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Mapping of Tsunami disaster evacuation pathways based on Tsunami altitude scenario using Network Analyst Method (case study: Palu City, Central Sulawesi)

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Abstract

Central Sulawesi's Palu city is one of the regions in Indonesia that is vulnerable to tsunami disasters. Tsunami disaster is a disaster that can cause many victims, both casualties and material. One of the disaster mitigation to reduce the victim's fall is by evacuating the community to a safer place, to evacuate the population required evacuation routes that can direct people to evacuation sites. The aim of the study was to make a tsunami runoff and to make tsunami evacuation. Technical analysis in this research uses cost distance for mapping the tsunami runoff with a tsunami wave height of 15 meters from the coastline, then the tools closest facility in network analyst to mapping the tsunami evacuation route looking for the closest line in Arcgis 10.4 software. The most affected regional analysis is the Northern Palu sub-district with a total area of 8.643528 km^2, and there are 93 evacuation routes with 92 evacuation points. The longest evacuation route is 4,297 M with a travel time of 27.6 minutes with running and the shortest evacuation route of 96 m with a travel time of 0.6 minutes by running.

Keywords: Evacuation Points, Evacuation Routes, Palu City, Tsunami Runoff

1. Introduction

A natural disaster is an event or series of events caused by natural phenomena or natural factors that can cause environmental damage, material loss, or human victims (Kamadhis UGM, 2007). Indonesia is a disaster-prone island country, such as earthquakes, tsunamis, and land or landslide movements. This disaster is caused because Indonesia is located on 3 continent plates namely Eurasian plate, Indo-Australian plate, and Pacific plate which continue to move in collide/converging, away/divergent, and cross-pass/transform to cause tectonic earthquakes and trigger the occurrence of tsunami wave (BNPB, 2012). Catastrophic tsunami will ruin what is passed and swallow many casualties. According to (BNPB, 2011) , tsunamis are a series of gigantic waves of waves arising from a shift in the seabed due to earthquakes. One of the Indonesian areas that is a few times the tsunami disaster is the city of Palu and its surroundings.

Palu City is located on the plains of Palu Valley and Palu Bay, with an average altitude of 0 – 700 meters above sea level, located at position 0 º,36 "-0 º,56" South latitude and 119 º, 45 "-121 º, 1" east longitude. The area of Palu city is 395.06 km^2. The city of Palu consists of 8 sub-districts and 48 village areas. The population of Palu was 379,782 inhabitants in 2017 (BPS, 2018). In the area of Palu and surrounding areas, several pieces of fault are potentially generating earthquakes that are quite strong and potentially tsunami. The fault is a hammer-Koro fault that extends from Palu to the south and southeast through the northern South Sulawesi to the south of Bone to the Banda sea (Daryono, 2011).

The city of Palu and surrounding areas have been struck by tsunami disasters, based on the Indonesian Tsunami catalog of 416-2018 (BMKG, 2019) and the Tsunami Trail recording of the Palu Bay 2018 (Pribadi *et al*., 2018), can be seen also in **table 1**. The first occurred on 14 May 1921 in central Sulawesi, the earthquake Force 6.3 Richter Scale (SR) with a tsunami wave height of 1 Meter (m). On 1 December 1927, there was an earthquake with an apparent magnitude of 6.3 SR and followed by a tsunami that was sourced in the city of Palu. The tsunami altitude reached 15 m, the number of victims was 15. The 3 m wave altitude of tsunami occurred at Parigi on 20 May 1938 with the 7.6 SR earthquake force, resulting in a casualty of 50 people.

Eleven years in the aftermath of the 20/05/1938 earthquake and tsunami struck Parigi, with the 7.6 SR earthquake force with a height of 3 m tsunami wave, the victim inflicted a 50 person. On 14 August 1968, the earthquake and tsunami rocked the Bay of Tambu Balaesang Donggala with a wave height of 10 meters and a tsunami runoff reached 500 meters to the mainland of the coastline. 160 people died, 40 people were declared lost and 58 were severely injured. On 1 January 1996, the Toli-Toli earthquake occurred with the earthquake strength of 7.9 SR and a tsunami with a height of 3.4 from the coastline engulfed a total of 9 people. On 4 May 2000, there was an earthquake and tsunami centered on Banggai, with the strength of the earthquake 7.6 SR and a tsunami high of 6 m from the coastline. The casualties were 50 people. On 28 September 2018, there was an earthquake centered on Donggala with the strength of the 7.4 SR earthquake and caused a tsunami in the Donggala and Palu areas. The high tsunami wave of the coastline reached 11.3 m and had a victim of 2,037 people.

According to the fact, the city of Palu requires mitigation of the creation of a tsunami disaster evacuation route to provide information to the community to save itself from the tsunami disaster. An evacuation route is made using the geographic system of Geography (GIS), as it can generate geography-based maps. GIS can assist in the manufacture of evacuation routes by viewing the tsunami runoff. The runoff of tsunami hazards is made using the tsunami wave altitude scenario.

The objective of this study is (1) to create a tsunami hazard map using the tsunami altitude scenario of the coastline. (2) Determine the evacuation point and evacuation route of the tsunami disaster in Palu based on the tsunami hazard map. The benefits of this study are (1) seeing the tsunami-prone areas. (2) Provide information on evacuation points and evacuation routes so that people can save themselves during the tsunami. The scope of this research is the creation of a tsunami evacuation route, with the case study of Palu City.

2. Literature Studies

Research related tsunami evacuation route is done under the title of the use of GIS to mapping the evacuation route of the tsunami disaster in Tonggolobibi village of Sojol district of Donggala which was written by Nurfaida, DKK. The purpose of this research is to mapping the evacuation route of the tsunami, in line with the tsunami evacuation route using the system that is insyaAllah (SIG) and the determination of Shelter for the tsunami disaster in the village Tonggolobibi Sojol District Donggala. Research using the method of network analyst in GIS application is ArcGis 10.1. The preparation of the tsunami evacuation route uses the same parameters of the base map of which altitude, the road network, and the village administration map as well as the data of village monographic data. The results obtained are two evacuation routes, the first path of the width of the road 4, 56 meters, the length of the line 2225, 5 and the journey around 14 minutes. The CHNRD line has a road width of 2, 90 meters, road length of 2643, 9 and when it takes about 18 minutes (Nurfaida, 2016).

Another research titled Tsunami Insecurity Map and the plan of evacuation route in Desa Parangkritis Sub-district of Kretek District, Bantul regency of the special region of Yogyakarta, which was written by Gentur Handoyo, *et al*. This research aims to create tsunami-prone areas and draft tsunami evacuation routes. The study used overlay analysis in determining tsunami-prone areas and the evacuation route determination was determined based on the runoff of the tsunami area and based on BNPB rules in 2012. The parameters used are the topography altitude, the distance from the river, the distance from the coastline, the topography slope, the use of land, the tsunami runoff, the road network, the presence of hills, and high buildings. The result of this research is the main route for the evacuation of the Parangkritis village is Parangkritis Street, Jalan Parangkritis-Depok, and Depok Street. The evacuation route goes directly to the 12 temporary evacuation sites (TES) (Handoyo *et al*., 2014).

Conceptually, the above research has similarities with this research, namely to determine the evacuation route of the tsunami. This research focuses more on determining tsunami evacuation pathways based on tsunami run-ups. This research uses the cost-distance analysis in ArcGis software to determine tsunami-prone areas. For determining tsunami evacuation routes using network analyst.

Tsunami

A simple process of tsunami occurs due to a large amount of water volume shifting. Water moves in any direction forming tsunami wave tide, at the time of the water back to the initial front then there will be a tidal tsunami surge. And at the boarding time, the tsunami waves will beat and ruin all that he goes through and rescatter the oceans. Tsunami is caused by several factors, namely (1) The Underwater earthquake, (2) Submarine Volcano, (3) Landslide and (4) Falling Meteor (Tjandra, 2017). The wave height can be interpreted as a vertical distance between the highest sea-level conditions and the lowest sea-level conditions in a wave (Khoirunnisa *et al*., 2017). According to Abdurahman, *et al*. (2013) in Tjandra, 2017, based on the distance of the tsunami source to the territory of the tsunami is divided into 3 namely: (1) Tsunami with a distant source. Its run is more than 1,000 kilometers, for example, the Aceh tsunami of 2004, (2) the regional Tsunami radius of its run is no more than 1,000 kilometers from its source, (3) The local Tsunami is not more than 100 kilometers from its source. The following is a history of tsunami events in Palu.

Table 1. Tsunami Incident of Palu City

Da-te	Earth-quake magni-tude (SR)	Tsunami Source	Wave height (Metres)	Victims	Refere-nce
14 / 05 / 1921	6.3	Sulawesi Tengah	1	-	Sugeng Prihadi, dkk, BMKG 2018 (NOAA dan Newman (1939))

12/01/1927	6.3	Palu, Sulawesi Tengah	15	50	NOAA
20/05/1938	7.6	Parigi	3	15	Sugeng Prihadi, dkk, BMKG 2018 (NOAA dan Newman (1939))
14/08/1968	6	Teluk Tambu Balaesang Donggala	10	200	Sugeng Prihadi, dkk, BMKG 2018 (NOAA dan Newman (1939))
1/1/1996	7.9	Sulawesi Utara, utara Toli-toli	3.4	9	BMG, Pelinovsky *et al*. (1996)
4/5/2000	7.6	Banggai, Sulawesi	6	50	BMG
28/09/2018	7.4	Donggala, Sulawesi Tengah	11.3	2.037	BMKG, BNPB

Source : Katalog Tsunami Indoensia Tahun 416-2018, BKMG 2019 (BMKG, 2019) and Merekam Jejak Tsunami Teluk Palu 2018(Pribadi *et al*., 2018).

Tsunami Evacuation Route

The main strategy in the making of tsunami disaster mitigation is to create an evacuation route to quickly evacuate the public from a tsunami disaster. The tsunami evacuation route for 2 is: The horizontal evacuation route is a higher information delivery away from the disaster in security zones. The vertical evacuation route is the provision of information to be directed towards the building or nearest place, with the provisions where the Evakuasinya must be earthquake resistant, have a room that is spacious and easy to reach. This research focuses on creating horizontal evacuation lines using network analyst methods.

Geographic Information System (GIS)

The Geographic Information System (GIS) is an informational system consisting of hardware components, software, geographic data and human resources that work together to input, store, repair, process, update, analyse, integrate, manipulate and display all geographical data (Adil, 2017). The components that build an information system are computer systems, software, spatial data, data management, analysis, and humans that operate GIS. Based on the GIS data structure is divided into 2 spatial data models, namely raster data models and vector data models. Raster data is the data that is got from remote sensing systems whose objects are in the form of pixels. Vector data is the shape of the Earth's surface, which is in the form of lines, dots, and areas. Each spatial data has its weaknesses and strengths, depending on the purpose, data availability, the accuracy that will be made and easy analysis (Irwansyah, 2013).

Network Analyst

The process of mapping the tsunami evacuation route using the closest facility method in network analyst in Arcmap application. Analysis using the closest facility method will consider the road network, road width, and road length. In making a tsunami evacuation route using the closest facility is required to have a starting point and endpoint of the tsunami evacuation route. The starting point is the tsunami-prone area and the endpoint is the evacuation site.

Satellite imagery interpretation techniques

Image interpretation is an activity on satellite imagery or aerial photographs to identify objects in them and extract information and assign value to them. 3 activities are done to recognize objects that are detection, identification, and analysis. Detection is the observation of an object. Identification is to characterize a detected object by using an existing caption and the analysis is to collect further information. 2 divided interpretation techniques are visual and digital interpretation techniques (Al Amin, 2017).

Geometry correction

Geometry correction is the process for Meproyeksikan imagery to have geographical coordinates. Geometry correction has 3 objectives, namely: (1) perform rhetorician or image improvement to return to its geographical coordinates, (2) perform a redistribution or image match with a geometrid corrected image and, (3) perform registration or image matching with a map that has corrected geometry to produce a specific projection (Candra and Suprianto Ahmad Afif, 2015). In geometry correction, there are 2 types of methods used are Rectification method (image to map) and the method of registration (image to image). To reduce geometric distortion is done by the rectification of geometry. Rectification is the process of repairing imagery to the actual position caused by a position shift. The accuracy of the geometry correction is highly dependent on the number and spread of the Ground Control Point (GCP). The terms of the GCP range are as follows: (1) The perimeter side of the image, (2) the center of the area, (3) The border area, (4) spread evenly and, (5) adjusting the terrain condition. The GCP (Ground Control Point) or ground control point is a location point that can be identified in real Rungan (on the ground), which serves as an allied point between the map coordinate system and the photo coordinate system. An ICP (Independent Check Point) or an accuracy test point is as quality control of an object by comparing the coordinate of the model to the actual coordinates. ICP requires that the point of the join should spread evenly throughout the area of the object to be tested. The geometry accuracy component is divided into 2 namely: horizontal and vertical accuracy test. In this study will be tested in horizontal accuracy (Al Amin, 2017).

3. Method

Research materials

The materials used in this study are:

1. Palu City Satellite imagery
   Satellite imagery used to acquire/edit land use data, coastlines and road networks
2. Contour Map of Palu City
   Contour Map of Palu city is used to obtain tilt data
3. Surface roughness coefficient
4. Palu city administration and land use Data

Research tools

The tools used in this study are:

1. Laptop set Asus P452LJ 209 with a specification processor Inter Core i5 and RAM 4 GB
2. ArcGIS software version 10.3 used for data processing and map creation
3. Set Microsoft Office 2013.

Stages of research

Research stages can be seen in **Figure 1.**

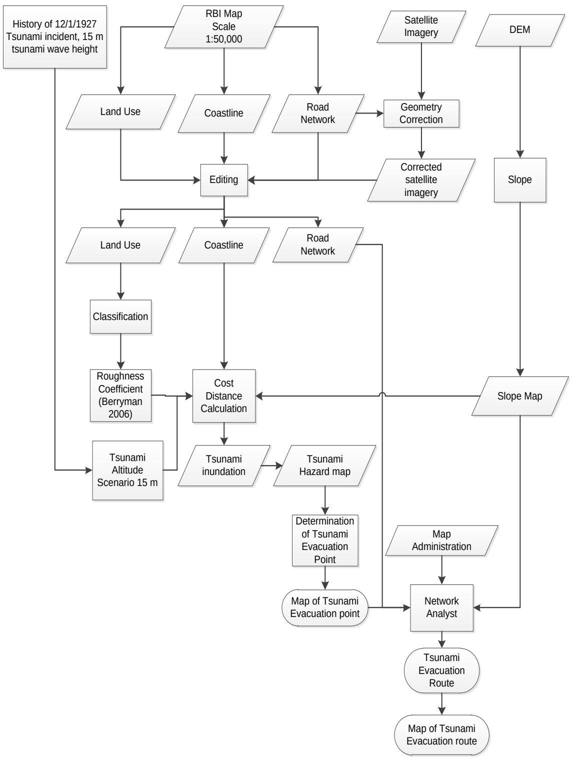

Fig 1. Research Stages

Broadly, there are 4 stages of research that is done, the first is the phase of data collection and preparation, the data in the improvement is secondary data. Basic map of Administration map, land use map, line map. Beach and road network maps are getting from (www.tanahair.indonesia.go.id) with a scale of 1:50,000, the Elevation Data map model (DEM) in Can of (www.tides.big.go.id/DEMNAS) on 6 october 2019 and satellite imagery data in a can from the Universal Maps Downloader (UMD) application.

The second stage is the data preparation phase, satellite imagery in geometry correction using the corrected road network geometry, the testing done is horizontal accuracy test. Then the basic map (land use map, the line will do the editing process by performing the satellite image interpretation manually with digital on-screen, with an analysis scale 1:5,000. After the editing process is completed, the next will be calculated on the surface roughness of land use data using Berryman numerical modeling. Here is the table of surface roughness values.

Table 2. Coefficient Surface roughness (Berryman, 2005)

Land type use/closure	Value of Manning's coefficient
Body of water	0.007
Bush/shrub	0.040
Forest	0.070
Plantation	0.035
Vacant Land	0.015
Farmland	0.025
Settlement	0.045
Mangrove	0.025
Pond	0.010

DEM will be done Slope process in the ArcGIS application to get the data slope. At the third stage of the Cost Distance calculation with a scenario of tsunami wave height of 15 m, which is in the history of a tsunami event in 12/1/1927, there is also table 1.1, using the Berryman equation:

$$H_{loss}=\left(\frac{167-n^2}{H_0^{\frac{1}{3}}}\right)+5.\sin S\text{............}(1)$$

Where:
Hloss = loss of tsunami altitude for 1 m of the propagation distance
H0 = The initial altitude of the tsunami on coastline
n = coefficient of surface roughness
S = slope surface

Considering the data on the surface roughness, land slope and the initial altitude of the tsunami of coastline, the result is a map of tsunami hazard. Furthermore, the determination of evacuation points. Further, determine tsunami evacuation pathways using a road network with the Analyst network method.

The fourth stage is the presentation of the results of (1) Tsunami hazard map of Palu City (2) tsunami evacuation route of Palu City.

4. Result and Discussion

Geometry Correction

The geometry correction method used in this study is a rectification (image to map). This method uses maps from RBI as a ground control point (GCP) Scale of 1:50,000. The map used is a road network map to pull the image back into an actual position. The geometry corrections are used on the road network map of RBI that has been corrected with geometry. In this study, the coordinate system used is with the Datum WGS 84 projection System 50 S. Selection of ground control points is done by looking at the position of clear natural objects, not easily changing or shifting in a short time, must be on the surface of the ground and have access to GCP locations such as crossroads or T-junction roads, sewers, and corner buildings.

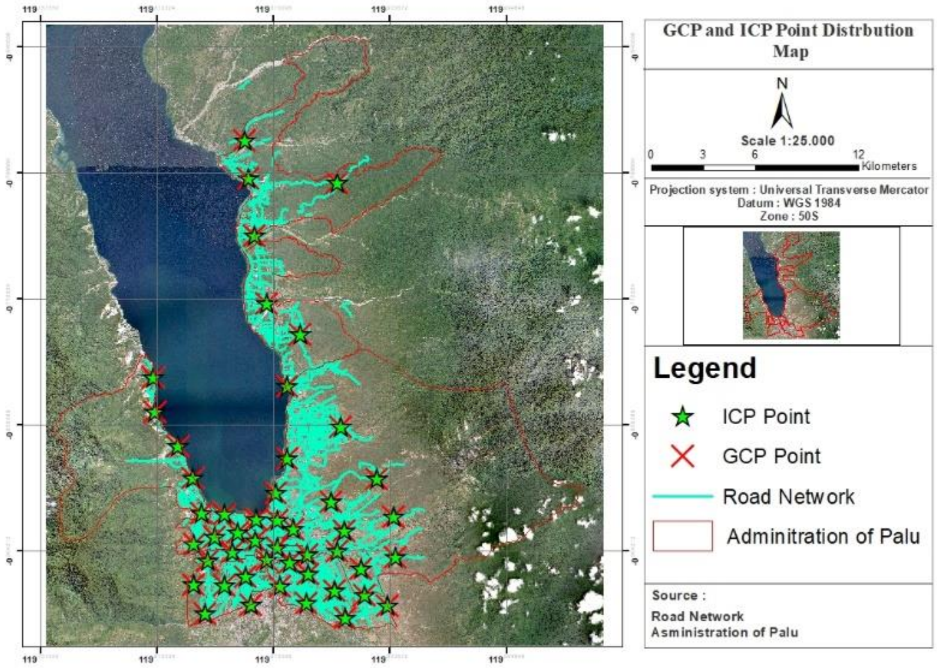

Fig 2. GCP and ICP point distribution map

GCP (Ground Control Point) is a location point identified in a real space (ground), which functions as an allied point between the map coordinate system and the photo coordinate system. GCP distribution requirements are (1) the perimeter of the image, (2) in the middle of the area, (3) the image border area, (4) evenly distributed and, (5) adjusting the terrain conditions. The geometry correction process is required to evenly scatter GCP and ICP on the mapping area. Testing of geometry accuracy is done based on the regulation of the Head of Information Agency Geospatial (BIG) No 15 years 2014 about technical guidelines basic map accuracy (Badan Informasi Geospasial, 2014). Testing is done by calculating the value of Circular Error 90% (CE90). The results of the accuracy-test can be 5.506. Based on the results of the standard accuracy test that is still allowed in the map performance is scale 1:25.000.

Land-use of Palu City

The use of Palu city land is divided by coefficient's surface roughness as in the table 2. Result of interpretation of land use of Palu water body, shrub/shrub, forest, plantation, vacant land, farmland, settlement, Pond/dam, and road network. There is no mangrove in Palu city. Dominating land use at the research site is forest. The land-use map of Palu city can be seen in **Fig 3.**

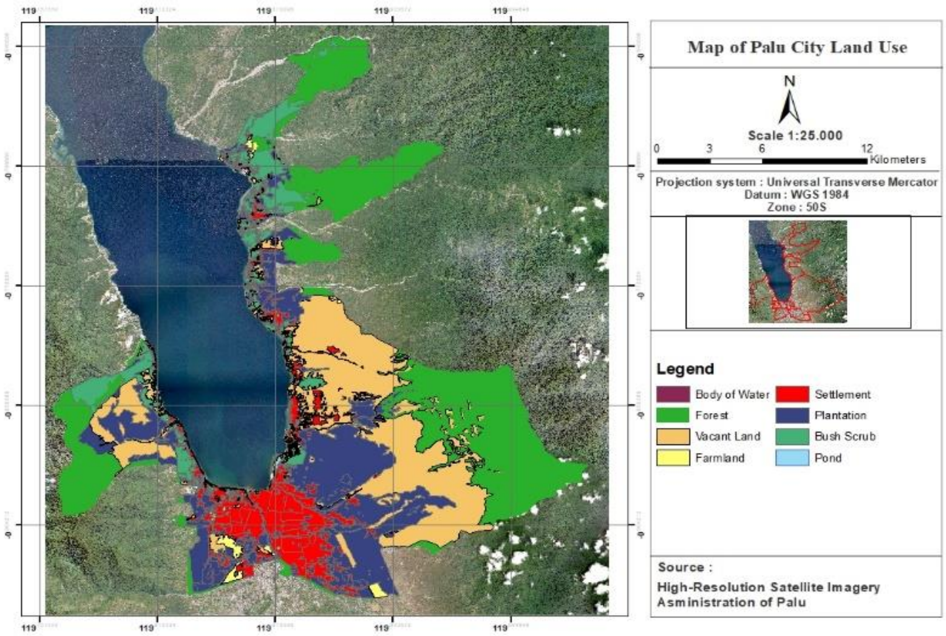

Fig 3. Map of Palu City Land-use

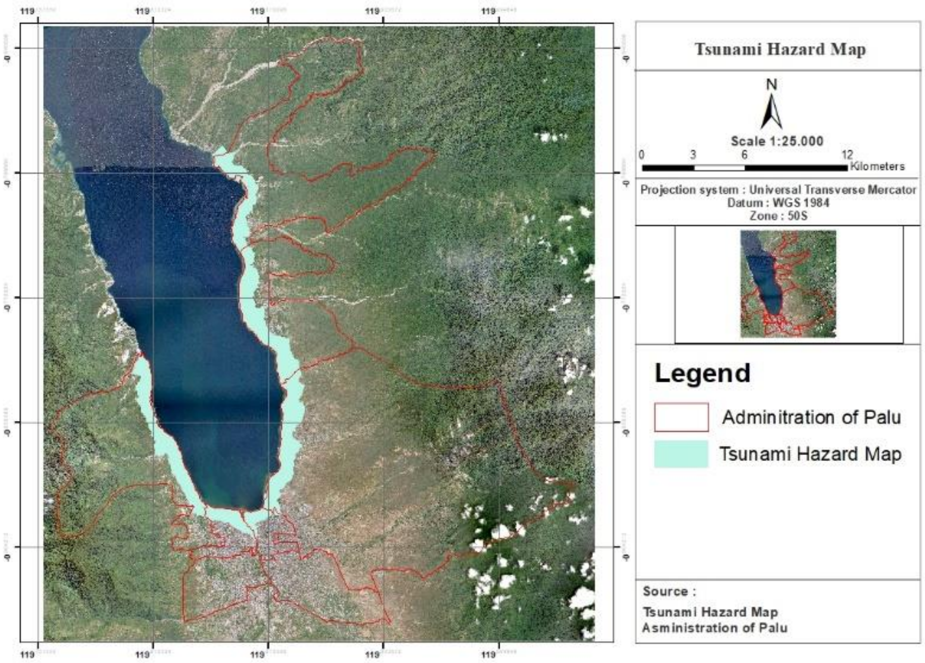

Fig 4. Palu City Tsunami Hazard Map.

Tsunami Hazard Analysis

Tsunami Hazard Analysis is achieved using equation (3.1). In the creation of a Tsunami hazard map, There are several inputs namely surface roughness map, slope map, shoreline and the scenario of tsunami altitude 15 m based on the Indonesian tsunami catalog in 416-2018, bmkg 2019. The tsunami hazard analysis also uses the tools cost distance to measure the loss of tsunami wave height of each pixel in uniform starting from the coastline. Based on the calculations obtained the most widespread subdistrict is the North Palu sub-district with a total area of 8.643528 km^2. Mantikulore district with an area affected 8.078757 km^2 District Ulujadi 2.201102 km^2, West Palu sub-district 7.971213 km^2. The district of the Taweili tsunami-affected by 5.210359 km^2 and East Palu Sub-district as much as 1.422311 km^2. District Tatanga and Palu Selatan are not exposed to the tsunami runoff because it is far from the beach. Can be seen in **Fig 4**.

Number of inhabitants of Palu

Population Data is used to determine evacuation sites. Not all of the inhabitants of Palu City were evacuated because some were not impacted by tsunami runoff. Palu City District, the most populated of the population, was 71.52 inhabitants in 2017. It can be seen in **Table 3.**

Table 3. Number of inhabitants (City of Palu BPS)

District Palu	Population
Palu Barat	62.293
Tatanga	39.997
Ulujadi	27.763
Palu Selatan	70.571
Palu Timur	71.452
Mantikulore	63.804
Palu Utara	23.196
Tawaeli	20.706

The data used to determine evacuation sites is land use data and tsunami hazard data. Analysis of the determination of evacuation places is a region or place that is not flooded with the tsunami. The existence of buildings and buildings is assumed by many people who activity the premises.

Mapping Tsunami evacuation pathways

The mapping of tsunami evacuation pathways is the result of this study. Planning tsunami evacuation lines using the gathering points and evacuation points that have been in the previous analysis. These two points are determined based on the outcome of tsunami hazard data. The evacuation route planning takes care of road type and width. The evacuation route was made as many as 93 lines divided into six sub-districts, namely Ulujadi District, West Palu Sub District, East Palu Sub District, Kecamtan Mantikulore, Taweili and, North Palu subdistrict.

Ulujadi District There are 13 evacuation routes, the longest line 2,717 m with a travel time of 17.5 minutes by running. Shortest path 96 m with a travel time of 0.6 minutes by running. The calculation of mileage obtained based on human average runs according to Weiner (1968) amounting to 1.29 m/s and is assumed if running twice. West Palu District There are 17 evacuation routes, the longest line 2,151 m with a time of 13.8 minutes by running. Shortest path 50 m with a travel time of 0.3 minutes by running. East Palu Sub-district there are 10 evacuation routes, the longest line 2,151 m with a travel time of 13.9 minutes by running and shortest path 160 m with a time of 1.0 minutes by running. Mantikulore District There are 25 evacuation routes, the longest line 2,887 m with a travel time of 18.6 minutes by running, the shortest path 111 m with a travel time of 0.7 minutes. North Palu Sub-district there are 13 evacuation lines, 4,274 m long line with

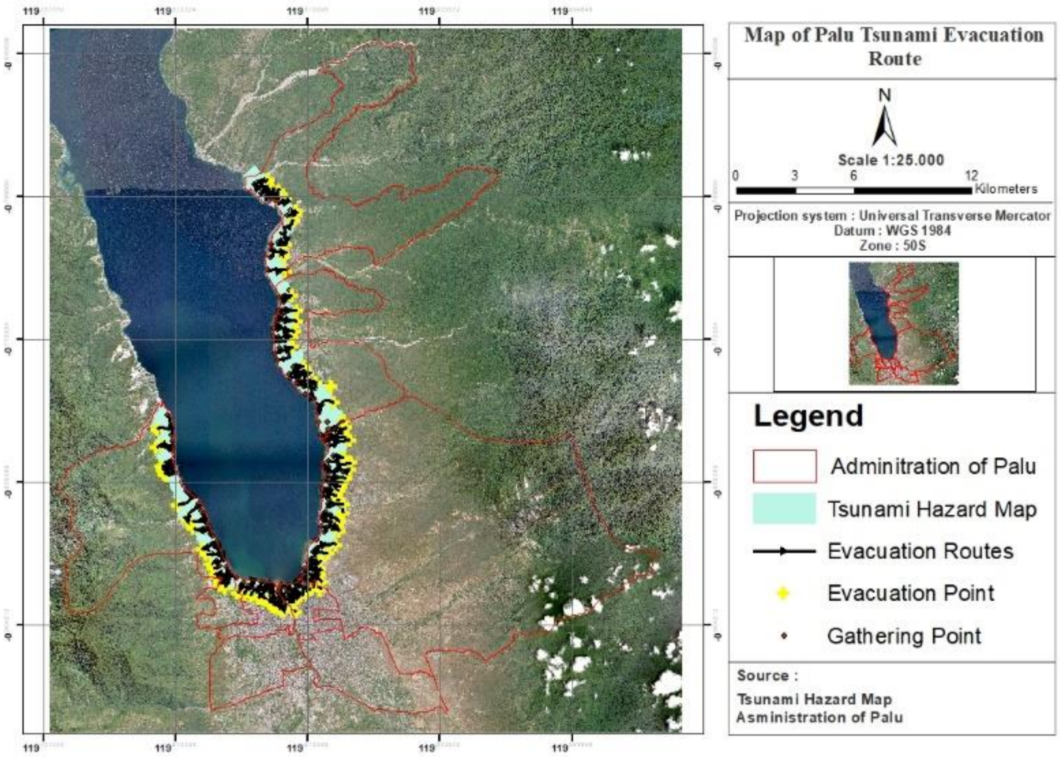

Fig 5. Map of Palu Tsunami Evacuation Route

27.6 minutes running and the shortest path of 63 m with a travel time of 0.4 minutes by running. Taweili subdistrict There are 15 evacuation routes, the longest line 2,017 m with a travel time of 13 minutes by running and shortest path 97 m with a travel time of 0.6 minutes by running. The longest time summary of the tsunami evacuation route is 27.6 minutes by running. The difference between earthquakes and tsunamis ranged from 15-30 minutes.

5. Conclusion

The tsunami runoff with the scenario of tsunami altitude of 15 meters is the first step to see the extent of the potential of the city of Palu against the tsunami disaster. The most impactful area is the North Palu sub-district with a total area of 8.643528 km^2. A possible mitigation is to create a tsunami evacuation route. The creation of a tsunami evacuation route is made using the network analyst method to produce 93 evacuation routes divided into six sub-districts namely North Palu Sub-district, Mantikulore, Ulujadi, West Palu East Palu, and Taweili. District Tatanga and Palu Selatan are not exposed to the tsunami runoff because it is far from the coastline so there is no need for tsunami evacuation routes. The longest evacuation route is 4,297 meters with a travel time of 27.6 minutes with running and the shortest evacuation route of 96 meters with a travel time of 0.6 minutes by running.

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