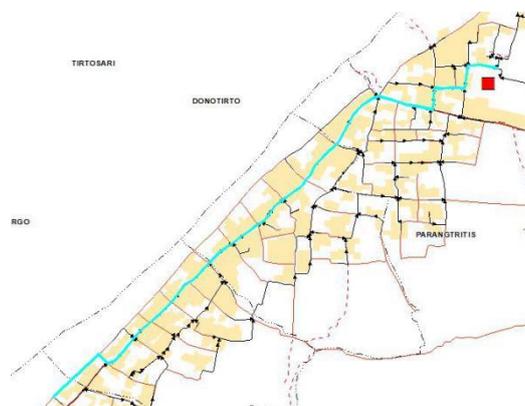


Figure 5. Example of one evacuation route.

Table 5. Evacuation route detail (route example from Location 18-Location 6).

| Nr. | Route Detail | Distance (m) | Time (min) |
|-----|----------------------|--------------|------------|
| 1 | Start at Location 18 | | |
| 2 | Go northeast | 55.4 | < 1 |
| 3 | Turn right | 44 | < 1 |
| 4 | Continue | 6.7 | < 1 |
| 5 | Turn left | 989.1 | 14 |
| 6 | Turn right | 99.6 | 1 |
| 7 | Turn left | 3.1 | < 1 |
| 8 | Continue | 267.2 | 4 |
| 9 | Turn right | 270.6 | 4 |
| 10 | Turn left | 80.8 | 1 |
| 11 | Turn right | 147.9 | 2 |
| 12 | Finish at location | | |
| | Total | 1964.3 | 29 |

4. Conclusion

The tsunami evacuation route modelling with Berryman and network analyst is able to provide detailed evacuation route recommendations. However, the weakness of this model is unable to represent an evacuation route outside the road segment, whereas several locations of assembly points are not located near the road segment. So the determination of the route is only based on the distance projection between the human activity points with the assembly point on a road segment. The actual distance between the assembly point and the main road segment is not considered by this model.

5. References

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