E3S Web of Conferences **447**, 01004 (2023)
The 15th AIWEST-DR 2023
https://doi.org/10.1051/e3sconf/202344701004

TSUNAMI HAZARD MAPPING AND EVACUATION PATH DETERMINATION USING FIELD SURVEY AND GEOGRAPHICAL INFORMATION SYSTEMS AT WIDARAPAYUNG WETAN, CILACAP

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In 2006, a tsunami hit Pangandaran, and its effects were felt in Cilacap. There were 664 fatalities, 498 injuries, and 55 million dollars in damages, and 1623 homes were destroyed or severely damaged due to the tsunami. Furthermore, the village of Widarapayung was among those devastated by the tsunami, which reached a height of up to 5 meters and claimed the lives of 12 people. In addition, Widarapayung is a popular tourist destination and one of the venues for 2019's professional surfing events. Therefore, disaster prevention measures are essential to lessen the impact of disasters and save lives. The objective of this study is to assess the vulnerability of the Widarapayung Wetan area to a tsunami and make recommendations for evacuation routes and regional infrastructure development to reduce casualties and damage. This research utilized COMCOT to model the megathrust segment with a possible magnitude of 8.7, with worst-case values acquired from the catalog PuSGeN 2017. Additionally, the data on topography and bathymetry collected by DEMNAS and BATNAS are utilized in this investigation. The modeling results indicated a 50-minute arrival time for the tsunami waves, a maximum run-up height of 14-18 meters, and a submerged area of roughly 4.57 km2. In addition, the most effective evacuation routes were determined by combining the outcomes of field surveys and Geographic Information System simulations. This research will provide local governments with helpful information for making informed decisions about infrastructure and spatial development in the future.

Keywords: Tsunami, Evacuation Map, COMCOT, Run up

1. Introduction

In July 2006, at 15:19:22, a seismic event of magnitude 6.8 occurred in the Southern region of Pangandaran, resulting in a consequential tsunami that affected the Cilacap Regency. The tsunami resulted in a cumulative loss of life of 664 individuals, with an additional 498 individuals sustaining documented injuries. Furthermore, the disaster caused substantial harm to a total of 1623 residential structures. The financial losses caused by this natural disaster were estimated to be 5.5 billion rupiah in the provinces situated in the southern area of Java Island. Based on the earthquake catalog released by the Agency of Meteorology Climatology and Geophysics, also known as Badan Meteorologi, Klimatologi, dan Geofisika (BMKG) in 2018, the Cilacap Regency experienced a catastrophic incident that led to a substantial loss of human lives. Based on the documented data, it can be observed that a total of 157 individuals lost their lives, while 104 individuals suffered injuries. Furthermore, it has been stated that 15 individuals were unaccounted for in the aftermath of the occurrence above. The tsunami waves generated during this catastrophic event attained a peak elevation of 20 meters in the Nusakambangan region while reaching a height of 5 meters in the Cilacap region[1].

Based on available historical records, the Cilacap region has seen at least four tsunamis throughout its history. These events occurred in 1904, 1921, 1957, and 2006, as documented by [2,3]. According to the [4], Cilacap has been ranked 437 in its multi-hazard threat assessments at the district/city level. Additionally, it has been assigned a ranking of 197 for its tsunami disaster risk, falling into the moderate risk class.

In the Widarapayung Wetan region, the tsunami recorded a height of 5 meters, resulting in 12 casualties. A monument honoring the tsunami victims is explicitly located on Widarapayung Beach [5]. Widarapayung has emerged as a prominent tourist attraction, with a significant influx of visitors. Additionally, in 2019, it was designated as the national venue for the Widarapayung surfing competition, attracting numerous professional surfers from domestic and international [6].

The southern region of Java has a potential for tsunamis due to the convergence of two tectonic plates, namely the Eurasian and Indo-Australian plates. These plates exhibit a relative motion of approximately 70mm per year, which can result in seismic activity, including earthquakes with a maximum magnitude of M8.7. Such earthquakes can generate tsunamis and can be felt across the entire island of Java with a maximum intensity of VII-VIII MMI in four coastal districts in Central Java [7].

The village of Widarapayung Wetan exhibits a predominantly lowland geography, lacking any significant mountains that could serve as natural barriers. Furthermore, several community activities, including educational institutions, commercial establishments such as marketplaces, and other vital infrastructure, are often situated approximately 1-2 kilometers from the coastal area. Given the likelihood that a tsunami would strike the region, an evacuation route must have the shortest travel distance and time to both the Temporary Evacuation Site (TES) and Final Evacuation Site (TEA). The Temporary Emergency Shelter (TES) serves as a temporary facility for disaster response, enabling the timely detection and rescue of those affected by the disaster. Once the critical period has elapsed, individuals can be relocated to the Final Evacuation Site (TEA) [8]. TES is also a form of tsunami disaster risk management [9]. TEA is the final evacuation location and serves as a place for family members to congregate after a disaster and refugees to receive aid until the recovery process [10].

The present study aims to do tsunami modeling utilizing the COMCOT program, which Dr. Xiaoming Wang developed at the Institute of Geological & Nuclear Science (GNS Science) in New Zealand. The outcomes of this modeling encompass data about the arrival timing of tsunami waves, the extent of run-up, and the extent of inundation. The mapping process will be conducted with topographical data obtained from DEMNAS (BIG) data, offering a significantly higher resolution than the low-resolution SRTM data employed in prior studies. This utilization of high-resolution data is expected to yield superior-quality data[11]. After that, the simulated data will be superimposed into the tsunami evacuation path.

The evacuation route that will be mapped is the quickest and shortest route to TES and TEA that can be used in the event of a tsunami. This route results from a comparison between direct field surveys and GIS modeling. Determining the tsunami evacuation route will eventually become one of the practical stages used as a guide in efforts to minimize potential risks and maximize community preparedness for tsunamis.

2. Method

2.1 Research Location

The village of Widarapayung Wetan is located in Cilacap, Central Java, in the Binangun subdistrict. It has a land area of 4.41 km2 and is close to the Indian Ocean in the south. With a population of 6,587 and a location of 7°41'12"S 109°16'12"E, it is the most populous village in the Binangun District, with a population density of 1,492/km^2: approximately 1992 households, 12 RT, and 3 RW [12]. Widarapayung Wetan has the potential to become a tourist destination due to its proximity to the Indian Ocean and its stunning coastline.

2.2 Research Data

The research data consists of bathymetry and topography information, which will then be processed with ArcGIS to generate a tsunami hazard map overlaid with field survey and GIS modeling-obtained evacuation route data.

a. Topography data
The utilized topographic data is the National Digital Elevation Model (DEMNAS) data acquired from the Geospatial Information Agency (BIG) with a 0.27-arcsecond (8.1m) resolution using the EGM2008 datum [13]. This grid comprises terrestrial gravity data, altimetry derivatives, and airborne gravity data [14].

b. Bathymetry data
The bathymetry data used is GEBCO (General et al. of the Oceans) bathymetry data with 30-arcsecond (926m) resolution. GEBCO operates under the International Hydrographic Commission (IOC) of UNESCO.

c. Deformation Data
Deformation data derived from PUSGEN in the form of strike, dip, and rake values representing the most significant earthquake potential (worst-case scenario). Calculations using the Wells and Coppersmith, Hanks and Kanamori, and Leonard formulas provide fault length, width, and displacement input data.

d. Evacuation routes data
The tracking of evacuation routes was conducted by a team that followed several road routes within Widarapayung Wetan Village. This was done by the evacuation route signs that had been put in the area, leading to the Temporary Evacuation Site (TES) and Final Evacuation Site (TEA) sites. Furthermore, other evacuation route data is processed through GIS modeling,

which considers the shortest route and the quickest travel time.

2.3 Earthquake Source Mechanism

The Java subduction zone exhibits distinct characteristics compared to the Sumatra subduction zone. Notably, the Java subduction zone is characterized by relatively calmer conditions when contrasted with the Sumatran subduction zone. Nevertheless, significant seismic events have occurred near Java Island, such as the M7.8 East Java earthquake in 1994 and the M7.8 Pangandaran earthquake in 2006 [7].

The South Java Subduction Zone has the potential for earthquakes, as indicated by the presence of a seismic gap [15], so it has the potential for earthquakes to occur at times, especially in the western and eastern parts [16].

The earthquake scenario employed in this study is characterized by a magnitude of M8.7 and a depth of 18 km. It occurred at a specific location approximately 195 kilometers southwest of Cilacap City, precisely at coordinates -9.47 South Latitude and -108.51 East Longitude.

Subduction Java, parts of Central Java and East Java, has a length of 440 km, a width of 200 km, and a slip rate of 4 cm/year [7]. Earthquake mechanisms can be determined from the geometry of a fault system [17]. The fault system's geometry can significantly affect tsunami generation [18].

The empirical relationship between magnitude, length of surface and subsurface rupture, length, and width of faults and dislocations uses the [19, 20] equations so that the fault geometry values are obtained as follows:

$$\log L = 0.58\, Mw - 2.42$$

$$\log W = 0.41\, Mw - 1.61$$

$$Mw = \; 2/3\,[Log\ Mo\; - \;6.07]\;\; (Mo \text{ in Nm})$$

$$Log\ Mo\; = \;1.5\, Mw\; + \;16.1 \text{ (Mo in dyne.cm)}$$

Where L is the length of the fault (km), W is the width of the fault (km), Mw is the Moment Magnitude, and Mo is the seismic moment (Nm = 107 dyne. cm).

Fault parameters such as strike angle, dip, and rake values are obtained from Global CMT.

By using the area of the fault with the definition of the seismic moment Mo = μ x d x A, the dislocations can be calculated using the equation [21]:

$$d\; = \frac{Mo}{\mu\, x\, L\, x\, W}$$

where L is the length of the fault (m), W is the width of the fault (m), d is the dislocation (m), Mo is the seismic moment (Nm = 107 dyne.cm), and μ is the rigidity (Pa = N/m2=10 -5bar)

the maximum displacement can be calculated using equation [22], and the average displacement can be calculated using the equation [23]:

$$log\,\overline{D}\; = \frac{5}{4}\,log\,W\; - \frac{3}{4}\,log C_1 + \;log\,C_2$$

$$log\,AD\; = \;0.88\,log\,L\; - \;1.43$$

Where $\overline{D}$ is the maximum displacement (m), AD is the average displacement, W is the fault width, C_1 is a constant (13.5 m 1/3), C_2 is a constant (7.5x10-5).

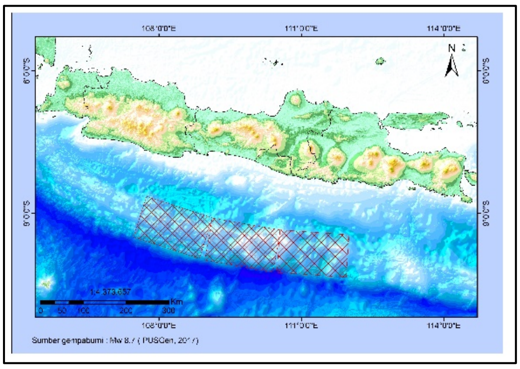

Figure 1. Source of the M8.7 tsunami generator

2.4 Tsunami Modelling

It is essential to employ appropriate modeling techniques to develop a tsunami model. This study utilized the Computational Model for Coastal and Oceanic Tsunamis (COMCOT) version 1.7 as the chosen modeling tool. COMCOT can generate numerous tsunami parameters, including generation, propagation, runup, and inundation. Multiple tsunami-generating mechanisms, including fault faults, landslides, water surface disturbance, and wave generators, can be implemented in COMCOT.

When a simulation involves a relatively small region when the earth rotation effect is absent, shallow water equations on Cartesian Coordinates are preferred. The following linear shallow water equation in cartesian coordinates is also implemented in COMCOT [24].

$$\frac{\partial \eta}{\partial t}+\left\{\frac{\partial P}{\partial x}+\frac{\partial Q}{\partial y}\right\}=-\frac{\partial h}{\partial t}$$

$$\frac{\partial P}{\partial t}+gh\frac{\partial \eta}{\partial x}-f\,Q=0$$

$$\frac{\partial Q}{\partial t}+gh\frac{\partial \eta}{\partial y}+f\,P=0$$

$$f=\Omega\sin\varphi$$

where P, Q volume fluxes in the X (West, East) and Y (South-North) direction, respectively, and both are products of velocity and water depth; g gravitational acceleration; h water depth; f Coriolis force coefficient; $-\frac{\partial h}{\partial t}$ reflect the effect of transient seafloor motion.

Since a tsunami propagates over a continental shelf and approaches a coastal area, linear shallow water is invalid. The wavelength of the incident tsunami becomes shorter, and the amplitude becomes more extensive as a tsunami's leading wave propagates into shallow water. The nonlinear shallow water equation, including bottom friction effects, adequately describes the flow motion in the coastal zone. The following nonlinear shallow water equations are implemented in Cartesian Coordinates:

$$\frac{\partial \eta}{\partial t}+\left\{\frac{\partial P}{\partial x}+\frac{\partial}{\partial y}\right\}=-\frac{\partial h}{\partial t}$$

$$\frac{\partial P}{\partial t}+\frac{\partial}{\partial x}\left\{\frac{P^2}{H}\right\}+\frac{\partial}{\partial y}\left\{\frac{PQ}{H}\right\}+gH\frac{\partial \eta}{\partial x}+F_x=0$$

$$\frac{\partial Q}{\partial t}+\frac{\partial}{\partial x}\left\{\frac{PQ}{H}\right\}+\frac{\partial}{\partial y}\left\{\frac{Q^2}{H}\right\}+gH\frac{\partial \eta}{\partial y}+F_y=0$$

Which H is the total water depth, and $H=\eta+h$; F_x and F_y represent the bottom friction in X and Y direction, respectively. Ang these two terms are evaluated with Manning's formula :

$$F_x=\frac{gn^2}{H^{7/3}}P\,(P^2+Q^2)^{1/2}$$

$$F_y=\frac{gn^2}{H^{7/3}}Q\,(P^2+Q^2)^{1/2}$$

Fault parameter as a tsunami simulation scenario.

Lat (°)	Long (°)	Length (km)	Width (km)	Depth (km)	Strike (°)	Dip (°)	Rake (°)	Dislocation (m)
107.7528	-9.4339	141	91	17	290	6	90	19
109.0420	-9.7829	141	91	18	280	8	90	19
110.3779	-9.9019	141	91	20	270	10	90	19

2.5 Mapping

Data processing starts with merging topography and bathymetry data, which is done via ArgGIS. The data is segmented based on the intended location.

Tsunami modeling uses the COMCOT program, with inputs from topography, bathymetry, and deformation data. The modeling results are then animated using Gnuplot and Imagemagick.

The affected map is created using data from the tsunami model and the ArcGIS mapping application to generate data in the form of tsunami-affected regions. Among the parameters obtained are the height of the tsunami, the location where it lands, and the time of its arrival.

2.6 Evacuation Route Field Survey

The purpose of this field survey was to ascertain the actual evacuation routes in the Widarapayung Wetan region. The research team thoroughly investigated multiple routes, starting at Pantai Indah Widarapayung and finishing at the Temporary Evacuation Site (TES) and Final Evacuation Site (TEA). In addition to retracing the route, the crew examined the previously installed signs for the tsunami evacuation route and calculated the travel time from the beach to the TES. Widarapayung Wetan is accessible from the seashore to TES/TEA via a single main road. It also contains several TES, including the Widarapayung Wetan village office, the SMP N 1 Binangun and TEA Binangun District Office, TEA SDN 1 Alangamba, and TEA Pasuruan.

(a)

(b)

Figure 2. TES Location for Widarapayung Wetan Village. (a) Vertical TES, (b) SMPN 1 Binangun TES

2.7 Evacuation Routes Based on GIS Modeling

Evacuation time is available for evacuation; this can be known after conducting tsunami modeling and if there is an early warning from nature or a tsunami early warning siren in the field [25].

Evacuation time or response time for the community can be calculated using the following formula [26]:

$$RsT = ETA - ToNW - RT$$

$$ToNW = IDT - INT$$

Where Rst/ET is the time required for people to evacuate, ETA is an estimate of the arrival of a tsunami, ToNW is a technical or environmental warning, RT is the time needed for the population to react, IDT is the time required for an institution to make a decision (Ina-TEWS), and WPI is the time needed for an institution to issue a warning (Sirene from the local government).

Network Analysis (extension on QGIS Desktop) utilized for evacuation route modeling considering TES and TEA accessibility and capacity. The optimal route for evacuating a hazardous area is determined using network flow proximity. Network flow evacuation aims to transport people from a specific starting location to a safe place outside the danger zone as quickly as possible [25]. The shortest distance will then be analyzed to get the shortest and fastest distance to TES and TEA [27].

3. Result

3.1 COMCOT Modelling

The modeled pattern of propagating tsunami waves forms a pattern according to the pattern of the earthquake scenario that has been made. The wave propagation is shown in Figures 2 to 5.

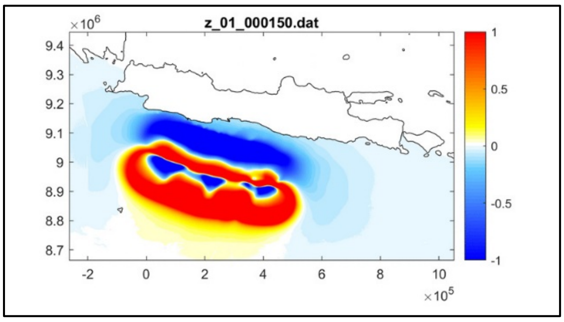

Figure 3. Initial propagation of a tsunami wave

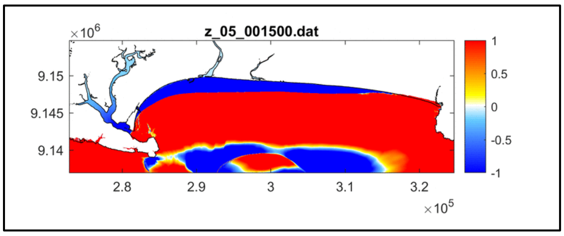

Figure 4. Tsunami wave propagation at 15 minutes.

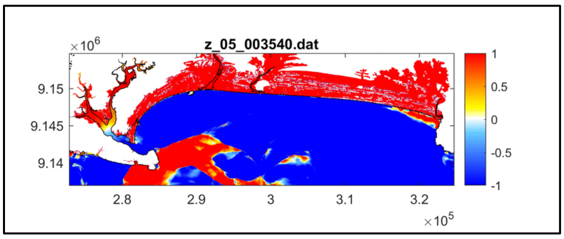

Figure 5. Tsunami wave propagation at 50 minutes.

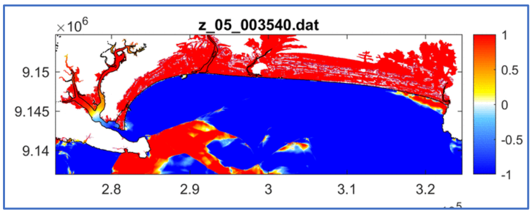

Figure 6. Propagation of the tsunami wave at 120 minutes.

3.2 Tsunami Hazard Map

Based on the earthquake source modeling results for the worst-case scenario with a magnitude of M8.7 in the Java-Central Java subduction segment, it is known that the tsunami waves began entering the Cilacap mainland or coast on average 50 minutes after the earthquake. Figure 6 displays the modeled inundation area and runup height using COMCOT. It has been shown that the tsunami waves submerged the entire Widarapayung Wetan Village area. In the red zone, tsunami surges reached up to 10 meters along the coast. The orange zone extends 1 to 3 kilometers to the north, with a tsunami height of 3 to 6 meters at 52 minutes. At 53 minutes, it enters the green, yellow, and orange zone with a height between 0.5 and 3 meters.

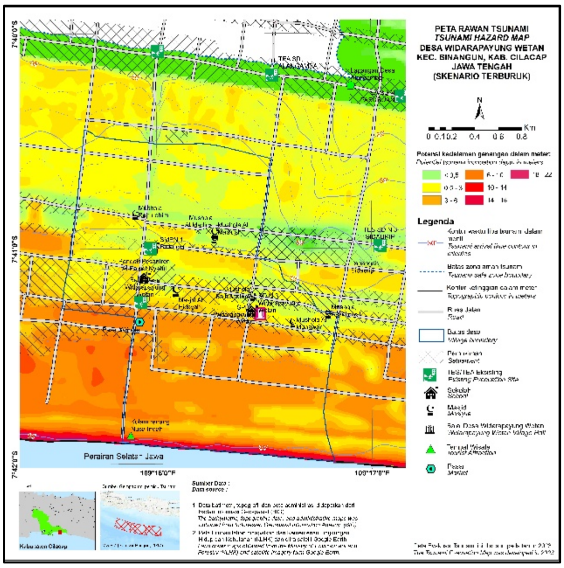

Figure 7. Tsunami hazard map of Widarapayung Wetan Village

3.3 Field Real Evacuation Map

The results of the evacuation map are the results of field surveys following the direction of the evacuation board. The evacuation route boards already existed and were installed based on the BMKG's Tsunami Hazard Map. Several routes can be followed in an evacuation; this can reduce the accumulation of people when evacuating.

3.4 GIS Modeling Evacuation Map

In order to find the shortest path, the input data were used as the starting point in this investigation. The travel time to the evacuation site can be accurately estimated using the average speed of the community's roads (0.75 m/s). TES and TEA are locations authorized as Evacuation Sites by the local government and community.

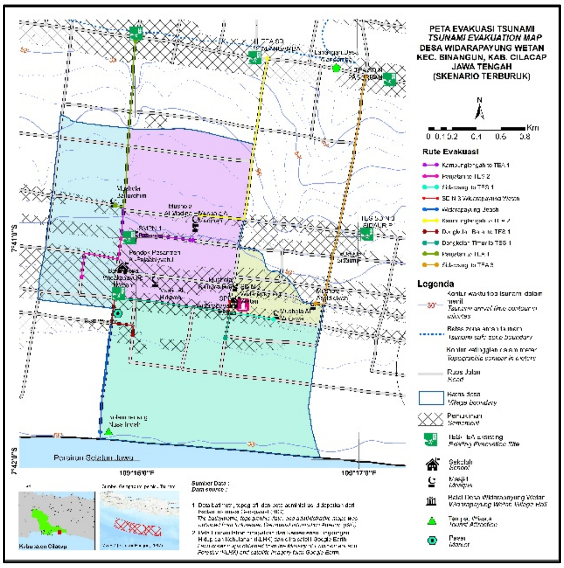

Figure 8. Tsunami evacuation map for Widarapayung Wetan Village

No	Starting Point	Evacuation point	Distance (m)	Travel time (minute)
1	Pantai Widarapayung	TES Balai desa	1217	15.2
2	Dusun Dongkelan bagian Barat	TES Balai desa	545	6.8
3	Dusun Dongkelan Bagian Timur	TES Balai desa	1188	14.9
4	Dusun Sidawangi	TES Balai desa	1305	16.3
5	Dusun Sidawangi	TEA SD Pasuruan	2013	25.2
6	Dusun Kampungtengah	TES SMP Binangun	583	7.3
7	Dusun Kampungtengah	TEA SD Alangamba	1726	21.6
8	Dusun Panjatan	TES SMP Binangun	1180	14.8
9	Balai Desa Widarapayung Wetan	TEA Kecamatan Binangun	2159	27.0

Based on the shortest network analysis results, the estimated distance from the recommended gathering point to the evacuation gathering point/location ranges from 583 to 2159 meters. Meanwhile, the time needed to reach the evacuation location with the average speed of parents walking varies between 7 and 27 minutes. The hamlet closest to the existing evacuation site/gathering point is the western part of Dongkelan Hamlet. Meanwhile, the hamlet farthest from the existing evacuation site/gathering point is Sidawangi Hamlet, which must travel up to 1.3 km. There are three hamlets and beach tourists who can flee to the Widarapayung Wetan Assembly Point Village Hall. Hamlet Sidawangi is a hamlet located horizontally from the nearest TES. Therefore, the hamlet residents should evacuate themselves to TEA SD Pasuruan.

Based on the map and table, it can be seen that the evacuation locations from each hamlet are unevenly distributed. TES locations, which are located close together on 1 Main Line, cause congestion. In addition, TES locations in the tsunami height zone of 0.5 – 3 meters also need to be considered for constructing vertical evacuation sites.

4. Conclusion

Based on the earthquake source modeling results for the worst-case scenario with a magnitude of M8.7 in the Java-Central Java subduction segment of the entire Widarapayung Wetan Village area, it reached damage by the tsunami. From 1 to 3 kilometers zone to the north, with a tsunami height of 3 to 6 meters at 52 minutes. At 53 minutes, it enters the after 3 km to the North zone with a height between 0.5 and 3 meters.

Based on the shortest network analysis results, the estimated distance from the recommended gathering point to the evacuation gathering point/location ranges from 583 to 2159 meters. The time needed to reach the evacuation location with the average speed of parents walking varies between 7 and 27 minutes.

Vertical evacuation site is significant because there is only a horizontal direction with a long distance and time, there are no shelter buildings or hills that can be climbed so that evacuation takes longer time, also taking into account the condition of the vulnerable community so they can be saved from the tsunami.

REFERENCE

[1] BMKG. Katalog Gempabumi Signifikan Dan Merusak 1821–2017, 1st ed.; Badan Meteorologi Klimatologi dan Geofisika: Jakarta, Indonesia, 2018; pp. 1–252.

[2] Soloviev, S. L. dan Go, Ch. N., 1974. A Catalogue of Moscow, “Nauka” Publishing House, 308h

[3] Wichmann A (1918) Die erdbeben des Indischen Archipels bis zum Jahre 1857 (Earthquakes of the Indian Archipelago Until the Year 1857), in Afdeling Natuurkunde Nederlandse Verhandelingen, 20 (1918): 193p

[4] Rapangilei, W., Widjaja, B. W., Kurniawan, L. (2023). Indonesian Disaster Risk Index (Resiko Bencana Indonesia (RBI)). Badan Nasional Penanggulangan Bencana (BNPB). Jakarta.

[5]https://www.antaranews.com/berita/38176/korban-meninggal-di-cilacap-bertambah-jadi-77-orang

[6] https://cilacapkab.go.id/v3/puluhan-peselancar-ikuti-widarapayung-surfing-competition-2019/

[7] National Earthquake Study Center Team. (2017). Earthquake Source and Hazard Map of Indonesia in 2017. Housing and Settlements Research and Development Center, Ministry of Public Works and People's Works. Jakarta

[8] Rifqi, M. G., Amin, M. S., & Sandi, E. A. (2019). Design of Tsunami Pods as Temporary Evacuation Sites (TES) to Create Disaster Resilient Areas. Potential: Polytechnic Civil Journal, 21(2), 74–82. https://doi.org/10.35313/potensi.v21i 2.1670

[9] Rahayu, H.P., Anita, Juarni. Planning for Temporary Evacuation Sites (TES) Tsunami. 2013. National Agency for Disaster Management (**BNPB**)

[10] National Agency for Disaster Management (**BNPB)**. 2014. Padang City Tsunami Disaster Evacuation Route Document 2014-2019 (Planning and Recommendations). Padang City Government.

[11] Wang, Z., & Jia, G. (2021). A novel agent-based model for tsunami evacuation simulation and risk assessment. Natural Hazards, 105(2), 2045–2071. https://doi.org/10.1007/s11069-020-04389-8

[12]. BPS-Statistic of Cilacap Regency. 2022. Binangun Subdictric in Figure 2022. Grafika Indah Cilacap. Cilacap.

[13] Badan Informasi Geospasial (BIG), 2018, DEMNAS, http://tides.big.go.id/DEMNAS/ diakses tanggal 22 mei 2019.

[14] Pavlis, N.K., Holmes, S.A., Kenyon, S.C. and Factor, J.K., 2012, The development and evaluation of the Earth Gravitational Model 2008 (EGM2008), Journal of geophysical research: solid earth, 117(B4).

[15] Widiyantoro S., E. Gunawan, A. Muhari, N. Rawlinson, J. Mori, N. R. Hanifa, S. Susilo, P. Supendi, H. A. Shiddiqi, A. D. Nugraha, and H. E. Putra. 2020. Implications for megathrust earthquakes and tsunamis from seismic gaps south of Java, Indonesia. Nature, 10:15274.

[16] Meilano, I., Tiaratama, A.L, Wijaya, D.D., Maulida, P., Susilo, S., Fitri, I.H. 2020. Analisis Potensi Gempa di Selatan Pulau Jawa Berdasarkan Pengamatan GPS. JLBG.

[17] Andrews, D. J, 1994, Fault geometry and earthquake mechanics, Annali Di Geofisica, Vol XXXVII, pp 1341-1348.

[18] Wendt, J., Oglesby, D. D., dan Geist, E. L, 2009, Tsunamis and splay fault dynamics, Geophysical Research Letters, Vol. 36.

[19] Wells, D. L., dan Coppersmith, K. J., 1994, New empirical relationships among magnitude, rupture length, rupture width, rupture area, and surface displacement, Bulletin of the Seismological Society of America, Vol. 84, pp 974-1002.

[20] Papazachos, B.C., Scordilis, E.M., Panagiotopoulos, D.G., Papazachos, C.B. and Karakaisis, G.F., 2004, Global relations between seismic fault parameters and moment magnitude of earthquakes, Bulletin of the Geological Societyof Greece, Vol 36, pp 1482-1489.

[21] Hanks, T.C. and Kanamori, H., 1979, A moment magnitude scale, Journal of Geophysical Research: Solid Earth, 84(B5), pp 2348-2350.

[22] Leonard, M., 2012. Earthquake fault scaling: Self-consistent relating of rupture length, width, average displacement, and moment release. Bulletin of the Seismological Society of America, 102(6), pp 2797-2797.

[23] Madrinovella, I., Widiyantoro, S. and Meilano, I., 2011, Relokasi Hiposenter Gempa Padang 30 September 2009 Menggunakan Metode Double Difference, JTM Vol. XVIII No. 1.

[24] Wang, Xiaoming. 2009. COMCOT Version 1.7. Institute of Geological and Nuclear Science. New Zealand

[25] Dewi, Ratna Sari. A-GIS-based Approach of an evacuation model for tsunami risk reduction. 2012. Journal of Integrated Disaster Risk Management

[26] Post, J., et al. (2009). "Assessment of Human Immediate Response Capability Related to Tsunami Threats in Indonesia at a Sub-national Scale." Natural Hazards Earth System Sciences No. 9: 1075-1086 pages.

[27] Indira, & Manessa, M.D.M. Generating Evacuation Route for Tsunami Evacuation Based on Megathrust Skenario Hazard Model in Palabuhanratu Village, Sukabumi, West Java. IJDM (2023)6:1,pp 35-48. DOI: https://doi.org/10.24815/ijdm.v6i1.31148