JPPIPA 10(Special Issue) (2024)

Jurnal Penelitian Pendidikan IPA

Journal of Research in Science Education

http://jppipa.unram.ac.id/index.php/jppipa/index

Model of Tsunami Mitigation and Evacuation Routes in Pancer Banyuwangi

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Received: June 3, 2024
Revised: August 8, 2024
Accepted: August 25, 2024
Published: August 31, 2024

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DOI: 10.29303/jppipa.v10iSpecialIssue.8358

Abstract: Banyuwangi has the largest tsunami disaster risk in East Java, about 45,305 affected people, Rp. 160,886,000,- for the risk of physical losses, Rp. 106,414,000,- for the risk of economic losses and 84 ha of environmental losses (BNPB, 2023). In addition, according to historical data, Banyuwangi was hit by tsunami on June 9, 1994 with magnitude of 7.8 which caused a maximum run up of 14.0 m and killed 238 lives (BNPB, 2023). Also based on Undang- undang No. 24 Tahun 2007 concerning Disaster Management, Indonesia should have preventive and mitigation measures for tsunami disasters both before and after as an effort to reduce the disaster risk (Putra, 2009) . Tsunami modeling in southern Java using COMCOT v1.7 as tsunami worst case scenario in Banyuwangi is the first step for mitigation. The initial results of COMCOT were then used for preparing tsunami disaster evacuation route planning based on the Tsunami Natural Disaster Evacuation Route Planning Guidelines, Dirjen Bina Marga, 2023. The final step is validation/routing survey of the 8 (eight) routes that have been determined. 2 (two) of the 8 (eight) routes fulfill the guidelines for planning tsunami mitigation routes. However, all routes can be considered due to the distribution of settlements, the number of affected residents and the number of routes needed.

Keywords: Field survey; Inundation; Tsunami travel time; Tsunami estimated time arrival; Virtual tide gauge

Introduction

Historical data has recorded the occurrence of destructive tsunami disaster in Banyuwangi on June 4, 1994 with a magnitude of 7.8 which caused a maximum run up of 14.0 m and killed 238 lives (BNPB, 2023). Seismicity data also shows high level of seismic activity (Yuniansyah, 2018). Thereby the potential for the revival of tsunami earthquake is high in this region. Banyuwangi has tsunami generating area in the form of subduction zone between the Indo-Australian Plate and the Eurasian Plate located in south Java This subduction zone causes many earthquakes with shallow depths (Widiyantoro et al., 2020).

There are several regencies/cities that have tsunami disaster risk both in terms of social, physical and economic, including Banyuwangi, Blitar, Jember, Malang, Lumajang, Trenggalek, Situbondo and Tulungagung (BNPB, 2023). Of these districts and cities, Banyuwangi has the largest tsunami risk, about 45,305 people affected by the tsunami, Rp. 160,886,000,- for the risk of physical losses, Rp. 106,414,000,- for the risk of economic losses and 84 ha of environmental losses.

Based on Undang- undang No. 24 Tahun 2007 concerning Disaster Management, Indonesia should have preventive and mitigation measures for tsunami disasters both before and after as an effort to reduce the disaster risk (Putra, 2009). These actions can be in the form of preparing tsunami disaster mitigation

How to Cite:
Trisnawati, T., Surjono, S., & Hakiem, L. (2024). Model of Tsunami Mitigation and Evacuation Routes in Pancer Banyuwangi. *Jurnal Penelitian Pendidikan IPA*, *10*(SpecialIssue), 604–613. https://doi.org/10.29303/jppipa.v10iSpecialIssue.8358

documents, determining tsunami evacuation routes, determining and building tsunami evacuation sites, and emergency response measuring from each required element. In addition, mitigation efforts are also carried out in the form of counseling and training on tsunami disaster mitigation for coastal communities to the government side (Aldison, 2021).

Tsunami modeling in southern Java using COMCOT v1.7 as tsunami worst case scenario in Banyuwangi is the first step for mitigation. By calculating the tsunami inundation, the evacuation route and assembly point can be determined in the shortest time that can be reached by the community. This study is expected to be a reference and consideration in tsunami mitigation in Banyuwangi in general and in Pancer Beach in particular.

Previous research has studied a lot about the tsunami inundation and mitigation route caused by modeling tsunami earthquake scenarios in several coasts in Indonesian territory without considering the facts. In this study, an assessment of tsunami inundation, mitigation and evacuation routes will be carried out from the results of tsunami modeling scenario. The initial results are then compared with the facts in the field obtained from validation/field survey with local residents' representatives. Thus more valid tsunami mitigation and evacuation routes are obtained.

Method

The location of the research is at Pancer Beach, Sumberagung Village, Pesanggaran District, Banyuwangi Regency. Pancer Beach is a crowded area with tourism activities, sports (surfing), as well as various resident activities such as gardening and gold mining activities.

This research uses mixed method approach, which consists of quantitative with a descriptive analysis method and a qualitative method in the form of validation/field survey. In the quantitative method, tsunami modeling was carried out using COMCOT v1.7 software, then the inundation model was mapped with the spatial analyst tools in GIS software. The parameters used were the height of the tsunami wave on the coastline, the slope of the area, and the surface roughness coefficient. Meanwhile, the qualitative method is carried out by validation/field survey where the researchers and the community representatives collaborate to determine the most appropriate evacuation route according to the guidelines for planning tsunami disaster evacuation routes. The results then compared with the theoretical assessment (quantitative method) to produced tsunami mitigation and evacuation model in Pancer Banyuwangi.

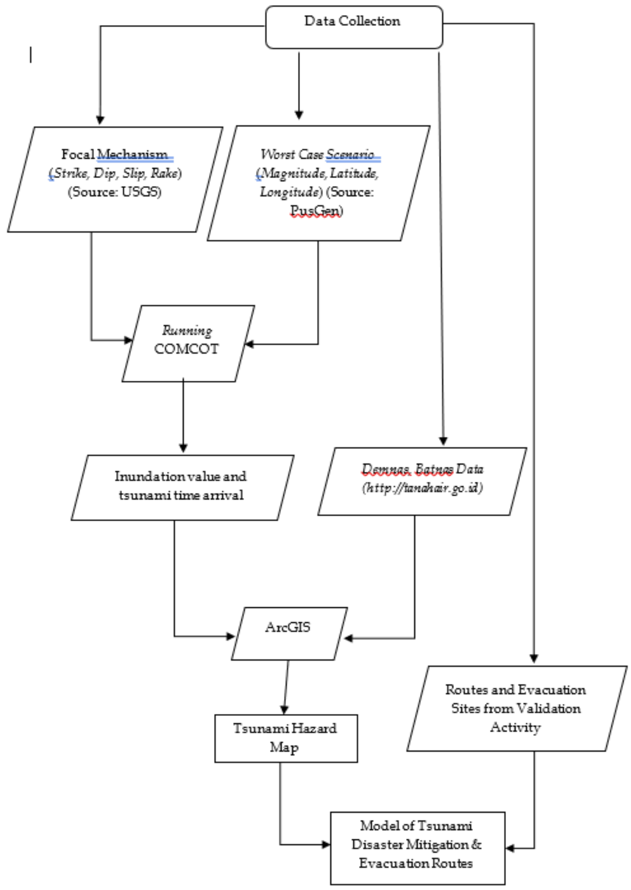


Figure 1. Research Schema

The tools and materials used in research process can be seen in Table 1.

Table 1. Tools and Materials

Tools and Materials	Utility
Laptop	Tsunami data processing and report preparation
Notepad	Script editing
COMCOT	Running script for tsunami modeling scenario
Global Mapper	Grid/layer creation, modeling and mapping
ArcGIS	Creating map
Microsoft Word	Report Arrangement
Microsoft Excel	Table creation
Camera	Documentation
Avenza	Tracking route application
GPS Map Camera	Application for documenting with location stamp

Before carrying out the validation activities / field survey, tsunami disaster evacuation route planning was carried out based on the Tsunami Natural Disaster Evacuation Route Planning Guidelines, Dirjen Bina Marga, 2023 (Direktorak Jendral Bina Marga, 2023). The technical planning of tsunami disaster evacuation routes includes 7 (seven) points, namely the projection of the number of affected people (P), evacuation time (tE), ideal evacuation route capacity (Q), range distance (S), number of evacuation routes (Nr), number of existing route capacity (K) and disaster information boards and signs (Rahayu & Anita, 2013).

The data used is primary data in the form of validation/field survey results with representatives of the Pancer community, and secondary data in the form of Demnas and Batnas data from https://tanahair.indonesia.go.id and tsunami scenario data from USGS and PusGen (National Earthquake Center). Demnas provides information on the shape of the surface (topography) and Batnas is bathymetric data that contains information on water depth. The USGS data was historical data of the Banyuwangi tsunami earthquake on June 4, 1994 in the form of focal mechanism data (dip, rake, slip, strike). Meanwhile, the PusGen data was in the form of earthquake magnitude values and epicenter locations in the form of latitude and longitude (Pusat Studi Gempa Nasional, 2017) .

Validation or field survey for tsunami disaster mitigation and evacuation routes have been carried out with the following details:

Activity name	: Validation / field survey for tsunami disaster mitigation & evacuation routes at Pancer Beach, Banyuwangi.
Time	: Tuesday , June 11th 2024 (13.00 – 17.00 WIB)
Participants	: 1 researcher, 1 colleague, 1 local guide
Location	: Pancer Beach Banyuwangi

Validation activities in the form of trail walking were carried out independently by the author assisted by 1 colleague and 1 local guide. Considering that the Pancer area is currently a sensitive area due to the conflict between local residents and the mining party, as well as considering the lack of recognition of the research area, the researcher decided to be assisted by 1 (one) local resident. Guide is an indigenous resident who was born and raised in Pancer who was a living witness to the 1994 Tsunami Banyuwangi and is a village official who has received socialization several times and has been the member of tsunami disaster management activities in Pancer.

This validation / trail activity begins by making observations either directly or by interacting with local residents regarding the history of the tsunami as well as community preparedness. Then it was continued by observing roads and tsunami disaster evacuation signs. The next activity is to check the existing tsunami evacuation routes. This check was carried out with the aim of conducting a trial and feasibility of the existing path. And the last activity is to conduct a simple simulation of the evacuation process from several points around Pancer. The process of tracing the path was simulated using the tsunami hazard map from COMCOT and the Avenza application. The author also conducted interviews with several local residents before and after the trail activity to validate the evacuation route.

Result and Discussion

Tsunami Earthquake Scenario

The tsunami earthquake scenario is based on historical data from Banyuwangi earthquake in June 9, 1994 (Pusat Studi Gempa Nasional, 2017). The tsunami earthquake scenario is as follows:

Table 2. Parameter of Tsunami Earthquake Scenario

Mww	Latitude (° LS)	Longitude (° BT)	Depth (km)	Strike (°)	Dip (°)	Slip (°)
8.7	11.03	113.04	15	278	7	89

The selection of the moment magnitude value is based on the results of PusGen research (National Earthquake Center, 2019). The location of the epicenter (latitude, longitude and depth) along with fault parameters (strike, dip and slip) is based on the Global CMT from the history of Tsunami Banyuwangi on June 9, 1994.

Tsunami Modeling Layer

The tsunami wave simulation in COMCOT uses numerical modeling that requires the determination of the layer of the research area using a nested grid or filtered grid. The determination of this layer aims to divide the time needed for the tsunami wave simulation process from the epicenter to entering the coastal and inland areas (Dilla et al., 2022). In this study, 4 (four) layers were selected with the following layer boundaries:

Table 3. Tsunami Modeling Layer Limits

Layer	X, Y Start	X, Y End
1	111.1436, -12.66972	115.9622, -7.6594
2	112.6911, -9.37638	115.2281, -8.2697
3	113.7578, -8.94305	114.4681, -8.5078
4	113.9556, -8.65694	114.0572, -8.5411

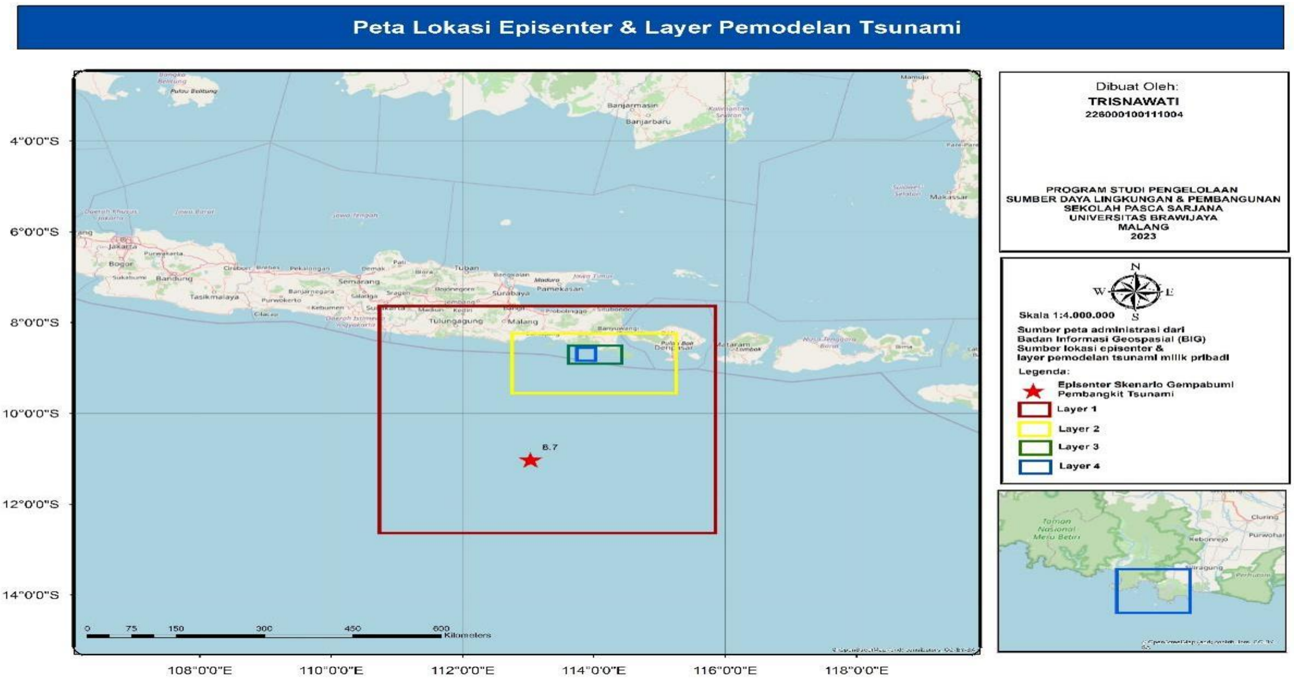


Figure 2. Map of Epicenter Location and Tsunami Modeling Layer

Virtual Tide Gauge Point

In COMCOT, the arrival time of the tsunami wave depends on the spread of the tsunami wave until it reaches the observation point. The observation point in this research is called virtual tide gauge. Virtual tide gauge is used to determine the arrival time of tsunami waves (Yuniansyah, 2018). The value of the arrival time of this tsunami wave will later be taken into account for determining tsunami mitigation and evacuation routes. In this study, 6 virtual tide gauge were selected as shown in Table 4.

Table 4. *Virtual Tide Gauge Location*

Virtual Tide Gauge Location	Latitude (°)	Longitude (°)
Tanjung Harapan	113.9967	-8.604167
IPPP Pancer	113.9983	-8.59222
Cemara Beach	114.0047	-8.590556
Point 4	114.0167	-8.592778
Pulau Merah Beach	114.0269	-8.599167
Pulau Merah	114.0242	-8.605278

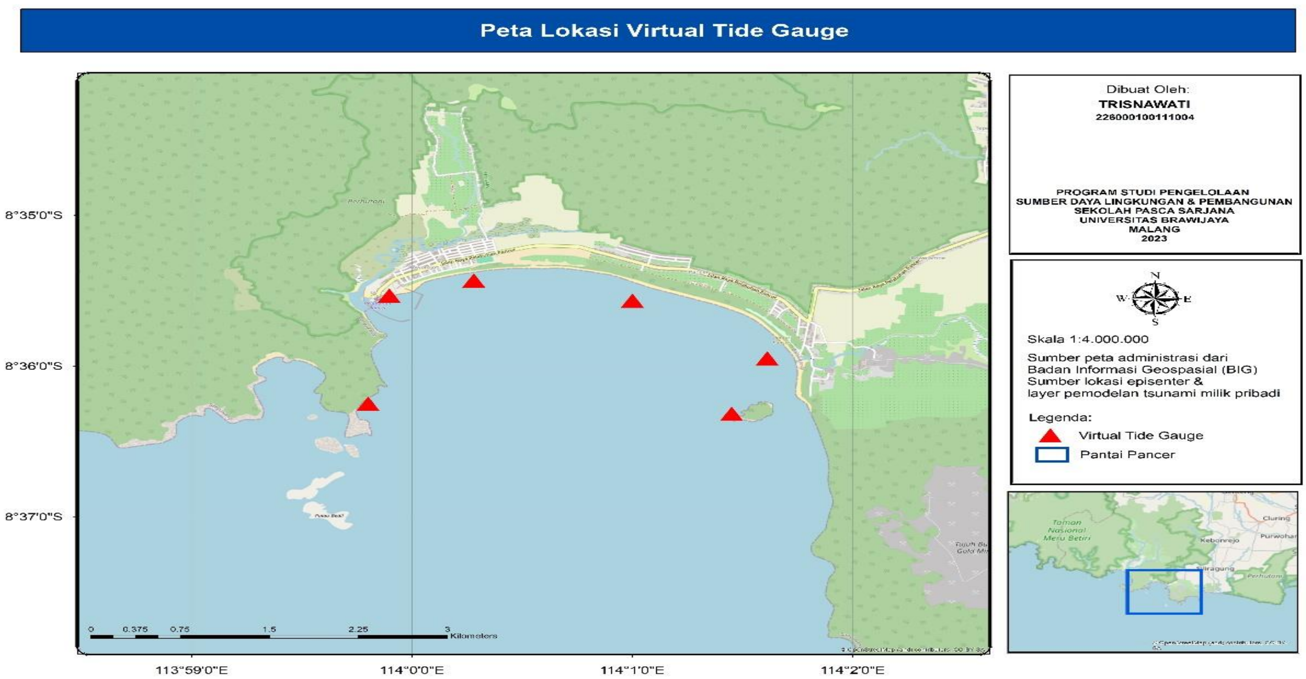


Figure 3. Virtual Tide Gauge Map

Tsunami Propagation Model Using COMCOT

The tsunami earthquake scenario parameters are inputted in the COMCOT script. The script was then run and produced a tsunami wave propagation model. The results then running using the Matlab application. From the results, the tsunami wave propagation is depict with ArcGIS. In one modeling, the map of tsunami wave propagation process was obtained which can be used as an earthquake sequence events until the tsunami wave reaches the mainland.

The tsunami earthquake scenario in COMCOT is depicted in tsunami earthquake source source map in the form of earthquake fault area from the epicenter. The earthquake fault area is mapped based on the results of the Scaling Law calculation.

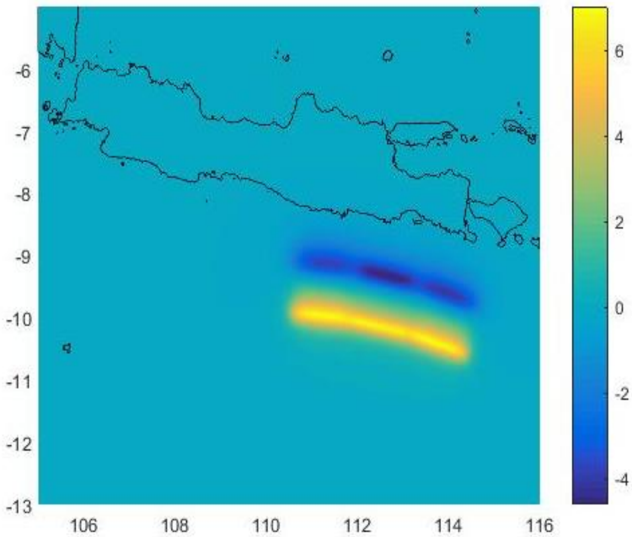
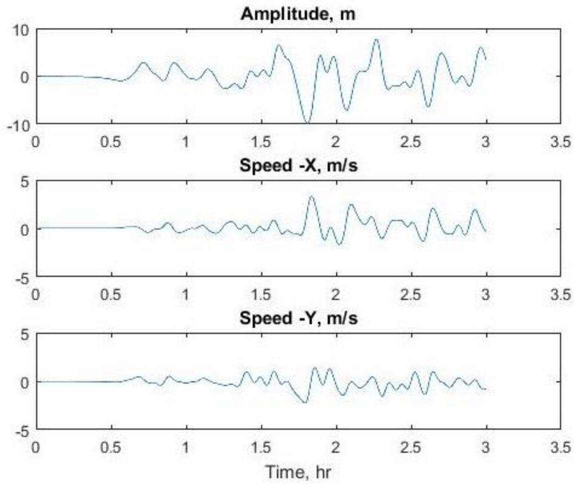


Figure 4. Tsunami Earthquake Scenario Fault Area Map Generating from COMCOT (Source: COMCOT)

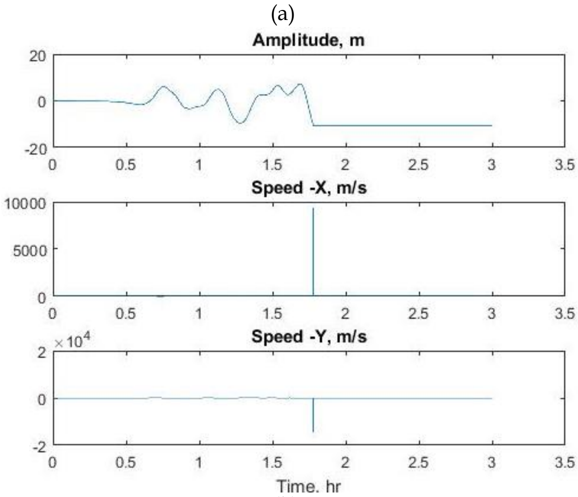
Tsunami Earthquake Scenario Fault Area Map is the first map produced by COMCOT running process. The scale on the left shows the value of latitude in degrees while the bottom scale shows the value of longitude in degrees. The scale of the right bar shows the deformation value of sea water which is characterized by a gradation of dark blue to the yellow color. The fault area is along the yellow and blue colors. The yellow area shows the displacement of seawater volume in the form of sea level rise of 2 – 7 meters, while the blue area shows the movement of seawater volume in the form of sea level decrease of 2 – 5 meters. The process of this earthquake is assumed to occur at 0 minutes.

Tsunami Run Up and Estimated Time Arrival at Virtual Point

The duration of the tsunami arrival time is modeled for 3 hours with an interval of 2 minutes. Each virtual gauge point has a different maximum height of tsunami wave and arrival time. This is because the location of the virtual gauge point has different condition such as beach's morphology, bathimetry, slope etc. The processing of tsunami wave arrival time modeling produces .dat exception files which are then processed using the Matlab application. From the Matlab processing, the results of the graph reading are as follows.



(a)



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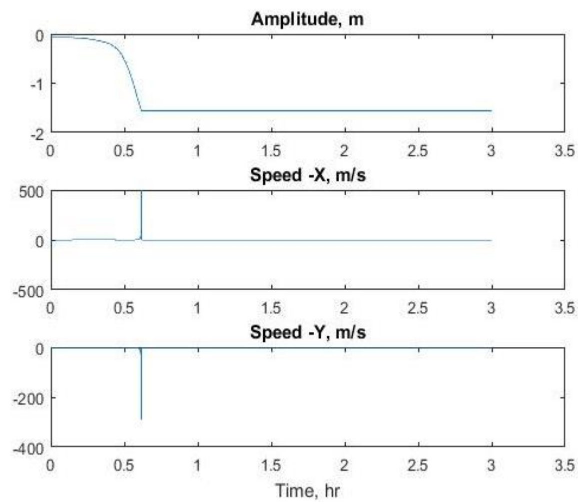

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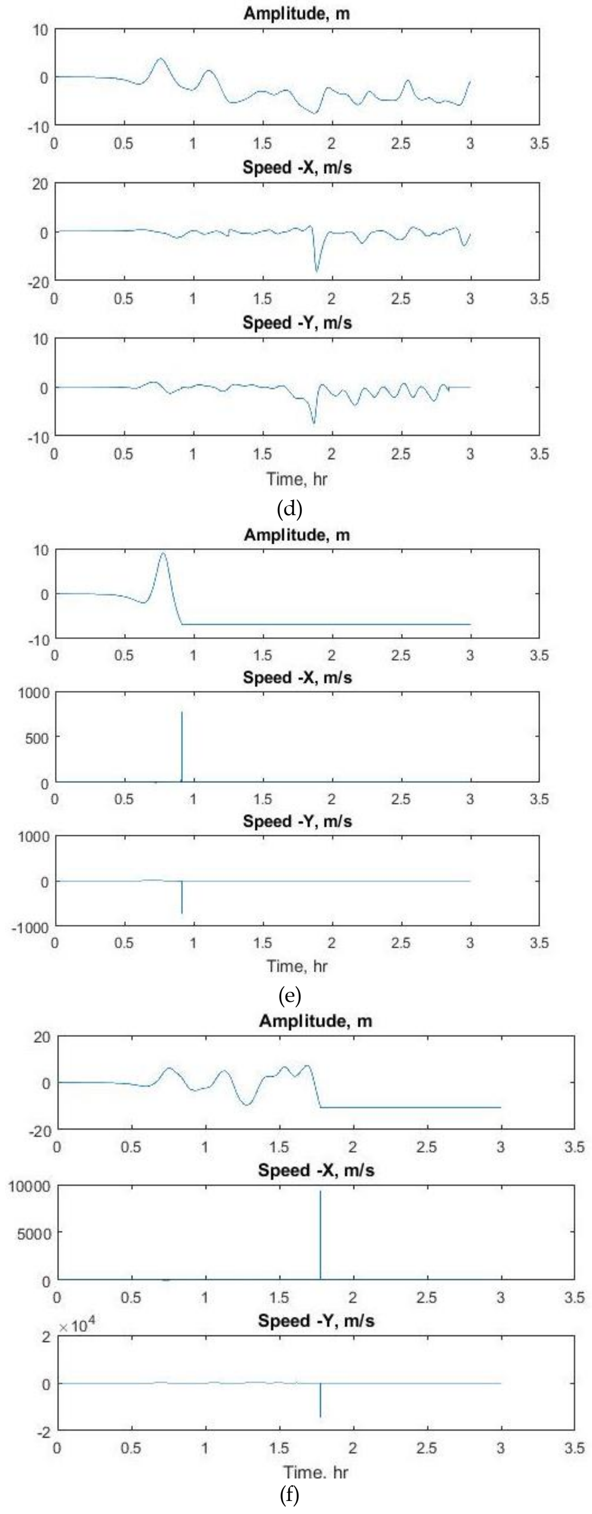


Figure 5. Tsunami Waves Spreading Graph to the Time of COMCOT Results in (a) Tanjung Harapan Beach (b) IPPP Pancer Office (c) Cemara Pancer Beach (d) Point 4 (e) Pulau Merah Beach (f) Pulau Merah

The conclusion of six virtual gauge location is, the locations 1 and 6, namely on Tanjung Harapan Beach and Pulau Merah, recorded the tsunami's maximum height value and recorded tsunami's maximum speed. This is because the location of Tanjung Harapan Beach and Pulau Merah has the closest distance from tsunami earthquake fault area and has strightly faces angle without any distruction to the epicenter.

Tsunami Hazard Map in Pancer Banyuwangi

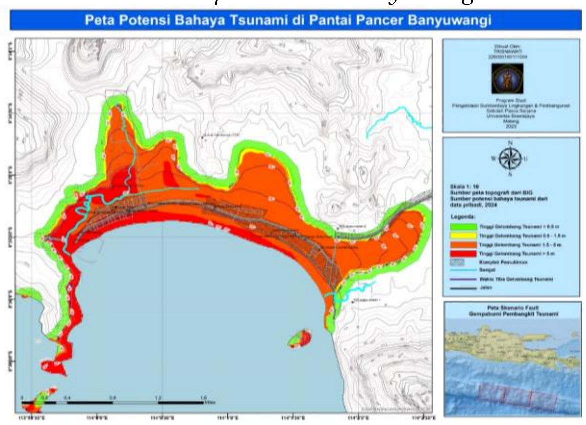


Figure 6. Potential Tsunami Hazards Map at Pancer Beach Banyuwangi

From the results of COMCOT inundation value, the map layout process can be carried out with GIS. Inundation values can be classified into 4 classes for easy map reading. The classification of areas with the potential for large to small tsunami hazards is in the following order, namely red, orange, yellow and green. The most hazardous area is represented by red with a tsunami wave height value of > 5 meters. Then the hazardous is decreasing and marked in orange with a tsunami wave value of 1.5 – 5 meters. The yellow color indicates the potential danger of a tsunami with a tsunami wave value of 0.5 – 1.5 meters. Meanwhile, the green color represents the area with the smallest tsunami potential with a tsunami wave value of < 0.5 meters.

The map also includes the estimated time arrival of tsunami wave which is depicted with a purple line. The tsunami wave arrived on the coast of Pancer Beach around the 16th to 22nd minute from the time of the earthquake event. Meanwhile, the arrival time of tsunami waves on land varies with the longest arrival of 34 minutes on land. The value of the arrival time of tsunami waves on land varies according to the topographic contours and the distribution of river flows (Santius, 2015).

Tsunami Disaster Evacuation Route Planning for Pancer Beach

The Calculation of the Number of Affected Population (Pt)

The calculation of the number of affected population can be calculated by finding the population growth rate using equation (Direktorak Jendral Bina Marga, 2023) (1) :

$$r = \frac{1}{t} + \frac{Pt}{P0} - 1 \quad (1)$$

Where:
Pt = Total population in year t
P0 = Number of inhabitants in the base year
t = The time period between the base year and the year t (in years)
r = Population growth rate

The number of Sumberagung Village's residents, Pesanggrahan District, Banyuwangi Regency in 2017 was 13.781 people (Kecamatan Pesanggrahan dalam Angka 2018, 2018). Meanwhile, for 2022 there are 15.253 people (Kecamatan Pesanggrahan dalam Angka 2023, 2023). The base year used is 2017, while year t is 2022. The time period between the base year and the t-year is 5 years. So from the calculation of the equation above, the projected value of the affected population is around 4.235 people.

Evacuation Time Calculation (tE)

The calculation of the evacuation time is based on formula (2) as follows:

$$tE = \mathrm{tB} - \mathrm{tP} - \mathrm{tR} \quad (2)$$

Where:
tB = Estimated time of tsunami arrival (minutes)
tP = Warning Time (minutes)
tR = Community reaction time (minutes)

From COMCOT tsunami wave propagation modeling, the tsunami estimated time arrival based on virtual gauge reading is about 16 minutes until the tsunami wave reaches the coast. Meanwhile, the value of the warning time which refers to the standard for delivering early warning information from BMKG is less than 5 minutes and the community's reaction time can be assumed to be 1 minute (Rahayu & Anita, 2013). So from the calculation of the equation above, the evacuation time is about 10 minutes.

Range Distance Calculation (S)

The distance to reach safer point is calculated to find the safe location. The calculation of the range distance uses the following equation:

$$S = VE \times tE \quad (3)$$

Where:
vE = speed of people moving (meter/minute)
tE = evacuation time (minute)

For the value of human walking speed, some experts use an average speed of 1.20 m/second (72 m/min) as a reference (Tanan, 2011) . Based on the modeling of tsunami wave propagation using COMCOT and the calculation from equation 3, the value of the evacuation time (tE) is 10 minutes. So that the value of the range distance is 0.72 km.

Calculation of the Number of Evacuation Routes

The number of evacuation routes is calculated using the following equation:

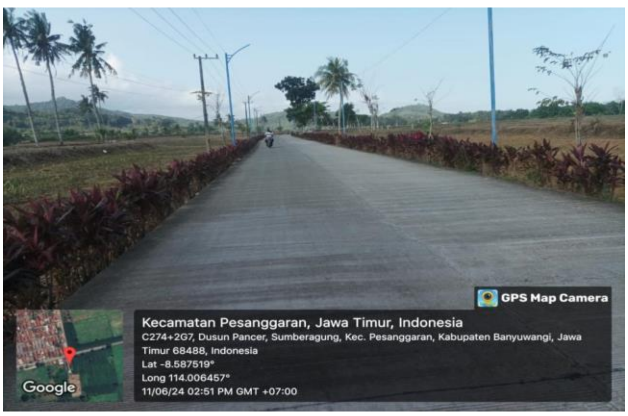
$$Nr = \frac{P}{Q \times tE} \quad (4)$$

Where:
P = Projection of the number of affected population (people)
Q = Ideal evacuation line capacity, (person/minute)
tE = Evacuation time, minutes

The P value (projected value of the affected population) has been calculated previously, which is around 4.235 people. The ideal evacuation lane capacity (Q) for a standard road width of 3.5 m is 70 people/min or can be calculated by yourself to suit the characteristics of local pedestrians. Meanwhile, the value of the evacuation time had been obtained previously was 10 minutes. From the calculation with equation 4, a value of 6.05 is obtained and rounded to 6. So that the number of evacuation routes based on the ideal calculation results is 6 routes.

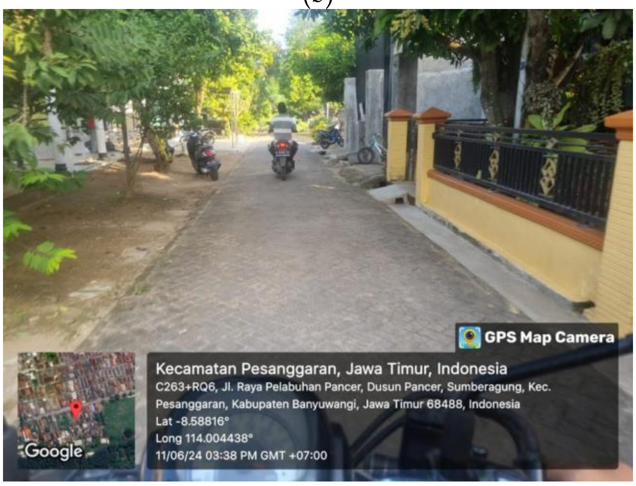
Validation / Field Survey of Tsunami Mitigation and Evacuation Route in Pancer Banyuwangi
Road Condition Validation Results

Roads in Pancer are divided into 3 types, namely cast roads, paving block roads and clay roads. The percentage of cast roads in total is around 40%, while the percentage of solid clay roads is around 35% and 25% is paving block roads. The condition of these three roads follow the road conditions principle in Pedoman Perencanaan Jalur Evakuasi Bencana Alam Tsunami, Dirjen Bina Marga, 2023.



(a)

(b)



(c)

Figure 7. Types and Conditions of Roads Around Pancer Banyuwangi (a) Cast Road (b) Solid Land Road (c) Paving Block Road

Tsunami Evacuation Sign Validation Results

There are 3 (three) types of tsunami disaster evacuation signs that have been placed in Pancer, namely tsunami evacuation route signs, assembly point signs and tsunami disaster-prone area information boards. Evacuation route signs and assembly point signs have been installed following the existing evacuation routes. The installation of the two types of signs is in accordance with Peraturan Kepala Badan Nasional Penanggulangan Bencana Nomor 07 Tahun 2015. As for the information board for tsunami-prone areas, it has not followed Peraturan Kepala Badan Nasional Penanggulangan Bencana Nomor 07 Tahun 2015 (Rahayu & Anita, 2013).

From the total amount, the signs of the evacuation route still do not follow the standards. This can be known from the validation /field survey simulation that has been carried out. Meanwhile, the number of assembly point signs does not follow the number determined by BNPB according to the results of Renkon 2013.

Figure 8. Tsunami disaster evacuation signs installed in Pancer Banyuwangi

Results of Tsunami Disaster Evacuation Route Validation

Based on validation, it was found that the number of existing routes for tsunami disaster evacuation routes in Pancer Banyuwangi is 5 (five) routes that have been determined by BNPB, 2013. Meanwhile, based on the calculations previously, the number of ideal evacuation routes for the Pancer area by considering the number of population etc is 6 (six) routes. From the validation results, 3 (three) evacuation routes also have been determined in addition to the existing routes. The 3 lanes are spread out to improve the density of evacuation routes. So that the public and tourists in Pancer can evacuate in a scattered manner with the aim of breaking up the crowd to support the success of the tsunami disaster evacuation process.

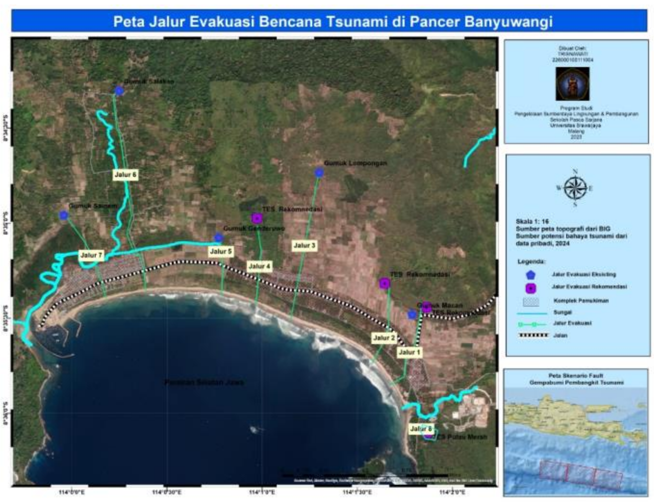


Figure 9. Tsunami Disaster Evacuation Route Validation Map in Pancer Banyuwangi

The Results of Tsunami Disaster Evacuation Distance and Travel Time Simulation

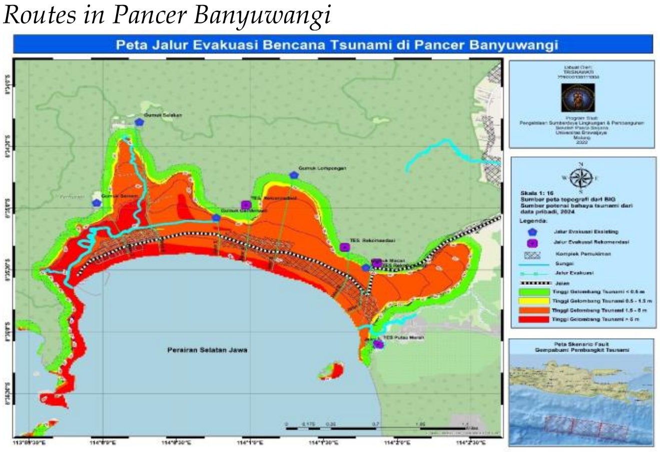
The simulation carried out was in the form of a simple simulation, where the distance and travel time from the starting point to the safe point were recorded. In this research scenario, the total travel time required is < 10 minutes by paying attention to the walking speed. The number of simulations carried out is 8 (eight) simulations with different routes. In this simulation process, there are 2 (two) large groups based on walking speed, namely the healthy and excellent group (Group A) with a walking speed in a crowd of about 1.01 m/s and the special needs group / Group B (seniors > 55 years old, pregnant women, children <10 years old, sick and disabled) with a speed of 0.9 m/second (Tanan, 2011).

Table 5. Tsunami Evacuation Simulation Results

Route	Distance (km)	Travel Time Group A (minutes)	Travel Time Group B (minutes)
1	1.01	16.67	18.7
2	0.8	13.2	14.8
3	1.46	24	27
4	0.78	12.8	14.4
5	0.59	9.6	10.9
6	2.04	33	37
7	0.92	15	17
8	0.23	3.8	4.26

Of the 8 routes that have been validated, both existing routes and recommended routes can be grouped into 3 (three) groups. Group 1 (one) with tsunami evacuation and mitigation travel time < 10 minutes is routes 5 and 8. Group 2 (two) is routes with evacuation and tsunami disaster mitigation travel times between 10 – 20 minutes, namely routes 1, 2, 4 and 7. While the group 3 (three) is route with evacuation and tsunami disaster mitigation travel time > 20 minutes, namely routes 3 and 6. So according to previous calculations, the route that follows the evacuation and tsunami disaster mitigation travel time < 10 minutes is group 1, namely routes 5 and 8.

Model of Tsunami Disaster Mitigation and Evacuation Routes in Pancer Banyuwangi



Picture 10. Map of Tsunami Disaster Evacuation Route in Pancer Banyuwangi

The model of tsunami evacuation and mitigation route in Pancer Banyuwangi is in the form of a map of the evacuation and mitigation route of the tsunami disaster and is layered with an inundation map from the results tsunami earthquake scenario in Pancer Banyuwangi. The tsunami danger level is divided into 4 (four) levels. The red color indicates the tsunami wave height of > 5 meters, orange indicates the tsunami wave height of ± 1.5 – 5 meters, yellow indicates the tsunami wave height of ±0.5 – 1.5 meters and green indicates the tsunami wave height of < 0.5 meters. So the red color is the area with the highest level of danger and the green color has the lowest level of danger.

The evacuation and mitigation routes for the tsunami disaster are depicted with a green line. The evacuation route is divided into 2 (two) groups, namely the existing evacuation route and the recommended evacuation route. The existing evacuation route consists of 5 (five) routes, while the recommended evacuation route has 3 (three) routes. Meanwhile, there are 8 evacuation sites, consisting of 5 (five) existing evacuation sites (marked with a blue pentagon) and 3 (three) recommended evacuation sites (marked with purple squares).

Conclusion

The results of the validation /field survey of tsunami disaster mitigation and evacuation route provide a lot of information about real conditions in the field. The 8 (eight) routes that have been validated can be considered to be used as a model for tsunami evacuation routes with several records. The results of the validation / tsunami disaster mitigation and evacuation route provide a lot of information about real conditions in the field. The 8 (eight) routes that have been validated can be considered to be used as a model for tsunami evacuation routes with several records. Among other things, the need for the local government to make a big contribution to providing decent road and bridge facilities for the sake of increasing the safety value of residents from the danger of tsunamis. Including the installation of tsunami evacuation route signs, gathering points and tsunami danger indicators in accordance with existing guidelines.

Acknowledgments
Thanks to all parties who have supported the implementation of this research. I hope this research can be useful.

Author Contributions
Conceptualization; T, S, L.H ; methodology; T, S, L.H ; formal analysis.; T, S, L.H ;investigation: T; resources: T: data curation: T, S, L.H ; writing—original: T; draft preparation: T; writing—review and editing: S, L.H ; visualization: T. All authors have read and agreed to the published version of the manuscript.

Funding

This research was independently funded by researchers.

Conflicts of Interest

The authors declare no conflict of interest.

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