Mapping of Tsunami Disaster Mitigation Evacuation Routes of the Movement of the Sunda Subduction Megathrust
(Case Study: Coastal Analysis of Southern Garut Regency)

R. A. E. Virgana Targa Sapanji[1,*], Dani Hamdani [2]

[1,2] *Information System Departments,University of Widyatama, Bandung, Indonesia*
[*]*Corresponding author. Email: rae.virgana@widyatama.ac.id*

ABSTRACT
Potential disaster due to the movement of the subduction zone between the Eurasian Plate and the Indo-Australian plate, extending from the west of Sumatra to the south of Java, Bali, and Nusa Tenggara. This subduction zone is called the Sunda subduction arc. It has several segments. The Java segment has a lower seismic magnitude and frequency. Megathrust is a shallow part of the subduction lane which has a shallow dive angle, so the impact on the southern part of Garut Regency has the potential for earthquake and tsunami disaster, has been analyzed spatially and geoprocessing with geographic information systems, plotting 149 earthquake points from 1958 to 1920, planning evacuation routes for earthquake and tsunami disaster mitigation, as well as measuring coordinates, height, slope, and width between the coast and settlements, tourist attractions, main roads south of West Java, and evaluation of existing evacuation routes so that the community has an evacuation route adequate and safe.

Keywords: *Megathrust, Sundanese Subduction, Disaster Mitigation, Spatial, GIS*

1. INTRODUCTION

Law of the Republic of Indonesia Number 24 of 2007 concerning disaster management, states that Preparedness is a series of activities carried out to anticipate disasters through organizing and through appropriate and efficient measures, while mitigation is a series of efforts to reduce disaster risk, both through physical development. as well as awareness and capacity building to face the threat of a disaster, and disaster emergency response is a series of activities carried out immediately at the time of a disaster to deal with the adverse effects, which include activities to rescue and evacuate victims, property, the fulfillment of basic needs, protection, management of refugees. , rescue, and restoration of infrastructure and facilities.

One of the important points in article 45 paragraph 2 point e, in this law, is the preparation of evacuation sites, especially if the megathrust subduction of Sunda occurs and the earthquake that occurs has an effect on the occurrence of a tsunami, if the tsunami moves 2 kilometers to 4 kilometers from the lip beach, then the community only has a limited time to move away from the shoreline and to a higher place.

Garut Regency, especially in the southern part, has a unique topography, from the shoreline it can be seen towering large mountains, such as Mount Malabar, Mount Papandayan, which can be seen very clearly from the shoreline. So that for partial evacuation routes it can be easy to find a sufficient height to save oneself, but if it is analyzed more specifically on the southern road of West Java that stretches in this area from west to east if you pay close attention, several road segments are not far away. from the shoreline, then several villages which are also not far from the shoreline. So that community preparedness, and signs of evacuation routes must be reproduced along the southern route of Garut Regency, so that when a disaster comes, any community, whether local people, migrants, tourists, can see the signs of the evacuation route.

In this study, survey and combining the feasibility of the existing evacuation route signs were then carried out spatial analysis using geographic information system tools, to determine the feasibility of the evacuation route signs from the threat of earthquakes and tsunamis according to the peculiarities of the location, altitude, and land slope. , many residents, tourist attractions, and so on.

2. LITERATURE REVIEW

The government and the people of Indonesia already had a law on disaster management in 2007 [1], although it was a little late decades since Indonesia's independence, after major disasters occurred, such as the movement of the megathrust subduction of Sunda on the tip of the island of Sumatra resulting in an earthquake and tsunami in Nangroe Aceh Darusallam in 2004, even the earthquake and tsunami on the island of Sulawesi in 2018, which devastated Palu City due to the movement of the Palu Koro fault, simply from the impact on Palu City and the huge death toll, at a glance According to the researcher, this proves the ineffectiveness of this law at the lower regional level, the importance of disaster preparedness and mitigation, especially in areas that have the potential for major disasters.

The National Disaster Management Agency (BNPB) already has a National Disaster Management Plan especially for the 2015-2019 masterplan [2], the policy document of this plan should be understood and implemented at lower regional authorities, at the provincial and district/city levels, which have been widely used. Having a Regional Disaster Management Agency (BPBD), this institution is the foremost institution to prepare local governments and communities to always be prepared for and respond to disasters.

The National Center for Earthquake Studies (Pusgen) has the latest Indonesian Earthquake Hazard and Source Map released in 2017 [3], this document is very, very important for all Indonesian governments and people to always be aware of the environment in which they live, and become a reference document for development and development. its spatial plan.

Documentation of sources and the dangers of earthquakes has existed from ancient times, in the form of fairy tales such as the tale of Sangkuriang in the Sundanese, there is a translation related to the shift of the Lembang fault in the 14th century, documentation of kingdoms in Indonesia, Dutch documentation, and documentation of disasters after Indonesian

Independence all this documentation can be a lesson for us all to be prepared and responsive to disasters, especially earthquakes.

In developed countries such as Australia, New Zealand, the United States, studies on earthquake and tsunami preparedness and response, in particular, have deep and comprehensive studies such as the Tsunami Evacuation Signs document [4] [5] [6] [7] [8]], these documents are similar to some documents that have been released by BNPB or local governments that have the potential for earthquakes and tsunamis, but in this study, we will compare the documents that have been released by our government and by governments of other countries.

Some important studies when the evacuation took place were traffic arrangements and transportation routes that were jammed and chaotic, we can see in the last events when the earthquake hit South Banten in 2019, Alhamdulillah the tsunami that occurred was not as big as it was thought to be only 1 or 2 meters in shoreline, but the chaotic conditions that occur during an evacuation, people can die from car and motorbike collisions, not because of the earthquake and tsunami itself, in some countries, there are several standards for transportation arrangements when a disaster occurs such as Emergency Management Signing and Sign Policy and Guidelines [10] [11], it is not the best but has a plan that is better than none.

Researchers will make thematic maps [12] to be able to describe the evacuation route, the height, and slope of the land, the location of the village, population density, tourist locations, the distance from the coast to the population and the southern main route of Garut Regency.

The spatial and geographic information system software that researchers will use is Quantum GIS [13] [14] [18], a very complete and comprehensive tool, and has been widely used in disaster planning such as in Nangroe Aceh Darussalam, and more importantly this software. open sources so that it will not burden the research budget.

In this study, researchers used a research methodological framework by C. R. Kothari [15], for addressing the analysis and measurement of soil resources using a geographic information system by Burrough P., Stephanie Rogers, and Patricia Vivas [16] [17].

3. METHOD

According to C. R. Kothari [15], detailed process steps to provide useful procedural guidance in the research process are as follows:

(1) Formulating The Research Problem, researchers 1 and 2, at this stage the researcher will reexamine the importance of the research problem of Mapping the Tsunami Disaster Mitigation Evacuation Route, the movement of the Sunda Subduction Megathrust (Case Study: Coastal Analysis of South Garut Regency), several mitigation activities along the coastline south Garut Regency has carried out signs of the direction of evacuation, but some of the early warning tools for the earthquake and tsunami are not very clear, so the researchers will observe the problem again in the field for the existence of this disaster preparedness and mitigation tools.

(2) Extensive Literature Survey, researchers 1 and 2, initial literature surveys have been conducted by researchers, it is found that in developed countries, signs such as evacuation routes, tsunami signs, early warning systems appear to be more advanced with in-depth research studies, so that With the addition

of studies that have been carried out by the Government, the National Disaster Management Agency, the Earthquake, and Tsunami Assessment Agency, in analyzing this research, researchers use spatial methods such as geoprocessing using geographic information system tools, and researchers will review the appropriate spatial literature for the study. In this disaster, the researcher will reconstruct its suitability in the field with existing disaster indicators.

(3) Development of Working Hypotheses, researchers 1 and 2, according to the title of the study that the importance of reviewing the mapping of the Tsunami Disaster Mitigation Evacuation Route, the movement of the Sunda Subduction Megathrust (Case Study: Coastal Analysis of South Garut Regency) is due to the potential for earthquake and tsunami disasters that will impact on the community along the southern route of southern Garut Regency

(4) Preparing The Research Design, the research design itself is a methodology in itself, the researcher will start from formulating the research problem, then conducting a study on disaster preparedness and mitigation with a case study area along the southern route of Garut Regency, then conducting an initial hypothesis on this problem, trying to find examples of secondary data related to this research, then conducting a primary data survey along the southern route of Garut Regency carried out in wardriving, then analyzing data by geoprocessing and doing output visualization with a geographic information system, the results were analyzed, and interpretation of whether the tsunami disaster mitigation evacuation route along the southern route of Garut Regency is appropriate and adequate, then prepares a final report on this research activity.

(5) Determining Sample Design, researcher 2, will make an example of the initial research design plan with existing data, such as required spatial topography along the southern route Garut Regency can be obtained from the Geospatial Information Agency (BIG), population density data, dense residential locations are needed, tourist locations, altitude, land slope, the distance between the beach and the main road in the southern route of Garut Regency.

(6) Collecting The Data, researcher 1, will conduct field observations and surveys along the southern route of Garut Regency, see and study the signs of evacuation routes on all main roads along the southern route of Garut Regency, observations are also made at densely populated locations and tourist locations, starting from Ranca Buaya District in the west to Pameumpek District in the east. Garut Regency has a beach length of approximately 80 km, maybe about 30 km is the Sancang Protected Forest area in the east, then the rest are residential areas, tourist sites, gardens, etc., observations and surveys will be carried out in wardriving to be able to reach areas isolated.

(7) Execution Of The Project (Geo-Processing Data & GIS Visualization Output), researcher 1, will perform a geo-processing process of existing secondary and primary data, and create visualizations with a geographic information system.

(8) Analysis of Data, researchers 1 and 2, the results of the geo-processing and geographic information system, will be analyzed and synthesized whether the disaster evacuation routes along the southern route of Garut Regency are safe and adequate.

(9) Hypothesis-Testing, researchers 1 and 2, with data analysis the data will be concluded whether the signs of tsunami evacuation routes, especially along the southern route of Garut Regency are safe and adequate.

(10) Generalization and Interpretation, researchers 1 and 2, will carry out generalization and interpretation of this research and will provide evaluations and recommendations that can be given for this research, particularly on signs of tsunami disaster evacuation routes along the southern route of Garut Regency. Preparation Of The Report, researchers 1 and 2, will prepare the final report of this research, hopefully, it can add to the study of the importance of tsunami evacuation route signs, especially in the southern route of Garut Regency for disaster preparedness and mitigation.

4. RESULT

Research on the Evacuation Route for Tsunami Disaster Mitigation the movement of the Megathrust Subduction of Sunda (Case Study: Coastal Analysis of South Garut Regency, starting with the search for past earthquake data, the researcher searched two reliable sources, namely:

1) Indonesian Agency for Meteorological, Climatological and Geophysics (Badan Meteorologi, Klimatologi, dan Geofisika or simply BMKG) [19]
2) The United States Geological Survey (USGS) [20]

These two secondary data sources found past seismic data, especially in the South Garut area, search for 100-year earthquake data, which researchers found only between 1958 and 2020, found 149 earthquake data, as in Table 1.

Table 1. Example of Sea Earthquake Data in South Garut, 1958 – 2020, Found 149 Records

time	latitude	longitude	depth	mag
2020-08-23T21:05:36.372Z	-77.972	1.073.366	58.81	4.1
2020-08-16T15:12:35.976Z	-76.793	1.073.531	29.84	4.2
2020-04-09T07:20:55.527Z	-80.814	1.078.508	55.63	4.4
2020-03-18T08:45:48.597Z	-75.152	1.076.753	117.12	4.2
2020-01-08T22:05:33.881Z	-77.621	1.079.297	69.72	4.6
…	…	…	…	…
1977-08-10T07:07:26.900Z	-8.172	107.644	52	5.7
1977-01-01T02:18:20.100Z	-7.833	107.866	90	4.7
1975-06-16T04:14:03.800Z	-7.808	107.927	88	5
1973-01-22T03:17:00.000Z	-7.575	107.262	88	4.9
1958-02-19T19:25:27.000Z	-7.817	107.482	35	6

The researchers carried out the geoprocessing process to get the spatial information. As seen in Figure 1, the earthquake points in the sea off the south coast are scattered in all locations, although not all of them have the potential for a tsunami.

In Figure 2 you can see the seismic pattern, the color on the map is getting darker, then earthquakes occur very often, only with Figure 2. Only we can simply conclude, if and hopefully, it doesn't happen, the earthquake that causes the tsunami appears from that frequent pattern, at a minimum, the authorities can make better mitigation and evacuation plans for the earthquake and tsunami disaster.

Learning from the Aceh tsunami in 2004, with the following data. Indian Ocean Tsunami of December 26, 2004, Earthquake Parameters (USGS) [20]:

(1) Latitude: 3.3N
(2) Longitude: 95.8E
(3) Origin Time: 00: 58: 53UTC on December 26, 2004
(4) PST on December 25, 2004
(5) Information Center Magnitude: 9.0

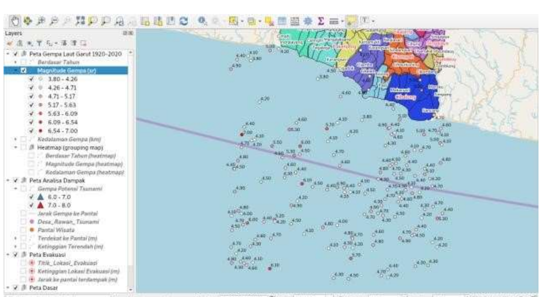

Figure 1 The distribution of 149 earthquake points in the coast of South Garut between 1958-2020

The nearest coast on the island of Sumatra, it is only 85.14 km. But only God Almighty knows when the earthquake that became the tsunami occurred, and which location was hit, in the 2004 Aceh tsunami there were many extraordinary stories, how the nearest point was

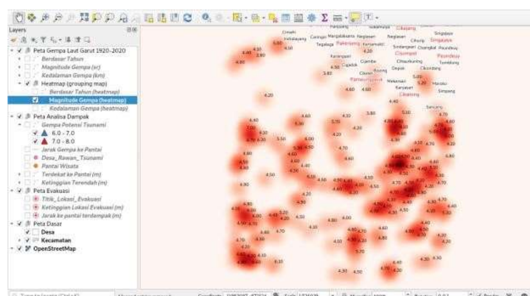

Figure 2 Grouping maps of 149 earthquake points on the coast of South Garut between 1958-2020

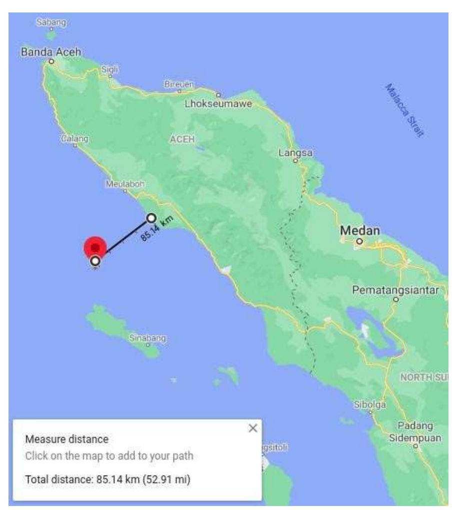

Figure 3 The 2004 Indian Ocean Earthquake Epicenter

Table 2. Sea Earthquake in South Garut With a Magnitude of More Than 6 on The Richter Scale And There Is a Potential for a Tsunami

time	latitude	longitude	depth	mag	Earthquake Distance to Beach
2009-0902T07:55:01.050Z	-7.782	107.297	46 km	7 SR	35.6 km
1996-1209T03:54:16.310Z	-7.936	107.489	50.9 km	6.1 SR	41.28 km
2016-0406T14:45:29.620Z	-8.2036	107.3857	29 km	6.1 SR	70.77 km
2003-0514T07:40:36.100Z	-8.06	107.315	79.1 km	6 SR	63.72 km
1958-0219T19:25:27.000Z	-7.817	107.482	35 km	6 SR	30.4 km

okay those that are farther from the point of the earthquake are more devastating, our common task is to educate the public that the potential for earthquakes and tsunamis exists and to make proper disaster mitigation plans.

From 149 records of earthquake data in the South Garut Sea from 1958 to 2020, there are 5 earthquake data with the potential for a tsunami, as in Table 2. We can see the potential for earthquakes and tsunamis in the southern part of Garut Regency, how Pangandaran Regency was destroyed by the tsunami, the potential for earthquakes and tsunamis by the Sundanese megathrust subduction does have potential, when he appears only God Almighty who knows best.

In Figure 4. the researchers got from the USGS, there was a potential tsunami in the earthquake on April 6, 2016, at 14:45:29, with magnitude 6.1, the depth of the earthquake was 29 km in the South Garut Sea. And the distance of the coordinates of the earthquake to the nearest South Garut coast is only 70.77 km, smaller than the earthquake point of the 2004 Aceh tsunami, which is 85.14 km to the nearest beach.

If we spatially plot 5 earthquakes, 4 earthquakes with magnitude 6 and 6.1, and 1 earthquake with magnitude 7 (2009), as in Figure 5.

After knowing the potential for a tsunami earthquake that was in South Garut, then the researcher conducted a study of the estimated affected area, previously the researcher conducted a survey and spatial analysis, the estimated affected area, the parameters used were:

1) Distance to residential or tourist areas closest to the beach
2) The height of the residential or tourist area closest to the beach

From the results of the analysis, the researcher found 26 points in the region that have the potential to be greatly impacted when the tsunami earthquake comes, as in Table 3.

The data is processed spatially, producing the geographic information system shown in Figure 6.

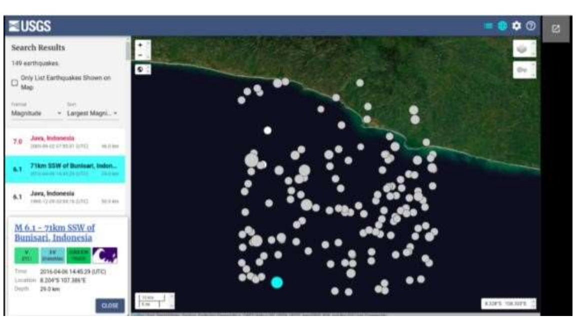

Figure 4 USGS Tsunami Early Warning System in South Garut Sea [20]

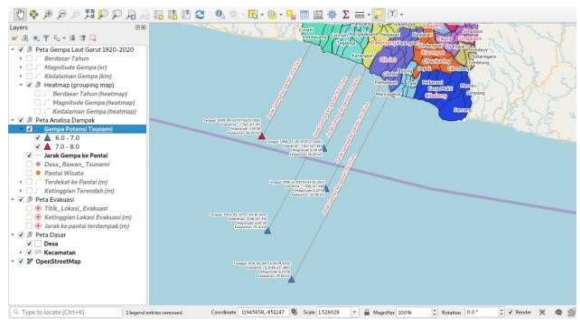

Figure 5 Sea earthquake in South Garut with a magnitude of more than 6 on the Richter scale and there is a potential for a tsunami

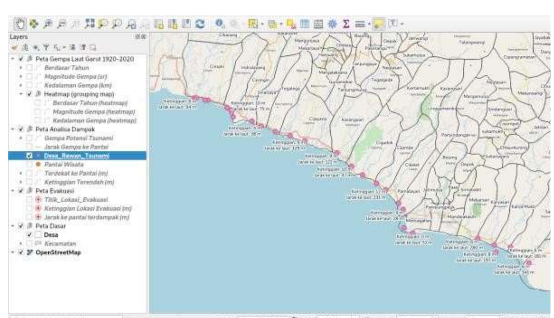

Figure 6 Spatially plotted, 26 areas that have the potential to be greatly impacted if the tsunami earthquake comes in South Garut

Table 3. Example of data, from 26 regional points that have the potential to be greatly impacted when the tsunami earthquake comes in South Garut

Latitude	Longitude	Altitude (m)	Distance to Sea (m)	Village
-7.668.280.556	1.076.969.028	0	50.54	Mancagahar
-7.682.365.415	1.077.947.456	2	39.79	Karyasari
-7.528.705.556	1.074.798.139	2	35.92	Purbayani
-7.639.622.222	10.768.535	4	28.49	Cilauteure un
-7.508.612.718	1.074.462.273	4	266.62	Indralayang
-754.005.777	107.513.649	4	38.02	Karangwangi
-7.661.624.836	1.076.860.461	5	10.91	Pamalayan
-7.703.945.753	107.837.022	6	341.37	Sagara
-7.684.619.444	1.078.147.944	6	181.09	Karyamukti
-7.674.405.646	1.077.752.257	6	280.45	Mekarsari
-7.598.397.222	1.076.362.417	6	27.52	Cigadog

Figure 7 is an example of a 4-point visualization map of the distance and height analysis area towards the coast, of the 26 points of the area that have the potential to be greatly impacted if the tsunami earthquake comes in South Garut.

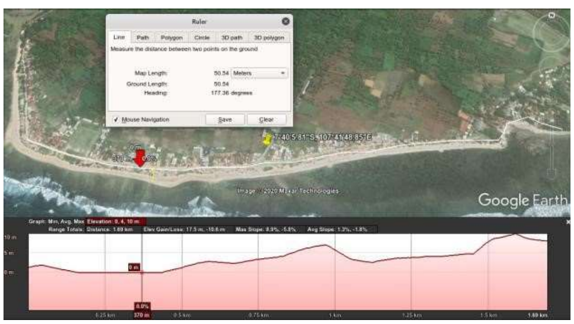

Figure 7 Wisata Sayang Heulang Beach, in this area, there are settlements only 50.54 meters to the beach, and a height of 0 m above sea level, meaning that it is parallel to the sea, even though there are large reefs on the coast

From Figure 7, it can be very simply concluded that if there is a tsunami it may be badly affected, and those that are more difficult to evacuate are areas such as the area of Sayang Heulang Beach and Santolo Beach, the elevation or height of the ground in this area is very low on average. with a very large area, so that if the community is going to run from a tsunami in this area, it will be difficult to find higher ground, and once again learn from the Aceh tsunami the wave height starts from 3 meters to 30 meters and can reach the land up to 4.5 km, so areas such as Pantai Sayang Heulang and Pantai Santolo should be brought to

Table 4. Example data from point 26 of the evacuation area to reach the minimum safe plateau

Evacuation Latitude	Evacuation Longitude	Evacuation Altitude (m)	Evacuation Distance to Sea (m)	Evacuation Village	Evacuation District
-7.636.225	107.725.786	50	4882.55	Panyindangan	Pameungpeuk
-7.674.847	107.797.539	60	842.71	Karyasari	Cibalong
-7.526.725	107.485.147	40	615.72	Purbayani	Caringin
-7.625.767	107.701.869	50	2292.02	Pamalayan	Cikelet
-7.508.422	107.467.264	50	401.08	Indralayang	Caringin
-7.534.211	107.522.539	50	579.42	Karangwangi	Mekarmukti
-7.632.903	107.718.606	50	4334.48	Jatimulya	Pameungpeuk
-7.687.556	107.833.942	55	1878.65	Sagara	Cibalong
-7.681.278	107.818.897	50	801.82	Karyamukti	Cibalong
-7.664.642	107.778.214	55	1106.05	Mekarsari	Cibalong
-758.785	107.642.078	47	1259.41	Cigadog	Cikelet

the attention of the authorities to put up signs for the escape route of a larger and clearer tsunami.

After analyzing the points of the area that are estimated to be badly affected when a tsunami arrives, then an analysis of the evacuation route for an earthquake-tsunami when it comes, to a higher and safer area.

The results found 26 points of evacuation areas, with higher ground, and for a relatively affordable distance, just running to the plain is less than 1 km uphill, there are 14 points in the area, and 10 points of more than 1 km to get to the plateau at least safe, some seem to have to ride a vehicle, with the data in Table 4.

For the record, the researchers chose the point of the evacuation area with an average height above 40, 50, and 60 meters, and the people in the area can still move to higher areas, if they feel that the height is not safe, with reference when looking at the Aceh Tsunami records, the altitude the maximum wave height is 30 meters and can push inland up to 4.5 km, although as a record the highest tsunami wave height ever recorded and documented in Alaska is 85 meters high and pushes inland tens of km.

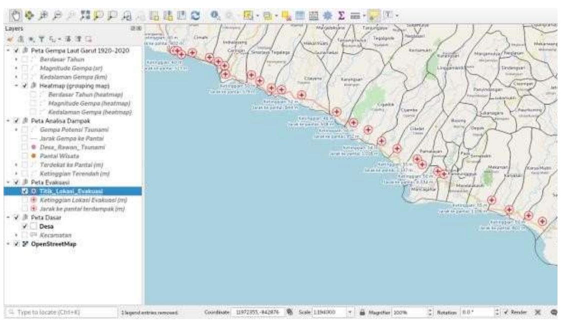

Figure 8 Spatial plot to 26 points of evacuation area to reach the minimum safe plateau

Figure 9 The yellow pinpoint is a residential area close to the beach and has a low elevation

Figure 10 The famous Santolo Beach, with its white sand and beautiful beaches

Figure 8 is a plot of the 26 points of the evacuation area to reach a minimum safe plateau. Figure 9 and Figure 10 are 2 examples of spatial visualization maps for selecting evacuation area points, from the 26 evacuation area points that have been selected by the researcher, with minimal altitude and distances that can be reached by vehicle, and some simply run to the area.

The evacuation point is at an altitude of 55 meters with a distance of 1876 meters (1.8 km), and it is still possible to move to higher ground.

In this area, there are many inns on the shoreline, and to reach a height of 50 meters the evacuation point requires a distance of 4334 meters (4.3 km), and this is difficult if not using a vehicle to reach the evacuation site in a short time.

Figure 11 is a combined visualization spatial plot between the possible affected area points and the evacuation area points with a safe height and a relatively short distance.

Figure 12 is a visualization plot of 5 earthquakes in the South Garut Sea with magnitudes 6 and 6.1 (4 blue dots), magnitude 7 (1 red point), combined with the predicted affected points, and the closest evacuation route.

5. CONCLUSION

From the descriptions above, we all must care about the potential for this tsunami earthquake, it is very unfortunate that the researchers mistakenly guessed, in these areas of southern Garut there are still minimal signs or symbols of evacuation rescue routes when a tsunami earthquake comes, this is necessary.

Make a large sign or symbol or signs of a rescue route for evacuation when a tsunami earthquake occurs, especially in dense settlements near the coast and coastal tourism areas, so that the community and the authorities together, train to mitigate and evacuate the possibility of a tsunami disaster this, hopefully, it will be good for all.

The WebGIS results of this research can be found here: https://sites.google.com/view/desa-rawantsunami-garsel/

AUTHORS' CONTRIBUTIONS

R. A. E. Virgana Targa Sapanji, Born in Bandung, September 21 1977, his Master's Degree in Information Technology from Department of Informatics Engineering, Bandung Institute of Technology in 2013. Currently hes is a lecturer at Widyatama University and he can contact through rae.virgana@widyatama.ac.id, contributed to this research as a data analyst and a GIS specialist.

Dani Hamdani, Born in Bandung, August 20 1987, his Master's Degree in Information Technology from Department of Informatics Engineering, Bandung Institute of Technology in 2013. Currently he is a lecturer at Widyatama University and he can contact through dani.hamdani@widyatama.ac.id, contribution in this research as a software engineer.

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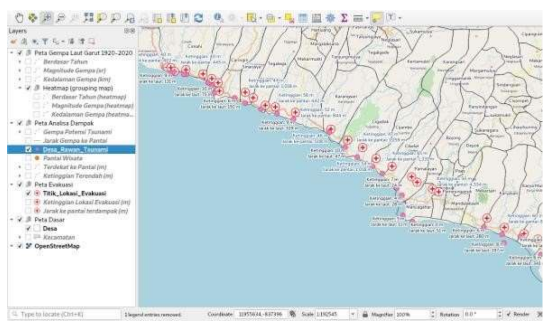

Figure 11 The combined visualization spatial plot between the points of the likely affected area and the evacuation area points with a safe height and a relatively short distance

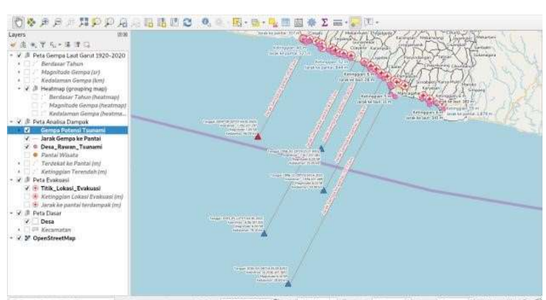

Figure 12. Plot visualization of 5 earthquakes in the South Garut Sea with magnitudes 6 and 6.1 (4 blue dots), magnitude 7 (1 red dot), combined with the predicted affected points, and the nearest evacuation route

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