p-ISSN 2089 – 0133 e-ISSN 2477-6416
URL: https://jurnal.uns.ac.id/ijap/article/view/97008

Indonesian Journal of Applied Physics (IJAP) Vol. 15 No. 1 page 204
DOI: https://doi.org/10.13057/ijap.v15i1.97008

ESTIMATION OF TSUNAMI HAZARD AND EVACUATION SITES USING THE CORNELL MULTIGRID COUPLE TSUNAMI METHOD IN SOUTH BUTTON REGENCY

Ilham[1,2], Jamhir Safani*[2], Muliddin[2], Teguh Sulistian[3], Sorja Koesuma[4]
[1]Kendari Geophysical Station, Agency of Meteorology, Climatology, and Geophysics, Indonesia
[2]Magister of Geography, Faculty of Mathematics and Natural Sciences, Halu Oleo University, Indonesia
[3]Agency of Geospatial Information, Indonesia
[4]Department of Physics, Faculty of Mathematics and Natural Sciences, Sebelas Maret University, Indonesia
*jamhir.safani@uho.ac.id

Received 26-12-2024, Revised 27-02-2025, Accepted 02-03-2025,
Available Online 01-04-2025, Published Regularly April 2025

ABSTRACT

The 1992 earthquake and tsunami in the Flores Sea proved that the tsunami impacted the people of the South Buton Region. This research aims to map tsunami hazards and estimate evacuation routes and sites in the South Buton Regency. These evacuation routes and sites are very crucial for disaster preparedness and reducing the risk of tsunami disasters. This research simulates the tsunami wave hazard from the 1992 Flores earthquake using the Cornell multigrid coupled tsunami (COMCOT). We designed the study area in five layers and seven sublayers, encompassing 13 villages on the coast of South Buton Regency. The research generated seven tsunami hazard maps based on the number of existing sublayers, each equipped with evacuation routes and locations. In general, the seven study areas have two tsunami hazard levels: a hazard level with an inundation height of less than 0.5 m and a hazard level with an inundation height of 0.5–3 m. The tsunami inundation distance for the height of 0.5-3 m varies. The shortest inundation distance is 5–33 m in Lakambau and Laompo Villages, while the farthest distance is 57–98 m in Katampe, Lamaninggara, and Molona Villages. Apart from that, the tsunami wave arrived around 35–45 minutes after the earthquake. The fastest arrival time is 35 minutes in Bahari Village, which is closest to the source of the tsunami. The results of the study recommend 17 temporary evacuation sites (TES) and 7 final evacuation sites (FES) in the research area.

Keywords: COMCOT; tsunami; evacuation route; evacuation site; tsunami travel time

Cite this as: Ilham., Safani, J., Muliddin., Sulistian, T., & Koesuma, S. 2025. Estimation of Tsunami Hazard and Evacuation Sites Using the Cornell Multigrid Couple Tsunami Method in South Button Regency. *IJAP: Indonesian Journal of Applied Physics, 15*(1), 204-215. doi: https://doi.org/10.13057/ijap.v15i1.97008

INTRODUCTION

Numerous islands in Indonesia were created as a result of the convergence and subduction of the Indo-Australian Plate, the Pacific Plate, and the Eurasian Plate [1]. The movement of these tectonic plates causes earthquakes, and some produce tsunamis. From 416 to 2018, Indonesia saw 246 tsunami events. From 1674 to 2018, the ten most lethal tsunami catastrophes caused a total of 275,708 deaths [2]. Tsunamis produce lasting effects, such as trauma, changes in landform, and economic and social repercussions.

Extensive research is being conducted on tsunamis in Indonesia. The content encompasses tsunami risk assessment studies along the Aceh coast [3, 4], investigations of tsunami susceptibility and hazards on the west coast of Banten [5], and numerical modeling to identify critical elements associated with tsunami hazards [6]. A multitude of individuals utilize tsunami modeling tools, such as the Cornell Multigrid Coupled Tsunami (COMCOT) employed in this work, to conduct tsunami simulations, as they more effectively simulate the largest waves and their travel time to the coast compared to tsunami hazard assessments probabilistic [7]. This differs from tsunami modeling employing the JAGURS numerical approach conducted in the southern region of Sulawesi Island, adjacent to the Flores Fault, where inundation modeling was not performed due to the lack of high-resolution DEM data [8]. This research utilized the bathymetric data for the marine area next to the South Buton shore. The establishment of evacuation routes is enhanced using Geographic Information System (GIS) technology, which employs two parameters derived from COMCOT data.

The Flores back-arc thrust (FBT) is an active fault under the Flores Sea. This fault is the source of earthquakes that often trigger tsunamis. The Flores earthquake on 29 December 1820 triggered a tsunami on the southern coast of Sulawesi, Bima City, and Sumba [9]. In 1992, another earthquake on the FBT triggered a tsunami [10]. This tsunami wave reached the South Buton Regency area. The historical tsunami run-up stated by Horspool et al. at 2014 [11] is an "alarm" that a tsunami could happen again in South Buton Regency. However, research on the hazards and risks of tsunami disasters in this region is still very general. The description of tsunami hazard parameters in studies lacks detail. The lack of accurate information is an obstacle for the South Buton Regency government in formulating tsunami disaster risk reduction plans. Therefore, this research is intended to provide accurate information about which areas are threatened by tsunamis based on maximum inundation parameters and tsunami wave arrival times [12]. We will estimate these two parameters using the Cornell Multi-Grid Coupled Tsunami (COMCOT) method [13]. These two parameters can help the government determine priorities for affected areas that must receive capacity strengthening so as to achieve a "tsunami-ready community" as planned by the Intergovernmental Oceanographic Commission (IOC) [14].

This research also provides recommendations for routes and locations for temporary evacuation sites (TES) and final evacuation sites (FES) by utilizing the resulting tsunami hazard map and tsunami propagation time. With this information, the government can calculate the location and number of evacuation signs, facilities, and logistics requirements for TES and FES.

MATERIALS DAN METHODS

The research data includes bathymetric data from the Geospatial Information Agency (BIG), information on land cover, and earthquake and tsunami source data for FBT. The topographic elevation comes from the National Digital Elevation Model (DEMNAS). Additionally, data was gathered regarding the layout of the research area, including road access, government offices, public facilities, and health facilities.

This study employs the Cornell Multigrid Coupled Tsunami (COMCOT) method [13] to model tsunami inundation and propagation time. This strategy makes use of two-dimensional horizontal (2DH) modeling approaches. The COMCOT program has established its ability to do simulations with excellent accuracy and efficiency, as evidenced by the Indian Ocean tsunami [15, 16]. This method may mathematically simulate the behavior of tsunami waves, offering a visual picture of how these waves spread from the originating epicenter to nearby coastal regions.

The COMCOT method involves the application of two-dimensional horizontal (2DH) modeling techniques through the use of the shallow water equation (SWE) as follows:

$$\frac{\partial \eta}{\partial t} + \left\{\frac{\partial P}{\partial \psi} + \frac{\partial Q}{\partial \psi}\right\} = -\frac{\partial h}{\partial t} \quad (1)$$

$$\frac{\partial P}{\partial t} + \frac{\partial}{\partial \psi}\left\{\frac{P^2}{H}\right\} + \frac{\partial}{\partial \varphi}\left\{\frac{PQ}{H}\right\} + gH\frac{\partial \eta}{\partial \psi} + F_x = 0 \quad (2)$$

$$\frac{\partial Q}{\partial t} + \frac{\partial}{\partial \psi}\left\{\frac{PQ}{H}\right\} + \frac{\partial}{\partial \varphi}\left\{\frac{Q^2}{H}\right\} + gH\frac{\partial \eta}{\partial \psi} + F_x = 0 \quad (3)$$

where η is the height of the water surface (m), t is the wave propagation period, h is the water depth (m), and P and Q are the flux in the horizontal (x) and vertical (y) directions (m^3/s). The coefficient g indicates the Coriolis force, H denotes the overall water depth (m), and F_x and F_y are the forces caused by bottom friction in the x and y directions. The equation below uses the basic friction coefficient n to evaluate the F_x and F_y values:

$$F_x = \frac{gn^2}{H^{\frac{7}{3}}}P(P^2 + Q^2)^{1/2} \quad (4)$$

$$F_y = \frac{gn^2}{H^{\frac{7}{3}}}Q(P^2 + Q^2)^{1/2} \quad (5)$$

The basic friction coefficient values used are shown in Table 1 [17].

Table 1. The basic friction coefficient values (n)

Type	Friction coefficient (n)
Coastal and riverine areas	0.025
Farmland	0.02
Forest	0.03
Low-densityUrban	0.04
Medium density urban	0.06
High-densityUrban	0.08

When employing the COMCOT approach to estimate tsunami hazards and evacuation routes, the research area is divided into nested grid layers, as shown in Figure 1. We organize the

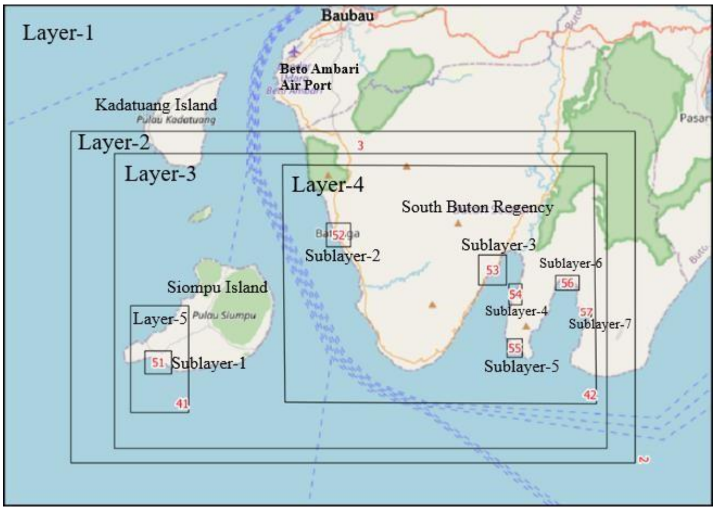

Figure 1. Design of nested grid layers to estimate tsunami-affected areas and evacuation routes in the coastal area of the South Buton Regency.

layers into five nested grids, starting with Layer-1 and progressing to Layer-2, Layer-3, Layer-4, and Layer-5. Layer-5 is nested within Layer-3, not Layer-4, because it is located on a separate island, Siumpu. The projections focus on low-lying areas with dense communities along South Buton Regency's shoreline. Therefore, we conduct estimations in locations that meet both of these criteria. Table 2 shows that seven zones or sublayers match the criteria in question, which include 13 communities.

Table 2. Village coverage on each layer

Sub-layer	Village coverage
1	Katampe, Lamaninggara, and Molona
2	Lakambau and Laompo
3	Katilombo nd Jayabakti
4	Tira
5	Bahari
6	Lapandewa, Windu Makmur, and Gerak Makmur
7	Gaya Baru

The input data of COMCOT method includes coordinates, topography height, sea depth, and the location of generating sources. The processing technique produces three outputs: inundation height, inundation distance, and tsunami transit time. We arrange the output data to generate hazard maps and indicate tsunami evacuation routes and locations. Temporary evacuation locations (TES) and final evacuation sites (TEA) are verified for suitability in terms of access, topographic height, and existing infrastructure.

RESULTS AND DISCUSSION

Inundation Height, Inundation Distance, and Potentially Affected Settlements

The findings indicate two tiers of tsunami height in the South Buton Regency: an inundation height below 0.5 m and an inundation height ranging from 0.5 to 3 m. Figure 2 illustrates the tsunami hazard map, delineating inundation height and distance for each sublayer. The subsequent part will provide a more comprehensive description of each sublayer, along with the delineation of evacuation routes and locations.

The results show that regions with an inundation height of 0.5-3 m are predominantly situated in bays or possess basin-shaped coasts. This occurs due to the accumulation of tsunami waves from a broader maritime expanse converging toward a constricted maritime zone (the bay). The villages notably impacted by the inundation of 0.5–3 m include Katampe, Lamaninggara, and Molona in Sublayer-1; Katilombo and Jayabakti in Sublayer-3; Tira in Sublayer-4; Maritime in Sublayer-5; Lapandewa, Windu Makmur, and Gerak Makmur in Sublayer-6; and New Style in Sublayer-7. In addition to the state of the shoreline, the configuration of the topography significantly affects the tsunami's impact. Despite being located in a bay, the region's elevated topography will mitigate the extent of inundation. This occurred in Tira Village within Sublayer-4. For a detailed examination of the immersion distance in each sublayer and the potential impact on affected towns, refer to Table 3.

Table 3 indicates that at a tsunami height ranging from 0.5 to 3 m, Sublayer-1 exhibits the greatest inundation distance, measuring between 57 and 98 m, followed by Sublayer-6 with an inundation distance of 16 to 65 m. This phenomenon arises due to the curvature of the coastlines and the inclined coastal topography of the two sublayers. It is noteworthy that the immersion distance at an inundation height of 0.5–3 m does not consistently affect communities. Sublayer-6 exhibits a submergence distance of 16-65 m, while the potential impact on communities is around 0.4 Ha. This is because settlements in this area were built relatively far from areas reached by the tsunami, which had an inundation height of 0.5–3 m.

A tsunami with a height of less than 0.5 m has the potential to submerge residential areas up to a distance of more than 200 m from the shoreline. Areas potentially affected by this include Lakambau and Laompo Villages in Sublayer-2, Katilombo and Jayabakti Villages in Sublayer-3, Tita Village in Sublayer-4, and Bahari Village in Sublayer-5. This long immersion distance certainly causes the submerged area to be larger, such as Katilombo and Jayabakti villages, which have a potential submerged area of around 20 ha, followed by villages in sublayer-2 and sublayer-5, which each have a potential submerged area of around 12 ha and 10 ha.

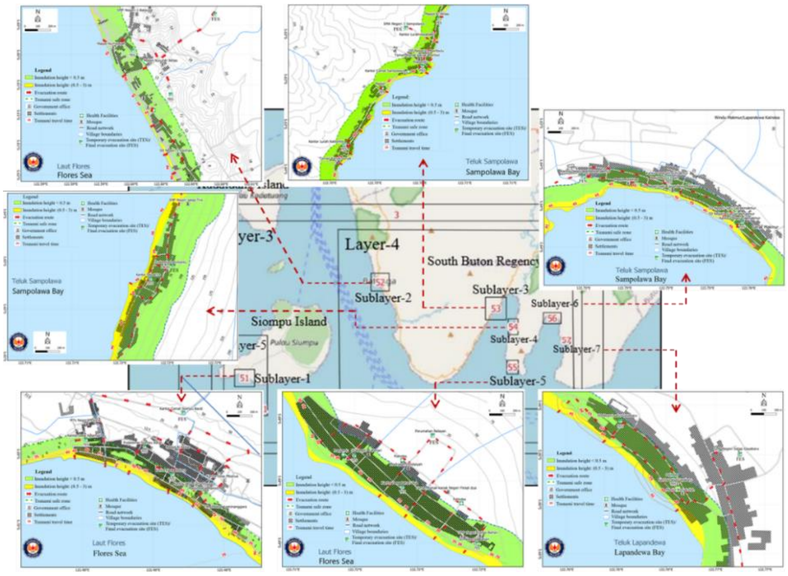

Figure 2. Tsunami hazard map for each sublayer of the southern coastal region of the South Buton Regency.

Table 3. Inundations and potential affected settlements

Sublayer	Inundation height (m)	Inundation distance (m)	Potentially affected settlement (Ha)
1	< 0.5	70 – 97	9.881
	0.5 - 3	57 – 98	4.552
2	< 0.5	217 – 236	12.048
	0.5 - 3	5 – 33	0.007
3	< 0.5	206 – 252	20.198
	0.5 - 3	8 – 40	0.249
4	< 0.5	204 – 229	6.127
	0.5 - 3	37 – 54	1.547
5	< 0.5	123 – 155	10.072
	0.5 - 3	3 – 50	0.030
6	< 0.5	63 – 111	11.186
	0.5 - 3	16- 65	0.405
7	< 0.5	54 – 70	1.945
	0.5 - 3	3 – 30	0.064

The section below explains tsunami evacuation routes and locations, including temporary evacuation sites (TES) and final evacuation sites (FES), based on an analysis of inundation height, inundation distance, and tsunami travel time (TTT) for each sublayer.

Tsunami Evacuation Routes and Locations at Sublayer-1

The tsunami submersion zone caused by an inundation height of 0.5-3 m is shown in yellow, while the submersion zone caused by an inundation height of less than 0.5 m is shown in green (Figure 3). The tsunami arrival time in the coastal area of Sublayer-1, which includes the villages of Katampe, Laminggara, and Molona, range from 35 to 45 minutes. Based on considerations of wave height approaching the coast (inundation height), immersion distance, tsunami travel time, road access, and facilities available at the evacuation site, the tsunami evacuation map for the three villages in Sublayer-1 is presented in Figure 3.

We propose the implementation of TES at three sites within this region: Katampe Village Office, West Siompu Public Health Center Office, and Molana Village Office. These three TES are relatively safe from the reach of tsunami inundation and they are at an elevation of 12 m above sea level. The Katampe Village Office functions as a TES, catering to Katampe Village and the western section of Molana Village. The Community Health Center Office in West Siompu is recommended as a TES for communities located in the central region of Sublayer 1, particularly in the western, central, and eastern areas of Molona Village. We propose the Molona Village Office as the designated TES for the residents of Lamaninggara Village and those in the eastern region of Molona. The time necessary to attain the three TES is approximately 10 minutes, which is relatively safe in comparison to the tsunami wave's arrival time of 35 minutes. The final evacuation site (FES) is the West Siompu Subdistrict Office, located in a secure tsunami shelter approximately 600 meters from the shore and at an elevation exceeding 25 meters above sea level.

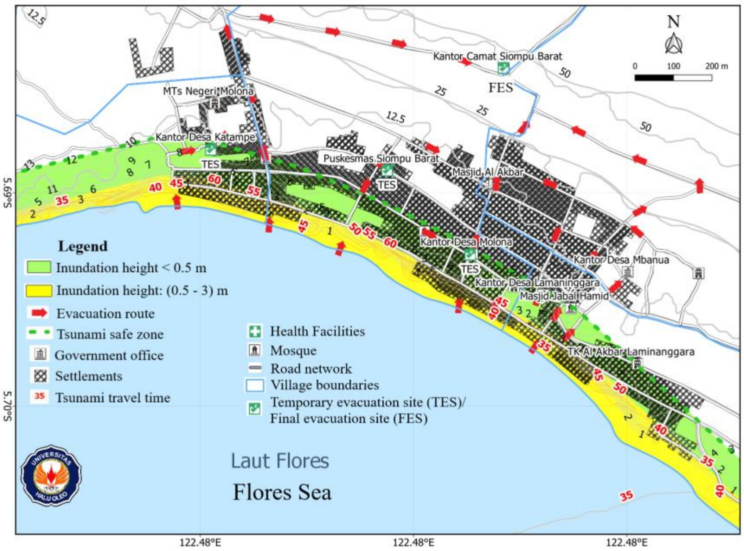

Figure 3. Tsunami evacuation map of Sublayer-1, involving villages of Katampe, Lamaninggara dan Molona.

Tsunami Evacuation Routes and Locations at Sublayer-2

Figure 4 presents the tsunami evacuation map for Lakambau and Laompo Villages within Sublayer-2. We advise both villages to employ two TESs: the Lakambau Village Office and the Batauga District Office. The elevation of both government offices exceeds 10 m above sea level. The Lakambau Village Office functions as the TES for residents in the northwest region of Sublayer-2, particularly for the inhabitants of Lakambau Village and the northwest area of Laompo Village. The population in the central to southeastern regions of Sublayer-2 is suggested to undergo temporary evacuation to the Batauga District Office. The travel time to these two TES is approximately 10 minutes, which is shorter than the tsunami wave arrival time of 40 minutes, indicating a relatively safe duration. The designated location for the final evacuation site (FES) is the headquarters of the B Pelopor Battalion Command of the Southeast Sulawesi Mobile Brigade Corps. Positioned in a tsunami-safe zone, this location surpasses 25 m above sea level and provides sufficient facilities to support the community.

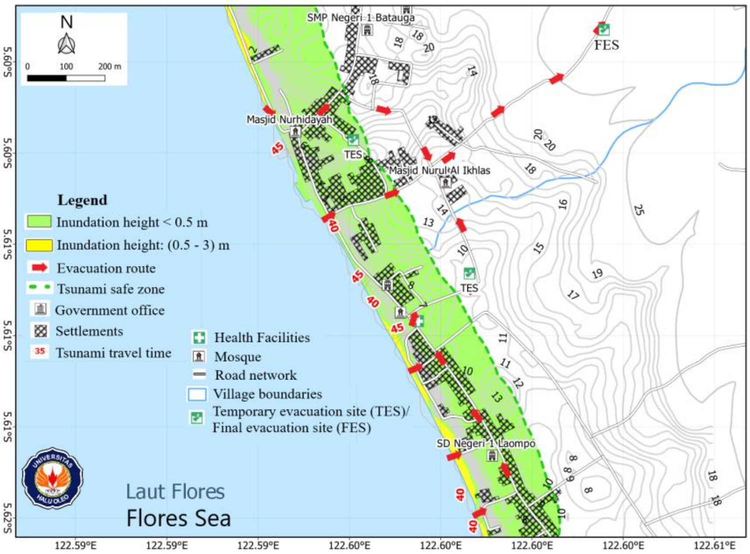

Figure 4. Tsunami evacuation map at Sublayer-2, involving villages of Lakambau and Laompo.

Tsunami Evacuation Routes and Locations at Sublayer-3

The tsunami hazard analysis results presented in Figure 5 propose four Temporary Evacuation Shelters (TES) along with designated evacuation routes for the residents of Katilombo Village and Jayabakti Village. The four Temporary Emergency Shelters (TES)

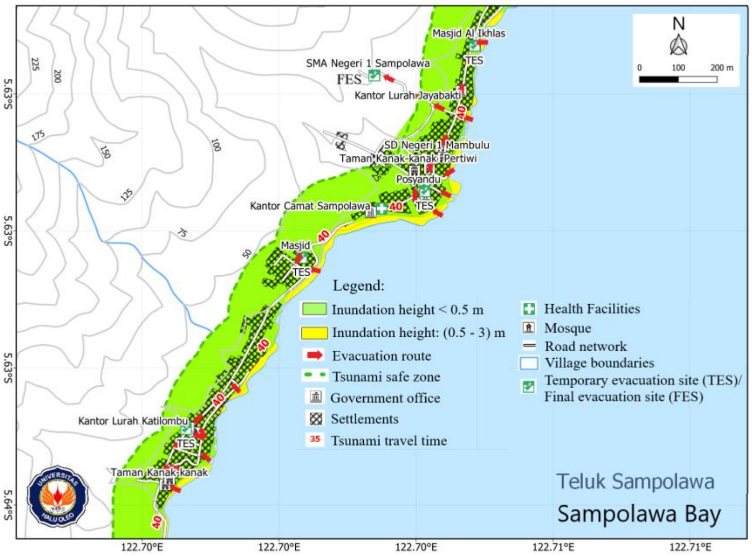

Figure 5. Tsunami evacuation map at Sublayer-3, involving villages of Katilombo an Jayabakti.

include the Jabal Nur Mosque for individuals temporarily evacuating from the southern region of Jayabakti Village, the Nurul Iman Mosque for residents in the eastern area of

Jayabakti Village, the Al Ikhlas Mosque for those in the northern section of Jayabakti Village, and the Katilombo Village Office, which serves all individuals in Katilombo Village. The TES are situated in proximity to the residential area, with a reach time of approximately 10 minutes, significantly shorter than the 40 minutes required for tsunami wave arrival. The FES recommended for the residents of Jayabakti Village is the SMAN 1 Sampolawa building, as this site is situated in a tsunami-safe zone, offers good road access, and is relatively nearby. For the residents of Katilombo Village, it is essential to consider establishing a TEA due to the considerable distance of approximately 2 km from SMAN 1 Sampolawa. The FES has recommended the SMAN 1 Sampolawa building for the residents of Jayabakti Village, as this site is situated in a tsunami-safe zone, offers good road access, and is relatively nearby. For the residents of Katilombo Village, it is essential to consider establishing a TEA due to the considerable distance of approximately 2 km from SMAN 1 Sampolawa.

Tsunami Evacuation Routes and Locations at Sublayer-4

A map of the tsunami danger zone as well as the location and tsunami evacuation route for the Tira Village community is presented in Figure 6. The results of the analysis recommend that this village has a TES located at the Tira Village Office for the temporary evacuation process. The travel time of the people to TES is around 10 minutes, while the arrival time for the tsunami wave is around 40 minutes, so there is still enough time to carry out a temporary evacuation. Meanwhile, for the final evacuation, the recommended FES location is the Tira Village Community Health Center office. This location is safe because it is at an altitude of 75 m above sea level and is not included in the tsunami inundation zone. The limited road network in this area means that people do not have many options for evacuating. This has the potential to cause mass accumulation, which can slow down the evacuation process. The government needs to be aware of this condition and create alternative routes that can be used for evacuation during a tsunami.

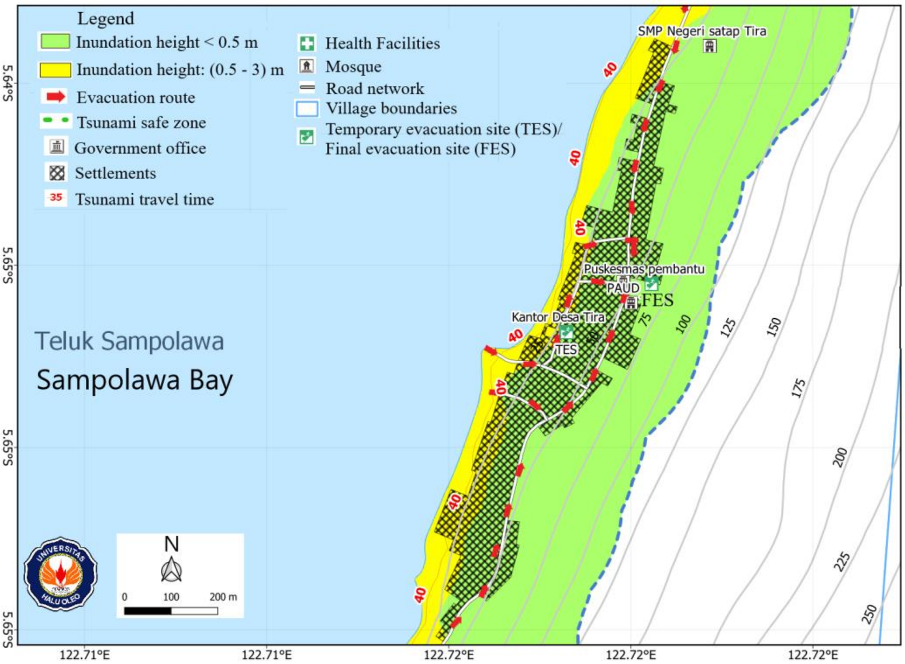

Figure 6. Tsunami evacuation map at Sublayer-4, involving Tira village.

Tsunami Evacuation Routes and Locations at Sublayer-5

The analysis of tsunami hazard data for the Bahari Village area indicates that this village has three designated emergency shelters: SDN 1 Bahari, the Bahari Village Office, and SDN 2 Bahari (Figure 7). We suggest SDN 1 Bahari as a suitable TES for residents in the northwest. The Bahari Village Office serves as a recommended TES for communities residing in the central area of Bahari Village, whereas SDN 2 Bahari is designated for those in the southeastern region. The journey to reach these three TESs takes approximately 10 minutes. The travel time is quite secure, as individuals can promptly arrive at TES before the tsunami wave, which takes 30 minutes to reach the shore. The analysis results further suggest that FES should be situated in Fisherman's Housing. This location is situated in an area that is not affected by tsunamis, as it stands at an elevation of nearly 25 meters above sea level. In addition to that, the road access serves as a sufficient evacuation route, facilitating easier access for individuals to TES and FES. This village features at least three primary routes, each of which is well-connected. Tira Village features routes and locations for temporary and final evacuation sites that are exceptionally well connected.

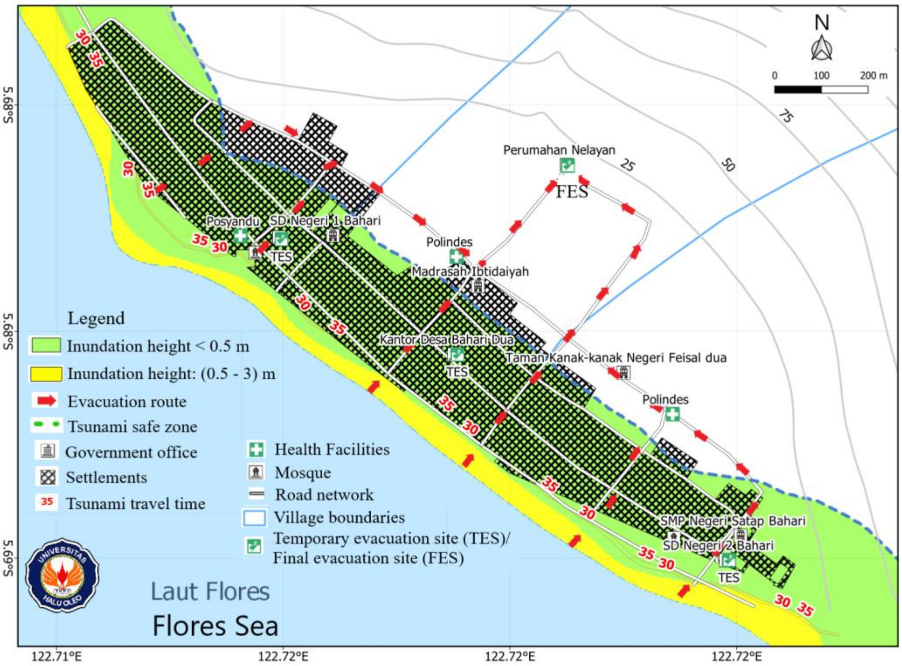

Figure 7. Tsunami evacuation map at Sublayer-5, involving Bahari Village.

Tsunami Evacuation Routes and Locations at Sublayer-6

Sublayer-6 comprises Lapandewa Village, Windu Makmur Village, and Gerak Makmur Village. Sampolawa Bay, situated to the south and connecting to the Flores Sea, directly faces these villages. The potential for a tsunami with inundation heights ranging from 0.5 to 3 meters (yellow) and heights below 0.5 meters may impact these three villages (Figure 8). The duration for tsunami waves to travel from the FBT earthquake source to the coastlines of the three villages was approximately 45 minutes. Analysis of tsunami hazard data and the condition of existing facilities in the three villages indicates that the most suitable TES includes the Lapandewa Village Office, Gerak Makmur Village Office, and Windu Makmur Village Office. The travel duration for local residents to reach these three TESs is approximately 10 minutes. This evacuation time duration is less than the arrival time of the tsunami wave, indicating sufficient time for community evacuation. Among the three suggested temporary evacuation sites, the Lapandewa Village Office is the most appropriate as a final evacuation location due to its safety from potential tsunami inundation and the availability of two access routes to it. Having a single FES to serve individuals from three villages is suboptimal. The distance from other villages to the Lapandewa Village Office is considerable. The government must establish a final evacuation site (FES) that is appropriate and easily accessible for the residents of Gerak Makmur Village and Windu Makmur Village.

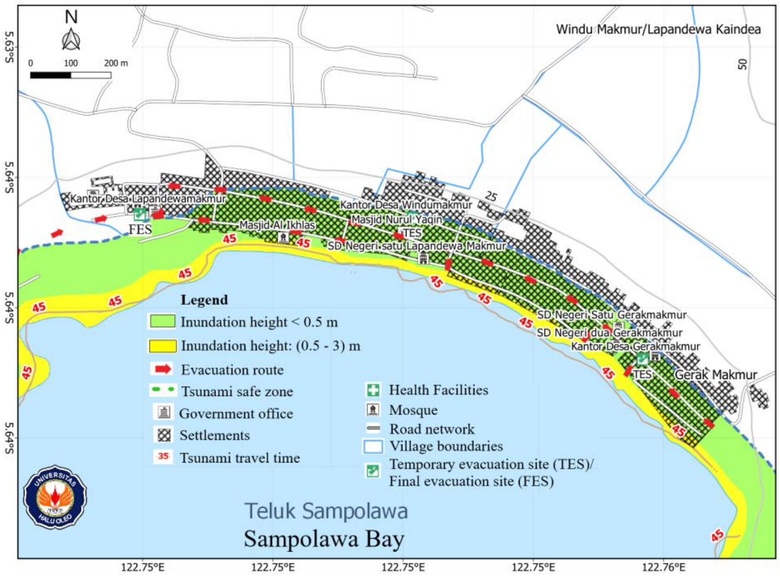

Figure 8. Tsunami evacuation map at Sublayer-6, involving villages of Lapandewa, Windu Makmur dan Gerak Makmur.

Tsunami Evacuation Routes and Locations at Sublayer-7

The assessment of the tsunami inundation zone, characterized by a tsunami height of 0.5–3 m (yellow) and a height of less than 0.5 m (green), alongside the status of village infrastructure in Sublayer-7, resulted in the creation of a tsunami evacuation map for Gayabaru Village, as illustrated in Figure 9. The analysis results indicate that Gayabaru Village should employ two

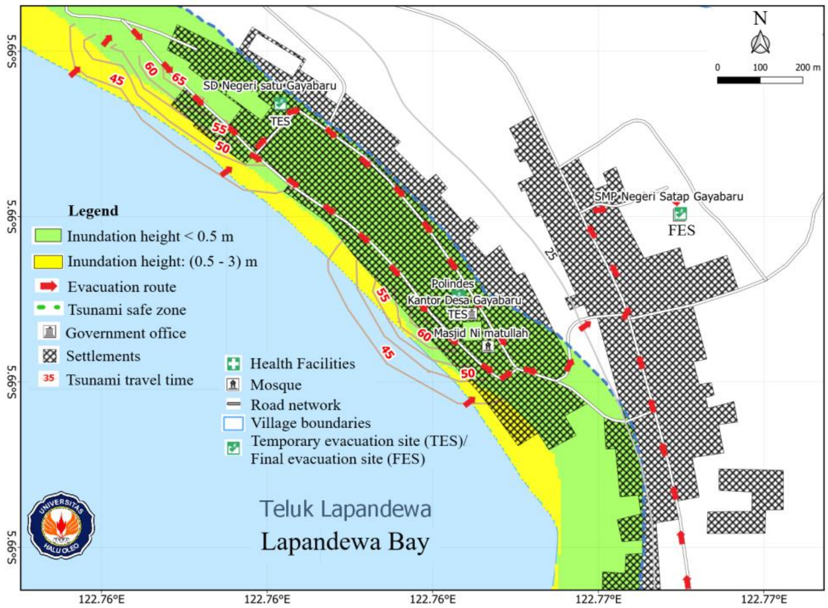

Figure 9. Tsunami evacuation map at Sublayer-7, involving Gayabaru village.

TES, specifically SDN 1 Gayabaru and the Gayabaru Village Office. SDN 1 Gayabaru is ideally designated as a temporary evacuation site for residents of the northwest region, while the Gayabaru Village Office is recommended as a temporary evacuation location for inhabitants of the middle section of the village. The duration required to arrive at these two TESs is approximately 10 minutes, whereas the travel time for tsunami waves to reach the coastline of Gayabaru Village is roughly 45 minutes. There remains ample time to execute the evacuation procedure. The FES is located at SMPN Satu-Atap Gayabaru. The final evacuation site sits at an elevation of about 25 m above sea level, approximately 200 meters from the shore. The FES location also has adequate facilities. The route to FES is on the main route to Gayabaru Village, so it is easy to evacuate when a tsunami occurs.

CONCLUSION

The conclusions from the results of this research are as follows:

1. The research region identifies two concerning tsunami heights: those with inundation levels of 0–0.5 m and those with inundation levels of 0.5–3 m. A tsunami with an inundation height of 0.5 to 3 meters results in submergence at different distances. The nearest inundation distance ranges from 5 to 33 meters in Katilombo Village and Jayabakti Village (Sublayer-2). The maximum immersion distance of 57-98 m occurred in Katampe and Molona Villages (Sublayer-1). Tsunami waves arrive 35–45 minutes post-earthquake, with the earliest arrival occurring in Sublayer 5, nearest to the tsunami generator's source.
2. The seven sublayers on the south coast of South Buton Regency have 17 recommended temporary evacuation sites (TES). There is one site in each village in Katampe, Lamaninggara, and Molona; one site in Lakambau and Laompo Villages; four sites in Katilombo and Jayabakti Villages; one site in Tira Village; three sites in Bahar Village; one site each in Lapandewa, Windu Makmur, and Gerak Makmur Villages; and two sites in Gayabaru Village. In general, all recommended TESs have met the criteria, both in terms of safety and required evacuation time.
3. The tsunami wave reached South Buton Regency approximately 35–45 minutes after being triggered by the Flores Fault, whereas the average evacuation time to the designated TESs was about 10 minutes.
4. The suggested final evacuation site (FES) comprises seven locations, each situated within its respective sublayer. Enhanced FES with accessible evacuation routes and sufficient facility support are necessary at various sublayers.

ACKNOWLEDGMENT

We express our sincere thanks to the Directorate of Research and Community Service at the Directorate General of Higher Education, Ministry of Higher Education, Science, and Technology, for research funding support through the Master's Thesis Research Scheme with contract number 049/E5/PG.02.00.PL/2024.

REFERENCES

1. Safani, J., Ibrahim, K., Wa Deni, Al Rubaiyn, Firdaus, & Harisma. 2023. Interpreting structural configuration of the Sengkang Basin of Indonesia using edge detection and 3-D Euler deconvolution to satellite gravity data. *Turkish J Earth Sci*., *32*: 894-914.
2. Triyono, R., Prasetya, T., Daryono, Anugrah, S. C., & Sudraja, A. 2019. *Katalog Tsunami Indonesia Tahun 416-2018*. Badan Meteorologi, Klimatologi, dan Geofisika, Jakarta.

3 Benazir & Oktari, R.S. 2024. Assessing tsunami risk along the Aceh coast, Indonesia: a quantitative analysis of fault rupture potential and early warning system efficacy for predicting arrival time and flood extent. *Natural Hazards*. https://doi.org/10.1007/s11069-024-06401-x.

4 Magdalena, I., Rif'atin, H. Q., Kongko, W., Marta, A. S. D., Khoirunnisa, H., Nurwijayanti, A., & Farid M. 2024. Aceh's tsunami wave evolution and its interaction with hybrid protection structure. *Physics of fluids, 36*(2).

5 Muzani, Mataburu, I., Tafiati. 2024. Vulnerability and tsunami disaster on the west coast Banten province, Indonesia. *All Earth, 36*(1), 1-12.

6 Zuliansah, A. B. R., Windujati, U., Rasyif, T. M., Mahlil, T., & Januriyadi, N. F. 2023. Performance Evaluation of DualSPHysics and COMCOT Programs through Numerical Testing for Simulating Tsunami Propagation and Overtopping on Seawalls. E3S Web of Conferences 447, 01014.

7 Ario, F., Pratama, C., Adipura, D. T. R., Rasyif, T. M., Mahlil, T., & Januriyadi, N. F. 2023. Building Vulnerability Analysis Due to Tsunami by Using Probabilistic Tsunami Hazard Assessment (PTHA): A Case Study of Pelabuhan Ratu, Sukabumi. E3S Web of Conferences, 447, 01003.

8 Pranantyo, I. R., Heidarzadeh, M., & Cummins, P. R. 2021. Complex tsunami hazards in eastern Indonesia from seismic and non-seismic sources: Deterministic modelling based on historical and modern data. *Geosci. Lett., 8*, 20.

9 Paskett, T., Whitehead, J. P., Harris, R. A., Ashcraft, C., Krometis, J. A., Sorensen, I., & Wonnacott, R. 2024. A tale of two faults: statistical reconstruction of the 1820 Flores Sea earthquake using tsunami observations alone. *Geophys. J. Int., 237*, 419–435.

10 Pranantyo, I. R., Cummins, P. R. 2019. Multi-Data-Type Source Estimation for the 1992 Flores Earthquake and Tsunami. *Pure Appl. Geophys*, *176*, 2969–2983.

11 Horspool, N., Pranantyo, I., Griffin, J., Latief, H., Natawidjaja, D. H., Kongko, W., Cipta, A., Bustaman, B., Anugrah, S. D., & Thio, H. K. 2014. A Probabilistic tsunami hazard assessment for Indonesia. *Natural Hazards and System Earth Sciences, 14,* 3105-3122

12 Pribadi, S., Hakim, M. L., Fauzi, Kurniawan, T., Nugraha, H. A., Daryono, Karnawati, D., Adi, S. P. 2023. *The Mount Anak Krakatau landslide scenario for tsunami modeling in Banten*. E3S Web of Conferences, *46418*, 010102. 2nd International Conference on Disaster Mitigation and Management.

13 Wang, X. 2009. *User Manual for COMCOT Version 1.7*. Cornell University, USA.

14 UNESCO. 2016. *Tsunami Glossary*. Intergovernmental Oceanographic Commission (IOC) Technical Series, UNESCO, Paris.

15 Syamsidik, Rasyif, T. M., & Kato, S. 2015. Development of accurate tsunami estimated times of arrival for tsunami-prone cities in Aceh, Indonesia. *International Journal of Disaster Risk Reduction*, *14*(4), 403-410.

16 Rasyif, T. M., Kato, S., Syamsidik, & Okabe, T. 2019. Numerical simulation of morphological changes due to theb2004 tsunami wave around Banda Aceh, Indonesia. *Geosciences*, *9*(125), 1-16. https://doi.org/10.3390/geosciences9030125.

17 Kotani, M. (1998). Tsunami run-up simulation and damage estimation using GIS. *P. Coast. Eng., JSCE*, 45, 356-360.