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EVALUATION OF TEMPORARY EVACUATION SHELTER (TES) FOR TSUNAMI IN BANGGAE TIMUR, MAJENE BASED ON LOCATION-ALLOCATION ANALYSIS

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ABSTRACT

Majene Regency, specifically the Banggae Timur District, is at considerable risk of tsunamis due to its coastal location and increasing urban density. This research evaluates the effectiveness of current Temporary Evacuation Shelters (TES) using a spatial analysis methodology combined with location-allocation modeling. The methodology included tsunami inundation mapping utilizing historical data, identification of building points, analysis of TES capacity, and modeling of service areas within a maximum evacuation radius of 935 meters.The study concentrated on two specific TES: Prasamya Stadium and the Majene Regency Police Station. Although both locations possess adequate capacity for hosting evacuees, they are situated within high-risk tsunami inundation zones (5–6 meters), making them inappropriate for safe evacuation. Spatial allocation modeling indicates that these TES predominantly serve the western section of Banggae Timur District, resulting in considerable underservicing of eastern coastal areas and increased risk. Of the 2,774 houses located within the tsunami inundation zone, 1,506 are currently unserved by the existing TES. The findings highlight the necessity of identifying and establishing new TES in safer, elevated areas with enhanced accessibility to improve evacuation coverage and safety. This study emphasizes the importance of spatial modeling in enhancing evidence-based disaster mitigation planning. It offers precise, data-driven insights for optimizing emergency infrastructure and minimizing population risk exposure in urban areas susceptible to tsunamis.

Keyword: *Disaster Mitigation, Location-allocation, Spatial Analysis, Temporary Shelters, Tsunami Evacuation.*

1. INTRODUCTION

Sulawesi Barat Province has the highest disaster risk index, with a score of 160.08 [1]. Of the five regencies in Sulawesi Barat Province, Majene Regency has the highest disaster risk index, with a score of 186.83. This score decreased from 2019 to 2023 (fig. 1) but remains in the high-risk category.

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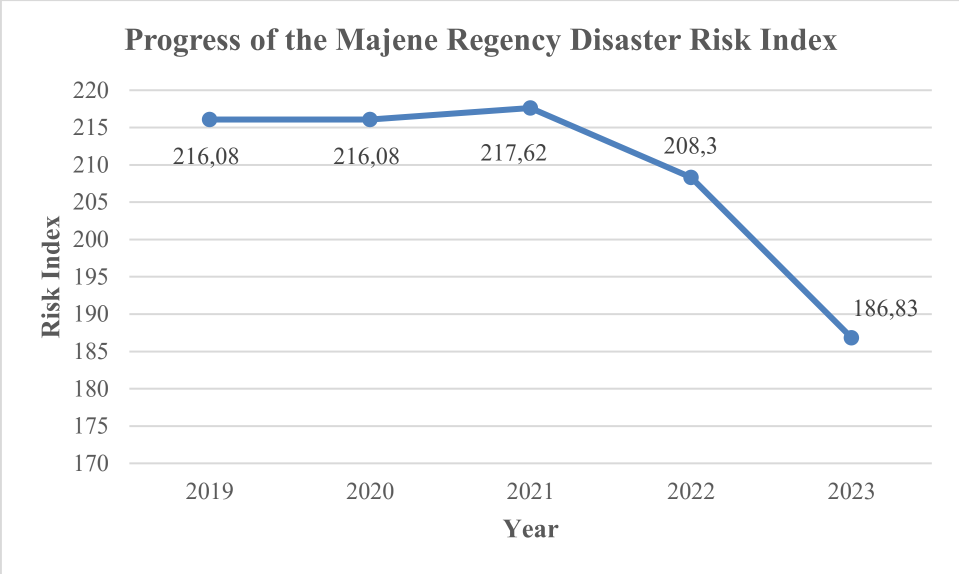

Figure 1. Progress of the Majene Regency Disaster Risk Index

The high disaster risk in Majene Regency is attributed to its elongated shape, its direct border with the Makassar Strait, and its geological location, which is influenced by the Makassar Fault, a tectonic feature exhibiting reverse movement with an average annual displacement of 1-5 mm [2]. These conditions make the Majene Regency highly vulnerable to tsunamis. Based on historical data, Majene Regency experienced earthquakes followed by tsunamis in 1967 and 1969 [3], with the 1969 event causing quite severe impacts due to tsunami heights reaching 2-6 meters in several areas [3] [4] [5]. Furthermore, based on studies conducted, Majene Regency and its urban areas are the areas in Sulawesi Barat Province with the most excellent chance of being impacted by a major tsunami disaster (with a height of more than 3 meters) in any given year [6].

The part of the Majene Regency that requires special attention in disaster management efforts is the Majene urban area, as the center of growth in this region is located in a coastal area that is seismically active [7]. The Majene urban area, encompassing two sub-districts, Banggae, and Banggae Timur, is a tsunami-prone area, with the distribution of tsunami-affected areas in Banggae Timur District being more extensive than in Banggae District [8] [9]. The Banggae Timur District is highly vulnerable to tsunamis, primarily due to its role as the center of urban growth driven by the presence of the Sulawesi Barat University campus. This situation will lead to increased population growth and land conversion, further contributing to disaster vulnerability. Therefore, mitigation as a disaster management effort is increasingly crucial in the development of the Majene urban area, particularly the Banggae Timur District.

Mitigation efforts play a crucial role in regional planning and structuring in the Majene Regency, as disaster management practices in Majene have not been well implemented, particularly regarding emergency response [10] [11]. Disaster management must be supported by effective planning, direction, support, coordination, and implementation of various activities carried out at the stages of damage mitigation, preparedness, intervention, and recovery in order to prevent disasters and reduce the damage they cause [12]. The strategy established by the Majene Regency needs to be adapted to regional conditions by ensuring that disaster management operations are effective, efficient, and sustainable [13]. One effort that can be made to organize an effective and efficient disaster emergency response is to improve disaster mitigation, which can be done by preparing a thorough evacuation plan. In this case, mapping evacuation shelter along with their characteristics and effective evacuation routes plays a vital role [14] [15]. In 2021, the government conducted a mapping of Temporary Evacuation Shelter (TES) in the urban area of Majene, including Banggae Timur District [16]. However, no evaluation of these TES has been conducted, therefore, this research aims to evaluate each TES in Banggae Timur District, particularly by considering aspects of tsunami vulnerability parameters and TES accessibility in reaching buildings potentially affected by tsunamis.

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2. RESEARCH METHODOLOGY

This research is a quantitative study using a spatial approach. Therefore, the approach used to solve the problem is a quantitative-spatial approach. This approach combines a spatial approach that places space as the primary element in every analysis [17], involving various geospheric phenomena related to tsunami disasters and contributing to disaster risk, consisting of hazard, vulnerability, and capacity components, and a quantitative approach that utilizes measurement, calculation, formulas, and numerical data certainty in the research process [18] (Musianto, 2010) [19].

The choice of this spatial approach is based on the type of data, which is primarily related to geographic conditions. This type of research, when viewed in terms of its application, falls into the category of applied research [20]. From a methodological perspective, it is considered developmental research.

Data collection in this study was conducted through documentation and field observations. The research data sources are divided into two:

a. Secondary data was obtained through literature studies and documentation from various institutions and official sources. The secondary data used consisted of spatial data, including both raster and vector formats. These data included raster DEM (Digital Elevation Model) data, which was converted into slope and topography vector data; raster data from very high-resolution satellite imagery, which was converted into land cover and building point vector data; vector data from coastlines; and vector data from Temporary Evacuation Shelter (TES).
b. Primary data was obtained through direct field observations in the Banggae Timur District. These observations were conducted to verify the existing condition of the Temporary Evacuation Shelter (TES). This primary data is crucial for ensuring alignment between modeling results and actual conditions on the ground, serving as a reference for determining effective and safe evacuation routes and points for the community.

The data analysis technique employed in this study was spatial modeling, utilizing network analysis. The data analysis stages in this study are as follows:

a. Mapping of building points potentially affected by tsunami inundation
   The process of mapping building points potentially affected by tsunami inundation in Banggae Timur District is as follows:
   1) Tsunami inundation modeling in Banggae Timur District
      Tsunami inundation zone modeling aims to identify the extent of inundation caused by future tsunami disasters [21]. According to the National Disaster Management Agency [21], the distribution of tsunami-affected areas is obtained from a mathematical formula developed by Berryman (2006), which calculates the tsunami height loss per 1 meter of inundation height based on distance, slope, and surface roughness, as follows:

$$H_{loss} = \left(\frac{167\, n^2}{{H_0}^{1/3}}\right) + 5\ Sin\ S \quad (1)$$

Where:
H_{loss} = tsunami height loss per 1 m of inundation distance n
n = surface roughness coefficient
H0 = tsunami wave height at the coastline (m)
S = slope gradient (degrees)
(Source: BNPB, 2021)

The surface roughness coefficient can be presented in the following table:

Table 1. Surface roughness coefficient

Land cover	Surface roughness coefficient value
Water Bodies	0.007
Brushes/Shrubs	0.04
Forests	0.07
Gardens/Plantations	0.038
Empty/Open Land	0.015
Agricultural Land	0.025
Settlements/Built-Up Land	0.045
Mangroves	0.025
Fish Ponds/Ribs	0.010

(Source: Berryman, 2006)

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The tsunami inundation modeling process was conducted using a geographic information system (GIS) approach using ArcMAP 10.4 software.

2) Spatial data preparation for network analysis modeling
In this research, the modeling of the TES service area was conducted using network analysis using the location-allocation technique. This modeling applies the principle of travel from demand to facility, so the spatial data used represents both. In this case, demand is the location of buildings estimated to function as residences, while the facility is the tsunami TES. The identification of building distribution points was carried out through on-screen digitization of high-resolution satellite imagery of the Majene urban area using ArcMap 10.4 software. After the distribution of building points was mapped, the data were then overlaid with spatial data for tsunami inundation zoning to identify buildings within the designated tsunami inundation zones. These points were assumed to be served by the TES.

3) Determining Temporary Evacuation Site (TES) Capacity
TES capacity was determined by considering the TES area size and the space requirements for each person during disaster evacuation. In this case, the minimum space requirement for evacuation is based on the assumption set by the American National Red Cross, which is 1.64 m^2 [22]. The capacity of the evacuation site can be calculated using a simple formula:

$$C = \frac{A}{S} \quad (2)$$

Where:
C = Capacity (persons)
A = TES Area (m^2)
S = Minimum Area Required during disaster evacuation (m^2 / per person)

4) Determining the TES Service Area
The location-allocation tool in ArcMap 10.4 software is used to model the service area of each TES. This tool was chosen because it can be used to determine the evacuation direction of each building point to a specific evacuation site, considering the distance factor, which enables an estimate of the evacuation direction from each building point to a specific evacuation site.

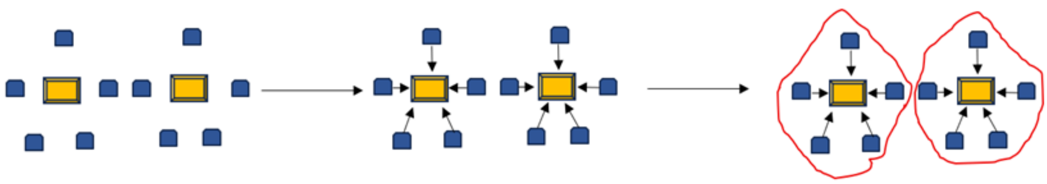

Figure 2. Service area modeling process with allocation-location

The distance factor in the modeling refers to the maximum distance that can be traveled for evacuation within a specified time limit. This is calculated by considering the estimated tsunami arrival time of 24 minutes [5], the average community response time after an earthquake that triggers a tsunami of 7 minutes [23] [24], and the velocity of people walking fast of 3.3 km/h [25]. The maximum evacuation distance is calculated using the following formula [26]:

$$Maximum\ evacuation\ Distance = (T_1 - W_t)\ x\ V_w$$

Where:
T_1 = tsunami wave arrival time
W_t = average community response time
V_w = normal walking speed during evacuation

Then, location-allocation modeling is conducted using the principle of maximized capacitated coverage. This principle enables facility selection to meet demand according to facility capacity while also considering distance as a factor. The stages of data analysis in the modeling process can be presented in the following flowchart.

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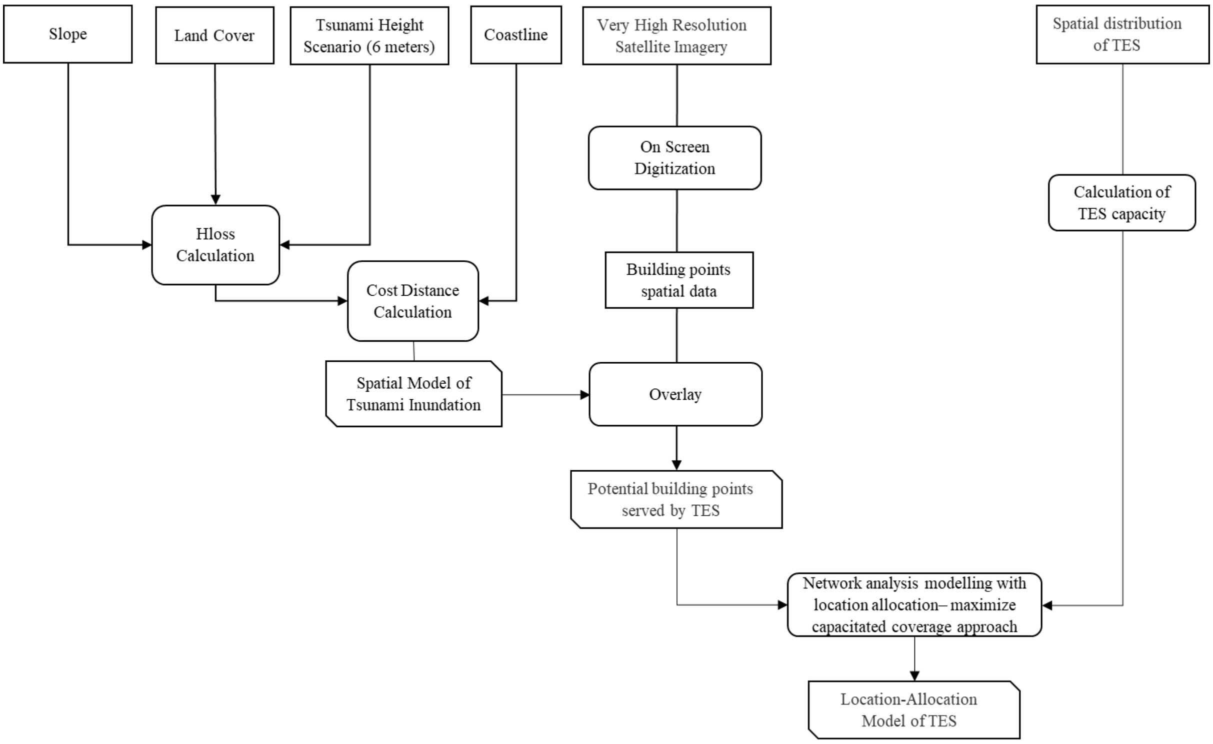

Figure 3. Data analysis process flowchart for the modelling

3. Analysis and Result

3.1. Estimation of Tsunami-Affected Areas in Banggae Timur District

According to historical data, in 1969, Majene Regency was affected by an earthquake that triggered a tsunami that swept across the land with heights varying between 2 and 6 meters [3] [4] [5]. Unlike the research conducted by Aksa [8], which used a 10-meter height scenario based on the tsunami hazard index classification issued by the National Disaster Management Agency, this study employed a 6-meter height scenario, representing the maximum tsunami height that could occur in Majene Regency, as determined by historical data. This height scenario served as the basis for modeling tsunami inundation in Banggae Timur District using a Geographic Information System (GIS) approach using ArcMAP 10.4 software. The modeling produced the following figure.

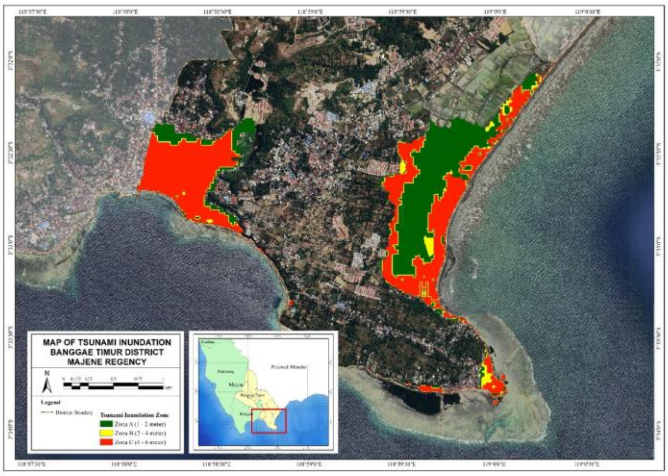

Figure 4. Map of tsunami inundation in Banggae Timur District

The map as shown in Figure 4 delineates three separate tsunami inundation zones, each associated with a specific range of potential sea depths and, therefore, differing levels of destructive force.

1. Zone A (1-2 meters inundation - Red): This zone denotes regions anticipated to encounter water depths ranging from 1 to 2 meters after a tsunami occurrence. It is primarily situated near the coastal

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margin but, importantly, extends further inland in various low-lying regions. A notable observation is the complete and broad engulfment of significant portions of the most densely populated residential and business sectors within this red zone. A flood depth of 1-2 meters can inflict significant structural damage to standard residential buildings, especially those made with inferior materials. Such depths can also displace light vehicles and present a significant, immediate danger to human life because to powerful currents and debris.

2. Zone B (2-4 meters inundation - Yellow): This zone signifies regions where tsunami waters are anticipated to attain depths of 2 to 4 meters. Although often less extensive than Zone A, it yet encompasses significant portions of the inhabited regions. These yellow zones typically emerge directly behind or close to Zone A, or within particular low-lying areas that facilitate greater water infiltration. Inundation depths of 2-4 meters are devastating, capable of obliterating most conventional structures, incapacitating essential infrastructure, and resulting in extensive casualties. The existence of inhabited regions inside this zone indicates a significantly elevated degree of susceptibility.
3. Zone C (4-6 meters inundation - Green): This zone signifies the maximum anticipated inundation depths, spanning from 4 to 6 meters. This zone is visually the least extensive of the three, typically located deeper inland, sometimes in underdeveloped agricultural regions or on the outside edges of populated places where the topography may be significantly lower. Despite being less prevalent in areas with high population density, an inundation of this scale possesses immense destructive potential, capable of demolishing edifices, inducing substantial erosion, and fundamentally altering the terrain.

The potential for buildings to be affected by each tsunami inundation class is presented in Table 2 and Figure 5.

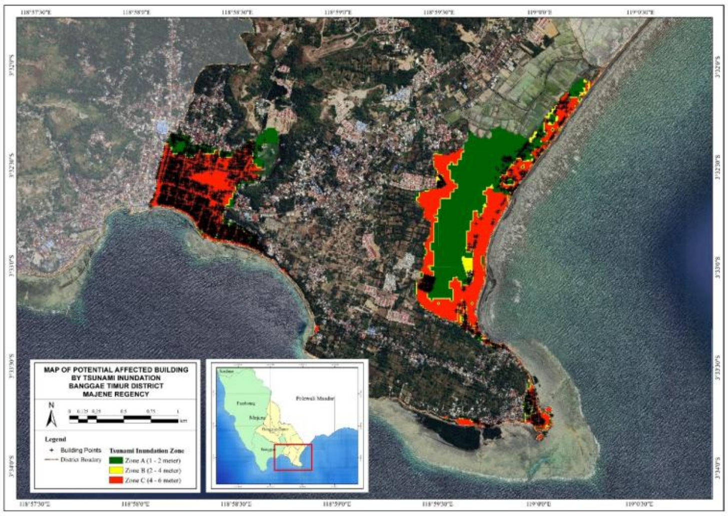

Figure 5. Map of the distribution of potential buildings affected by tsunami inundation in Banggae Timur District

Table 2. Potential for buildings to be affected by tsunami inundation in Banggae Timur District

Class of tsunami inundation	Number of building
1 - 2 m	529
3 - 4 m	259
5 - 6 m	1986
Total	2774

(Source: Data analysis, 2025)

The significant intersection of Zone A (1-2 meters) and Zone B (2-4 meters) with densely populated residential areas would result in massive and devastating damage to homes in the event of a tsunami. Even at the shallowest depth of Zone A, inadequately constructed residences will undoubtedly collapse, while even sturdier edifices would incur substantial damage, rendering them uninhabitable. The

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extensive flooding in populated regions indicates the displacement of thousands of individuals, resulting in an urgent humanitarian situation. The risk of significant loss of life is exceedingly high due to the direct exposure of a substantial population to perilous sea depths and strong currents. The map in fig 5. indicates that significant highways, especially those aligned with the shoreline and functioning as essential conduits linking coastal communities, are wholly contained within Zone A and Zone B in various areas. This geographical link signifies that these essential transit routes would become impassable at the onset of a tsunami catastrophe. This scenario would significantly obstruct initial evacuation efforts, thereby confining populations in high-risk areas, and would subsequently hinder post-disaster assistance activities by rendering entry to afflicted regions exceedingly difficult or unattainable. Moreover, critical services like as power grids, water supply systems, and communication networks are generally situated beside these major roadways or integrated inside the flooded residential and commercial zones. Their extensive failure would result in unavoidable repercussions, causing extended interruptions in vital services, intensifying the humanitarian catastrophe, and greatly hindering recovery initiatives.

3.2. Temporary Evacuation Shelter (TES) for Tsunami Disasters in Banggae Timur District

The government has identified and mapped potential locations for Temporary Evacuation Shelter (TES) for Tsunami Disasters in Banggae Timur District, consisting of two locations: Prasamya Stadium in Majene and the Majene Regency Police Station [16]. Prasamya Stadium, Majene, covers an area of 12,612 m². Assuming a population density requirement of 1.64 m² per person [22], Prasamya Stadium, as a TES, can accommodate approximately 7,690 people during evacuation. Despite its large capacity, in terms of tsunami vulnerability, this area is considered unsuitable as a temporary evacuation site. This is due to topographically, Prasamya Stadium, Majene, is located at an elevation of 6 meters. Compared to the spatial distribution of tsunami inundation zones, as shown in Figure 5, it is still within the zone with a potential tsunami inundation of 5-6 m (high vulnerability). The second TES location is the Majene Regency Police Station, which covers 14,789 m² and can accommodate up to 9,017 people. Although the Majene Regency Police Station does not have as much open space as the Prasamya Stadium, its capacity is still relatively large and can be utilized effectively, especially for residents closer to the cityHowever, this location is also within the 5-6 meter tsunami inundation zone (fig. 6), so even at an elevation of approximately 8 meters, it remains unsuitable for a TES, especially considering several previous studies, it is suggested that tsunami TES should be in the form of buildings with floors that are not submerged by tsunami inundation [25], or if it is open space, it should be located in an area with a height above the tsunami inundation [27] [28] [29].

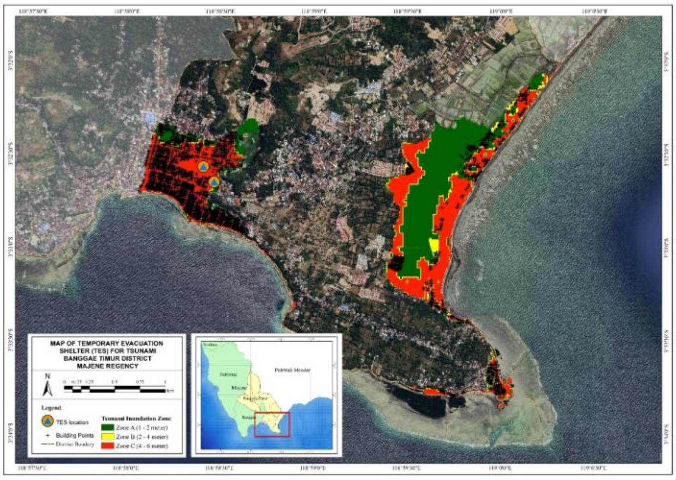

Figure 6. Map of Temporary Evacuation Shelter (TES) in Banggae Timur Disrict

The existing condition of the roads leading to the Temporary Evacuation Shelter (TES) in Banggae Timur District varies in terms of accessibility, road width, and ease of evacuation. Most routes to the TES, such as the Prasamya Stadium and the Majene Regency Police Station, are accessible by both two-wheeled and four-wheeled vehicles. However, some routes require infrastructure improvements to ensure a more efficient and safe evacuation process. The route to Prasamya Stadium is in reasonably good condition, with relatively broad and open access roads. However, there are areas prone to congestion during mass evacuations due to its proximity to densely populated residential areas. This location can be reached in less than 15 minutes from the coast, but care must be taken to avoid crossing rivers that could become tsunami routes. Meanwhile, access to the Majene Regency Police Station is also in good condition; however, some sections are narrow and could impede evacuation flows if not correctly managed.

(a) (b) (c)

Figure 7. Road conditions around Prasamya Stadium (a and b) and the Majene Regency Police Station (c).

3.3. Location-Allocation Modeling of Temporary Evacuation Shelter (TES) in Banggae Timur District

Determining the location and allocation of refugees is a strategic step in disaster mitigation efforts, particularly in the face of a potential tsunami. In general, this process aims to ensure that people living in vulnerable zones can quickly reach designated evacuation sites for safe shelter. Evacuation sites must be able to accommodate the number of refugees according to the surrounding population density. Meanwhile, refugee allocation is based on population distribution and accessibility to evacuation sites. The goal is to ensure that the evacuation process is effective and organized, minimizing risk when a disaster occurs. This approach is a crucial part of spatially based disaster management planning and rapid response in coastal areas.

TES location-allocation modeling was conducted using the Network Analyst approach in ArcGIS software to efficiently allocate refugees from disaster-prone zones to Temporary Evacuation Shelter (TES) based on distance and capacity. This analysis utilized the Maximize Capacitated Coverage model, which allows the mapping of evacuation facilities based on the maximum evacuation distance and the capacity limits of each TES. Based on calculations that take into account the estimated arrival time of the tsunami waves in the coastal area of Banggae Timur District [5], the average community response time after an earthquake that triggered a tsunami [23] [24], and the average velocity of people walking fast [25], the maximum evacuation distance is 935 meters, which is the limit for evacuees to reach the TES. This means that each house or population point will only be allocated to a TES if the distance is no more than 935 meters. If there are no facilities within this radius, the building point will not be served in the allocation scenario.

In the analysis settings, the number of facilities to choose from was determined to be two because this study only analyzed two predetermined TES: Prasamya Majene Stadium and the Majene Regency Police Station. These two points were input as facility points, while the house points were input as demand points or evacuation requests. As an accumulation attribute, the path length in meters from the previously constructed road network is used. This road network serves as the basis for calculating the shortest distance between each house and the TES, using actual routes rather than straight or euclidean distances. The model will select the allocation combination that maximizes the number of homes served within the distance constraints and available facility capacity.

Based on the results of the location-allocation analysis using the Maximum Coverage with Capacity approach in Network Analyst, of the total 2,774 houses spread along the coastal area of East Banggae District and located within the tsunami inundation zone, only 1,268 houses were successfully served or allocated to the available temporary evacuation sites (TES), namely the Prasamya Majene Stadium and the Majene Police Station. This analysis utilizes a maximum service distance limit of 850 meters and considers the maximum capacity of each TES. Thus, 1,506 houses are not served because they are

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outside the spatial reach and capacity of the two analyzed evacuation facilities. This condition indicates that the existing capacity of evacuation sites and current service coverage are insufficient to accommodate the entire population living in disaster-prone areas. Therefore, it is necessary to re-evaluate the distribution of TES locations and plan additional evacuation facilities at other strategic points so that the evacuation process can reach more residents in a tsunami disaster scenario.

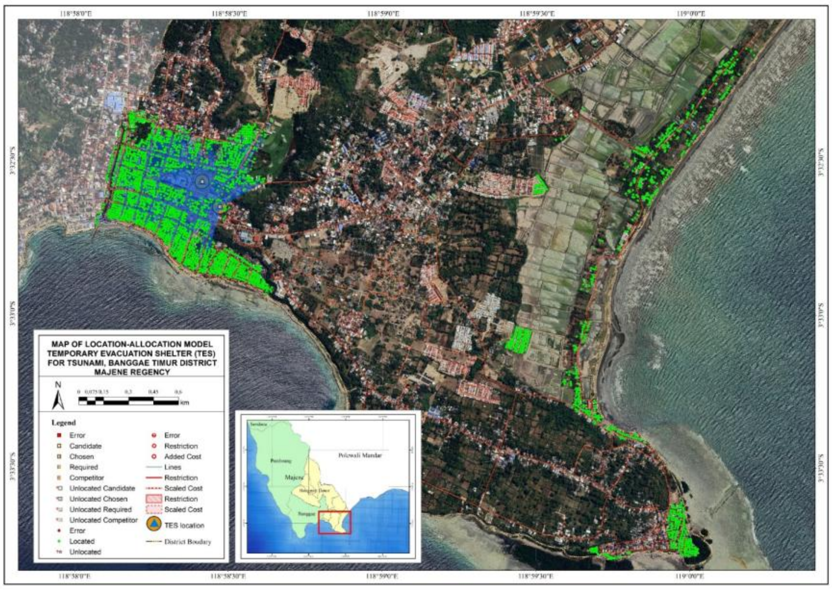

Figure 8. Map of Locations- Allocation of Temporary Evacuation Shelter (TES) in Banggae Timur District

Table 3. Number of houses served by TES based on location allocation analysis

TES	Demand Count
Prasamya Stadium	229
Majene Regency Police Station	1039

(Source: Data analysis, 2025)

Based on the spatial analysis of refugee allocation locations in Banggae Timur District, the map illustrates the distribution of residential areas and tsunami-affected areas, with a focus on the Labuang area and its surroundings. Evacuation locations are planned to accommodate populations from areas within the tsunami inundation hazard zone. The allocation of refugees takes into account the spatial proximity between settlements and the TES, as well as the nearest road route with quick access from the vulnerable zone. The map also shows that most households in the southern coastal area are included in the allocation coverage for both locations. The mapping results indicate that Prasamya Stadium has sufficient capacity to accommodate refugees from approximately 229 houses, while the Majene Regency Police Station can accommodate more, specifically up to 1,039 houses. Assuming that one house is occupied by a family of four, the number of refugees who may take refuge at the Prasamaya Stadium TES is 916 people, and at the Majene Police TES is 4,156 people. This number is still lower than the combined capacity of both TES, so the capacity of both locations remains sufficient to accommodate the potential number of refugees.

However, from the TES location-allocation model map in Figure 8, considering the maximum evacuation distance of 935 meters as impedance, the two designated TESs can only serve the central urban area of Banggae Timur District located on the western side of the area. In contrast, the tsunami inundation-affected areas in the eastern part cannot be served. Therefore, consideration will be needed in the future when selecting new locations that have the potential to be used as TESs. This is crucial in overcoming the problem of the two existing TESs, which, in terms of disaster vulnerability, are still located in the high tsunami inundation zone and, in terms of accessibility, are less able to reach the entire Banggae Timur District, which has the potential to be affected by the tsunami.

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This study's findings on the evaluation of Temporary Evacuation Shelters (TES) for tsunamis in Banggae Timur District, Majene, lead to the following policy recommendations aimed at improving disaster mitigation and preparedness:

1. The primary recommendation is to promptly identify and establish new Temporary Evacuation Shelters (TES) in areas that are clearly outside of high-risk tsunami inundation zones. The existing TES (Prasamya Stadium and Majene Regency Police Station) are located within the 5-6 meter tsunami inundation zone, making them inadequate as safe evacuation sites despite their capacity. New locations must be selected through comprehensive topographical analysis, ensuring they are situated at elevations considerably above the maximum expected tsunami height, as indicated by prior research.
2. The expansion of TES coverage to underserved areas is necessary, as the current locations primarily serve the western urban regions of Banggae Timur District, resulting in significant portions of the eastern coastal areas being underserved and vulnerable. Policy should require a thorough assessment of the spatial distribution of populations at risk from tsunamis and strategically position new tsunami evacuation shelters to enhance coverage, especially in the underserved eastern areas.
3. Investment in evacuation infrastructure and route improvement is necessary, as some routes to existing TES are accessible, yet certain sections are narrow and may hinder evacuation flows. Investment in infrastructure improvements should be prioritized in policy, focusing on widening critical evacuation routes, ensuring adequate signage, and addressing potential congestion points, particularly in densely populated areas. Evacuation planning must consider the risk associated with crossing rivers that may serve as tsunami routes.

4. CONCLUSION

Using a spatial analysis approach with location-allocation modeling, this study assessed the efficacy of This research utilized spatial analysis and location-allocation modeling to assess the effectiveness of Temporary Evacuation Shelters (TES) in the Banggae Timur District of Majene Regency. The results reveal substantial shortcomings in the existing disaster preparedness framework. Both the Prasamya Stadium and the Majene Regency Police Station are located within high tsunami inundation zones (5-6 meters), making them inadequate as safe evacuation points during a tsunami disaster, despite having sufficient capacities. This spatial vulnerability significantly undermines their reliability as safe havens. The location-allocation analysis indicated that these two TES can serve only a limited segment of the tsunami-affected population, primarily focusing on the western urban areas of Banggae Timur District. The maximal evacuation distance constraint of 935 meters indicates that substantially high-risk areas in the eastern region are inadequately served. This highlights a significant shortcoming in the region's disaster preparedness planning, suggesting that a considerable number of households (1,506 out of 2,774) remain unserved within the tsunami inundation zone.

To enhance tsunami disaster mitigation in Banggae Timur District, it is essential to identify and establish new TES locations that are strategically located to optimize coverage of the affected population and are topographically secure, preferably at elevations well above the maximum expected tsunami height. Simultaneously, it is crucial to increase public awareness and upgrade evacuation infrastructure, which includes expanding key routes and ensuring clear signage, to enable timely and efficient evacuation processes. The incorporation of these essential efforts into holistic disaster management and urban planning frameworks will significantly improve community resilience to future tsunami occurrences in Majene Regency.

REFERENCES

[1] A. W. Adi *et al.*, *IRBI (Indeks Risiko Bencana Indonesia) Tahun 2023*, vol. 01. Jakarta: Badan Nasional Penanggulangan Bencana, 2023.

[2] E. Susanto, I. Nurana, and A. R. Setyahagi, "Pemodelan Run-up Tsunami di Wilayah Pesisir Pantai Sulawesi Barat," *Buletin GAW Bariri*, vol. 1, no. 2, pp. 87–93, 2020.

[3] Tim Pusat Gempabumi dan Tsunami, *Katalog Gempabumi Signifikan & Merusak Tahun 1821-2023*. Jakarta: Pusat Gempabumi dan Tsunami, Kedeputian Bidang Geofisika, Badan Meteorologi, Klimatologi dan Geofisika, 2024. [Online]. Available: http://scioteca.caf.com/bitstream/handle/123456789/1091/RED2017-Eng-

8ene.pdf?sequence=12&isAllowed=y%0Ahttp://dx.doi.org/10.1016/j.regsciurbeco.2008.06.005%0Ahttps://www.researchgate.net/publication/305320484_SISTEM_PEMBETUNGAN_TERPUSAT_STRATEGI_MELESTARI
[4] I. Pranantyo, A. Cipta, H. Ash Shiddiqi, T. Baba, and K. Imai, “Source Reconstruction of the 1969 Western Sulawesi, Indonesia, Earthquake and Tsunami,” *Pure Appl Geophys*, vol. 180, Jun. 2022, doi: 10.1007/s00024-022-03064-2.
[5] E. Susanto, M. Arsyad, Subaer, and A. R. Setyahagi, “Pemodelan Waktu Tiba Gelombang Tsunami di Wilayah Pesisir Provinsi Sulawesi Barat,” in *Prosiding Seminar Nasional Fisika PPs UNM*, Makassar, Dec. 2020, pp. 80–83.
[6] N. Horsphool *et al.*, “Kajian Nasional Bahaya Tsunami untuk Indonesia,” 2013.
[7] Yusman, A. Mulawarman, and A. Nurdin, “Evaluasi Tutupan Mangrove dan Analisis Citra Satelit untuk Mitigasi Tsunami pada Garis Pantai Majene,” *Bandar: Journal Of Civil Enginering*, vol. 4, no. 1, pp. 10–15, Apr. 2022, doi: https://doi.org/10.31605/bjce.v4i1.1553.
[8] A. Aksa, “Determinasi Tempat Evakuasi Sementara Dan Tempat Evakuasi Akhir Potensial Bencana Tsunami di Kawasan Pesisir Perkotaan Majene,” Skripsi, Universitas Sulawesi Barat, 2024.
[9] A. Wahyudi, A. Priadmodjo, A. Aksa, and F. A. Islaha, “Pemetaan Skenario Genangan Tsunami Berbasis Pemodelan Spasial,” *Jurnal Penelitian Pendidikan Geografi*, vol. 9, no. 1, pp. 44–51, 2024, doi: https://doi.org/10.36709/jppg.v9i1.214.
[10] N. Nur, F. Wajidi, A. Mulawarman, M. Adrian, and R. Gunawan, “Pemanfaatan Sistem Informasi Edukasi Mitigasi Bencana pada KSR PMI Unit Markas Majene,” *Jurnal Pengabdian Kepada Masyarakat Indonesia*, vol. 2, no. 3, pp. 375–388, Dec. 2022, [Online]. Available: https://journal.amikveteran.ac.id/index.php/jpkmihttps://journal.amikveteran.ac.id/
[11] A. Mawan, “Kalut Penanganan Gempa Mamuju-Majene, Mitigasi pun Minim,” 2021.
[12] K. Poser and D. Dransch, “Volunteered Geographic Information For Disaster Management With Application To Rapid Flood Damage Estimation,” *Geomatica*, vol. 64, no. 1, pp. 89–98, 2010, doi: https://doi.org/10.5623/geomat-2010-0008.
[13] M. R. Akbar, M. Muhayyang, S. N. F. Khaidir, A. Iswar, and F. A. Salam, “Mitigasi Bencana Berbasis Pengetahuan Lokal Masyarakat Majene,” *Kybernology : Journal of Government Studies*, vol. 2, no. 2, pp. 120–132, Oct. 2022, doi: 10.26618/kjgs.v2i2.9661.
[14] M. A. Ferreira, C. S. Oliveira, and R. Francisco, “Tsunami risk mitigation: the role of evacuation routes, preparedness and urban planning,” *Natural Hazards*, Apr. 2024, doi: 10.1007/s11069-024-07061-7.
[15] E. M. Bonilauri *et al.*, “Tsunami evacuation times and routes to safe zones: a GIS-based approach to tsunami evacuation planning on the island of Stromboli, Italy,” *Journal of Applied Volcanology*, vol. 10, no. 1, Dec. 2021, doi: 10.1186/s13617-021-00104-9.
[16] BMKG Stasiun Geofisika Gowa, “Laporan Survey Peta Bahaya Tsunami Wilayah Kota Majene, Kabupaten Majene, Provinsi Sulawesi Barat,” 2021.
[17] H. S. Yunus, *Metode Penelitian Wilayah Kontemporer*. Yogyakarta: Pustaka Pelajar, 2010.
[18] L. S. Musianto, “Perbedaan Pendekatan Kuantitatif dengan Pendekatan Kualitatif dalam Metode Penelitian,” *Jurnal Manajemen dan Kewirausahaan*, vol. 4, no. 2, pp. 123–136, 2010, [Online]. Available: http://puslit.petra.ac.id/journals/management/
[19] S. Arikunto, *Prosedur Penelitian: Suatu Pendekatan Praktek.* Jakarta: PT. Rineka Cipta, 2006.
[20] Sugiyono, *Metode Penelitian Pendidikan Pendekatan Kuantitatif, Kualitatif dan R&D*. Bandung: Alfabeta, 2013.
[21] P. C. Nugroho *et al.*, “Modul Teknis Penyusunan Kajian Risiko Bencana Tsunami,” Direktorat Pengurangan Risiko Bencana, Badan Nasional Penanggulangan Bencana, Jakarta, 2018. Accessed: Jun. 14, 2025. [Online]. Available: https://sites.google.com/view/krb-bnpb/proses-krb
[22] F. Usman and I. C. Sari, “Determining the Location of Shelters for Tsunami Evacuation Based on Service Area Analysis in Paseban Village, Kencong Sub-District, Jember District,” *IOP Conf Ser Earth Environ Sci*, vol. 328, no. 1, 2019, doi: 10.1088/1755-1315/328/1/012039.
[23] J. Post *et al.*, “Assessment of human immediate response capability related to tsunami threats in Indonesia at a sub-national scale,” *Natural Hazards and Earth System Science*, vol. 9, no. 4, pp. 1075–1086, 2009, doi: 10.5194/nhess-9-1075-2009.

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[24] T. Charnkol and Y. Tanaboriboon, "Tsunami Evacuation Behavior Analysis," *IATSS Research*, vol. 30, no. 2, pp. 83–96, 2006, doi: 10.1016/s0386-1112(14)60173-4.
[25] H. P. Rahayu and J. Anita, "Pedoman Teknik Perencanaan Tempat Evakuasi Sementara (TES) Tsunami," Jakarta, 2013.
[26] R. I. Liperda, I. Sukarno, N. Utami, and S. Yenda, "Location Design of GIS-Based Temporary Evacuation Sites (TES) by Considering the COVID-19 Pandemic Situation: A Case Study in Padang City)," 2023. [Online]. Available: http://ojs.stiami.ac.id
[27] E. M. P. Koemesan, J. I. Kindangen, and A. E. Tungka, "Perencanaan Jalur Evakuasi Bencana Tsunami di Kawasan Strategis Pariwisata Nasional Likupang Kabupaten Minahasa Utara dengan Metode Network Analyst," *MEDIA MATRASAIN*, vol. 21, no. 1, pp. 13–22, Jun. 2024, doi: 10.35793/matrasain.v21i1.56039.
[28] A. A. Yusri Tanra, R. Mulyadi, and M. M. Sir, "Analisis Perencanaan Tempat Evakuasi Sementara dan Jalur Evakuasi Tsunami di Area kurang Sistem Informasi Geografi studi kasus: Kabupaten Mamuju," *Jurnal Linears*, vol. 6, no. 2, pp. 87–95, 2023, doi: 10.26618/j-linears.v6i2.11572.
[29] F. A. Waluyo and M. K. Wardhani, "Perencanaan Wilayah Pesisir Berbasis Mitigasi Bencana Tsunami Studi Kasus Di Kabupaten Bantul Daerah Istimewa Yogyakarta," *Juvenil:Jurnal Ilmiah Kelautan dan Perikanan*, vol. 2, no. 3, pp. 226–235, 2021, doi: 10.21107/juvenil.v2i3.11659.