Spatial Analysis of Evacuation Sites for Tsunami Mitigation in Banyuwangi City

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Received: 28 September 2025 | Revised: 28 October 2025 | Accepted: 3 November 2025

 DOI: https://doi.org/10.48084/etasr.15201

ABSTRACT

Banyuwangi, a coastal region south of East Java, faces a potential tsunami risk due to tectonic activity in the Java subduction zone. The vulnerability of densely populated coastal regions necessitates the development of a comprehensive disaster mitigation strategy that includes identifying and providing sufficient evacuation sites. This study aims to assess the availability, spatial distribution, and capacity of tsunami evacuation sites in Banyuwangi City. The methods used include Geographic Information System (GIS)-based spatial analysis, tsunami hazard map analysis, and field observations at potential shelter sites with weighting analysis. The results show that several temporary evacuation sites or existing shelters are available. However, their distribution is uneven, and their capacity remains limited compared to the number of affected residents. This study recommends adding shelters in high-risk areas, enhancing evacuation routes, and integrating spatial planning with tsunami risk maps. These findings are expected to act as a reference point for local governments and communities in enhancing their tsunami preparedness.

Keywords-tsunami; evacuation; disaster mitigation; shelter; GIS; PTVA-3

I. INTRODUCTION

Indonesia is situated at the junction of three major tectonic plates, rendering it highly susceptible to earthquakes and tsunamis. The southern coast of Banyuwangi Regency in East Java, facing the Indian Ocean, is a region with a high tsunami risk [1, 2]. According to studies by the Meteorology, Climatology, and Geophysics Agency (BMKG) and the Regional Disaster Management Agency (BPBD), several coastal districts in Banyuwangi, such as Pesanggaran, Tegaldlimo, and Muncar, are potentially affected by tsunamis with wave heights exceeding ten meters [3-5]. Structural mitigation efforts, such as building tsunami shelters, are crucial for reducing the risk of loss of life. However, there are still limitations in the number, capacity, and distribution of evacuation sites in vulnerable areas [6]. Additionally, shelter construction remains quite expensive.

This study aimed to identify the locations of existing buildings, assess their capacity and accessibility, and offer recommendations to enhance the strategy for establishing tsunami evacuation sites in Banyuwangi. ArcGIS 10.8 with the Network Analyst extension was employed to determine shelter coverage zones. Analysis parameters using Network Analyst included shelter distribution, travel time converted into distance, and accessibility [7, 8]. Additionally, the study evaluated existing buildings in Banyuwangi City as potential temporary evacuation sites, using several parameters similar to those used in the Papathoma Tsunami Vulnerability Assessment version 3 (PTVA-3) [9]. Other references were based on previous research, especially regarding shelters used temporarily during tsunamis [10-12]. The novelty of this research lies in its focus on selecting vertical shelters as evacuation sites, a relatively uncommon practice among researchers, since shelters are usually limited to fields or large-capacity buildings like indoor sports halls.

II. LITERATURE REVIEW

Previous studies have highlighted that the presence of tsunami shelters is a decisive factor in determining the survival chances of coastal populations. The efficiency of evacuation depends mainly on the availability of strategically positioned evacuation facilities that are easily accessible within a short time window [7, 13]. For this reason, site selection models for tsunami shelters often incorporate variables such as population density, topography, accessibility, and distance from the coastline [14, 15]. Beyond technical considerations, shelters also symbolize community preparedness and resilience against disaster threats [16]. Studies show that integrating evacuation shelters with public facilities such as schools, mosques, and sports halls increases both feasibility and social acceptance [17, 18]. Such approaches are particularly vital in land-scarce coastal cities, where constructing new shelters is financially and spatially challenging [19].

The importance of strengthening multi-purpose public buildings is highlighted in both global and Indonesian contexts. Research following the 2004 Indian Ocean tsunami showed that insufficient shelter availability was a significant factor contributing to mass casualties in Aceh and other affected areas [20, 21]. In Indonesia, subsequent disaster management strategies have concentrated on using vertical evacuation buildings and improving evacuation routes through GIS-based spatial analysis. GIS-based network analysis has demonstrated effectiveness in evaluating coverage areas, accessibility, and service capacity of shelters, helping planners identify spatial gaps in disaster preparedness [8, 22]. In recent years, researchers have also studied the impact of socio-cultural factors on evacuation planning. Community involvement, awareness, and trust in evacuation infrastructure greatly affect compliance with evacuation orders [13, 22]. Furthermore, incorporating disaster education into schools has been shown to improve long-term community resilience [17, 23]. Overall, the research highlights that tsunami evacuation planning needs a mix of structural measures, such as adequate shelters and reinforced public buildings, and non-structural measures, such as education, awareness campaigns, and integrating disaster risk reduction into land-use planning. This research enhances existing studies by using a GIS-based weighted analysis and network service approach to assess tsunami evacuation shelters in Banyuwangi City, providing insights tailored to disaster mitigation in Indonesia's coastal areas.

Several studies on tsunami-adaptive buildings have used parameters from the PTVA-3 framework. In these applications, five building-related parameters are considered: building material, number of floors, function, location, and orientation [24, 25]. In the present study, building orientation and function are not included; instead, these parameters are replaced by accessibility and building dimensions, which are more directly related to a building's capacity to serve as an evacuation shelter. The Indonesian experience with the 2004 Aceh tsunami demonstrated that limited shelters and capacity led to many fatalities [20, 21]. Therefore, the suggestion to use public buildings as alternative shelters, as proposed in this study, aligns with global research emphasizing adaptive and integrated strategies for tsunami risk reduction.

III. RESEARCH METHOD

This study uses a descriptive-qualitative approach complemented by spatial analysis. The data includes a tsunami risk map created from topographic analysis, the current road network, and locations of tsunami shelters. Buildings or locations within safe zones should determine the distribution of evacuation shelters. Although there is an option to select buildings in moderate-risk areas, these buildings must meet several criteria, such as sufficient structural strength, being multi-story, and providing easy access [26]. This research enhances the use of ArcGIS with the network analysis extension. Network analysis considers factors such as the current road network, shelter locations, and other parameters that help define the coverage area, similar to evacuation zones, based on travel time [27-29]. In this study, shelters will be selected based on the availability of existing buildings in areas relatively safe from tsunami waves. Spatial analysis with GIS can be conducted by combining tsunami hazard maps with settlement data, road networks, and shelter locations to gain an overview of evacuation site accessibility. Buffer analysis is used to determine the radius of shelter coverage, but for more accurate results, network analysis is employed. This feature will generate service area sizes based on travel time, distance, and buffers centered on the road. Meanwhile, field observations were carried out to verify the locations of existing shelters and identify public buildings that could serve as temporary evacuation sites [14, 15, 19]. Figure 1 below displays the tsunami hazard map and the current road network in Banyuwangi. The contour lines in Figure 1 below show Digital Elevation Model (DEM) data from SRTM and information from the Regional Disaster Management Agency of Banyuwangi City related to tsunami hazard maps. All data was created using ArcGIS 10.8.

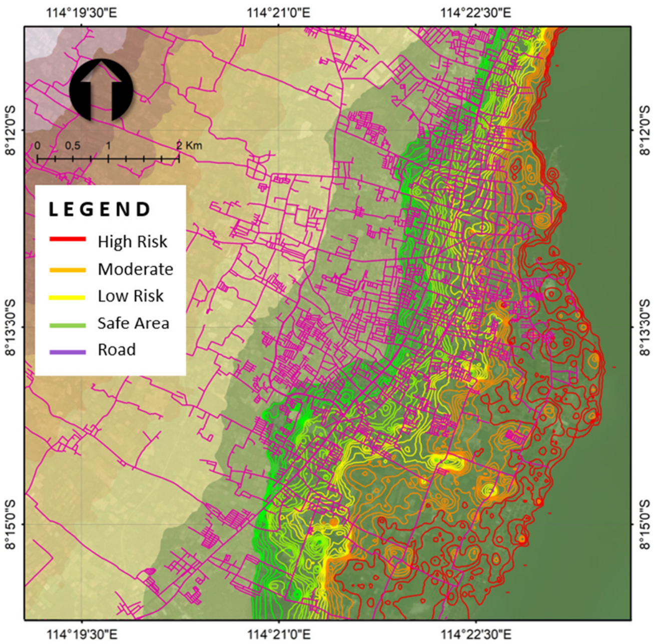

Fig. 1. Tsunami hazard map and existing road network.

This study evaluated various building types, including schools, mosques (places of Muslim worship), government offices, hotels, hospitals, and sports halls. Figure 2 shows the distribution of shelter-use buildings. Generally, buildings are selected based on the availability of public structures, especially in yellow and green zones. Additionally, a capacity analysis was performed by comparing the shelter's capacity to the number of potentially affected residents at the study site. The criteria for determining suitability for shelter include size or capacity, ease of access, and location in a safe area away from tsunami waves or within a multi-story building with robust construction and enough capacity for vertical shelters. Table I outlines the assessment tool used to evaluate a building's suitability as a shelter. The parameters used are similar to those of the PTVA-3, but in this study, building orientation parameters were not included [24, 25]. Instead, they were replaced with accessibility, which is closely related to the existing roads around the shelter leading to settlements [14]. To assess buildings, a Likert scale is used, with 1 indicating the worst score and 5 the best [30-32].

The shelter coverage area in this study is based on evacuees' travel time from residential areas to the shelter. If the average walking speed for evacuation is 1 m/s, then a travel time of 5 minutes corresponds to 300 meters, 10 minutes to 600 meters, and 15 minutes to 900 meters [33]. Therefore, this study includes two analysis stages: (1) a weighted assessment of potential buildings that can serve as shelters, and (2) an analysis of the coverage area using ArcGIS with the network analyst extension [34]. These two stages aim to provide an overview of how many evacuees can be accommodated and the coverage area of each shelter, based on the travel time from residential areas to available shelters.

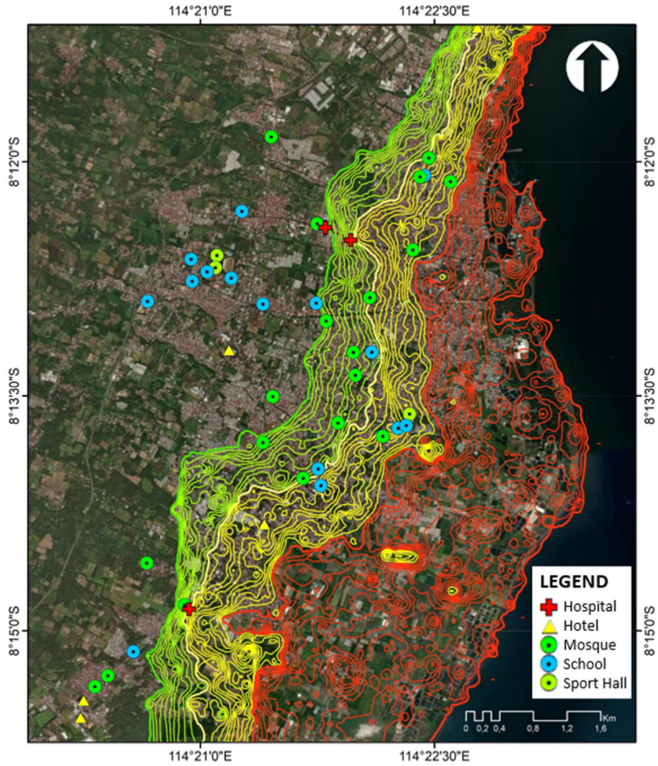

Fig. 2. Tsunami hazard map and existing road network.

TABLE I. PARAMETERS AND BUILDING SCORE

Code	Parameters	1	2	3	4	5
A	Construction	Wood		Brick		Concert
B	Dimension	< 1,000	1,000	2,000	2,500	> 2,500
C	Location	High risk		Moderate		Low risk
D	Accessibility	Local road		District road		Province road
E	Number of floors	1st floor		2nd floor		> 3rd floor

IV. RESULTS AND DISCUSSION

The research findings indicate that the distribution of current tsunami shelters remains limited and uneven, especially in densely populated urban coastal areas such as Banyuwangi. Regarding capacity, the available shelters can accommodate only approximately thirty to fifty percent of the population potentially affected within two kilometers of the coastline. This condition shows a significant gap between the demand for and the supply of facilities. Furthermore, access to several shelters still faces obstacles, such as evacuation routes lacking signs, lighting, or proper road pavement. Field observations also identified the potential to use public buildings, such as elementary schools, multi-story mosques, sports halls, hotels, and government buildings, as temporary evacuation sites if technical modifications are made, including structural reinforcement and the provision of adequate evacuation routes. Of the 45 buildings in Banyuwangi that can serve as shelters, only 33 meet the criteria for good construction, easy access, large capacity, and a relatively safe location away from tsunami threats. Therefore, 12 shelters located in the tsunami-affected area were removed from the analysis using ArcGIS Network Analyst in both scenario #1 and scenario #2.

Table II displays the weighting results for 45 potential buildings that could serve as shelters. All buildings located in the high-risk zone were automatically excluded from subsequent analysis in ArcGIS. In scenario #1, the coverage area analysis included only 21 shelters (high priority), while buildings in the moderate-risk zone were included in scenario #2 with 33 shelters, and buildings in the high-risk zone were included in scenario #3 with 45 shelters, which means all shelters were used in the spatial analyses of the coverage area. As shown in the table below, a building's location is crucial to evaluating its suitability as a shelter. Some buildings situated in high-risk zones receive a low-priority rating. Table II presents the results of the weighting analysis for 45 potential buildings that could serve as tsunami evacuation shelters. The assessment was carried out using five parameters: structural construction (A), building dimensions (B), location relative to tsunami hazard zones (C), accessibility (D), and number of floors (E). Each parameter was scored on a scale from 1 to 5, and the total scores determined the priority ranking of each building. The results indicate that 23 buildings are classified as high priority (***), indicating they have strong construction, appropriate dimensions, multiple floors, safe or moderate locations, and high accessibility. These buildings, such as hospitals, multi-story mosques, and sports centers, are among the most reliable evacuation sites because of their structural strength and ability to hold large numbers of evacuees.

TABLE II. SCORING RESULT OF POTENTIAL BUILDINGS

No	Building	Parameters					Score	Result
		A	B	C	D	E		
1	Luminor Hotel	5	3	1	3	3	15	*
2	Illira Hotel	5	5	3	5	3	21	**
3	Al-Irsyad Elementary School	5	3	1	3	1	13	*
4	Al-Hadi Great Mosque	5	5	1	5	3	21	**
5	At-Taqwa Mosque	5	4	1	3	3	16	*
6	Al-Fauz Mosque	5	3	1	3	3	15	*
7	Baitul Ma'wa Great Mosque	5	5	5	5	3	23	***
8	Salman Al Farisi Mosque	5	5	3	5	3	21	**
9	Baiturrahman Great Mosque	5	5	1	3	3	17	*
10	Baitul Hasanah Mosque	5	5	3	5	5	23	***
11	Baiturrohim Mosque	5	5	3	5	3	21	***
12	SMK PGRI 2 Senior High School	5	5	5	5	3	23	***
13	Yasmin Hospital Banyuwangi	5	5	3	5	3	21	**
14	Blambangan Regional Public Hospital	5	5	3	5	5	23	***
15	Tawangalun Indoor Sport Hall	5	5	3	5	5	23	***
16	Indoor Tennis court Banyuwangi	5	5	3	5	3	21	***
17	Atheletic Stadium	5	5	5	5	3	23	***
18	SMK Gajah Mada	5	5	3	5	3	21	**
19	SMPN 1 Junior High School	5	5	1	3	3	17	*
20	Tunas Zaintun Campus	5	5	3	5	5	23	***
21	Brindo International School	5	5	3	5	3	21	***
22	SMK PGRI 1 Senior High School	5	5	5	5	3	23	***
23	SMAN 1 Senior High School	5	5	3	5	3	21	**
24	SMA 1 Glagah Senior High School	5	5	1	3	3	17	*
25	SMA 1 Giri Senior High School	5	5	3	5	5	23	***
26	SMKN 1 Glagah Senior High School	5	5	5	5	3	23	***
27	Aston Hotel Banyuwangi	5	5	3	5	3	21	**
28	Santika Hotel Banyuwangi	5	5	1	5	5	21	**
29	Nurullah Mosque	5	5	3	5	5	23	***
30	Al-Furqon Mosque	5	5	5	5	3	23	***
31	Al-Mukarromah Mosque	5	3	3	3	5	19	**
32	Baitul Muttaqien Mosque	5	1	1	3	1	11	*
33	KH Admad Dahlan Great Mosque	5	5	3	5	5	23	***
34	SMA Muhammadiyah Senior High School	5	1	1	3	1	11	*
35	SMK Sritanjung Senior High School	5	3	3	5	3	19	**
36	Al-Huda Mosque	5	3	1	3	3	20	*
37	Baiturrahman Dadapan Mosque	5	5	5	3	5	23	***
38	Mendut Sport Center	5	5	3	5	5	23	***
39	Tridharma Sport Center	5	5	3	5	5	23	***
40	MAN 1 Banyuwangi Senior High School	5	1	1	3	1	11	*
41	SMKN 1 Banyuwangi Senior High School	5	5	3	3	3	19	**
42	SMA 17 Agustus 1945 Senior High School	5	3	1	3	3	15	*
43	Fatimah Islamic Hospital	5	5	5	3	5	23	***
44	Kakoon Hotel	5	5	5	3	5	23	***
45	eL Hotel Banyuwangi	5	5	5	3	5	23	***

Note: A. Construction, B. Dimension, C. Location, D. Accessibility, E. Number of floors, * Low Priority, ** Medium Priority, *** High Priority

Meanwhile, 12 buildings are classified as medium-priority shelters (**), which generally meet the requirements but have some limitations, such as smaller size or location within moderate-risk zones. These facilities may still function as evacuation shelters, but would need reinforcement or infrastructure upgrades to ensure safety and sufficient capacity. Finally, 10 buildings are classified as low-priority shelters (*), usually situated in high-risk areas, small in size, or with only one story. These sites are not suitable for vertical evacuation and should only be prioritized if significant structural changes and risk mitigation measures are implemented. This study discusses three scenarios related to the distribution of shelters, based on the results of the weighting analysis in Table II above. Coverage zones are identified by travel time from the shelter point to nearby residential areas using ArcGIS and the network analyst feature. Overall, Table II shows that while Banyuwangi has several potential buildings for tsunami evacuation, only half meet the high-priority standards for effective disaster mitigation. This reinforces the need for the selective use of public buildings and further investment in shelter construction or retrofitting in areas that currently lack adequate facilities.

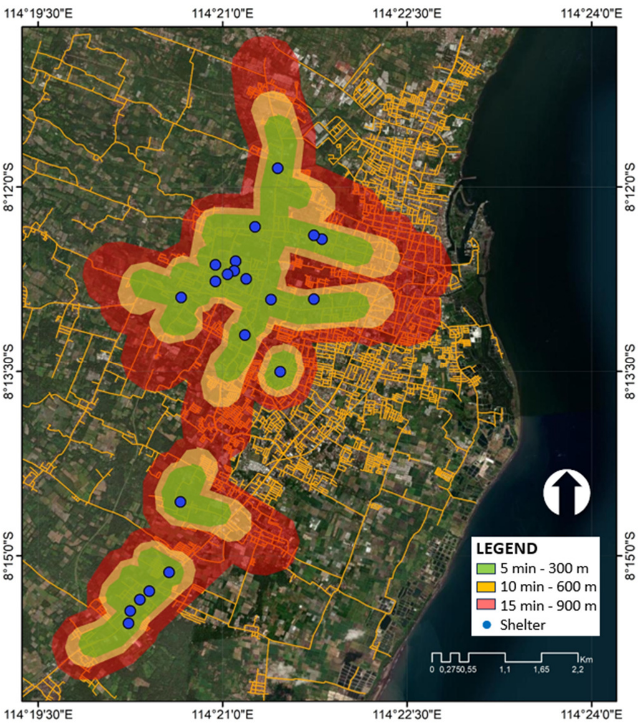

Fig. 3. Coverage area of 21 shelters in scenario #1.

Figures 3 and 4 show the difference in coverage areas between 21 and 33 shelters. Although the distribution of shelters appears fairly even when considering each shelter's coverage, the number of shelters remains insufficient for the affected urban areas. This study suggests adding buildings that can function as evacuation centers or shelters, while also considering important factors such as structural strength, capacity, location, and ease of access. Figure 5 shows the coverage area of 45 shelters. Based on network analysis in ArcGIS, the shelter service coverage doesn't even extend to the coastal area. Therefore, more shelters are needed to make sure evacuation buildings can serve all coastal residential areas.

Table III compares the shelter coverage area to the existing coastal area. With 21 shelters located in the safe zone, the coverage at 300 meters is only 11.49%. At a distance of 900 meters, the coverage extends to just 2,176 hectares, or approximately 37.63% of the coastal area. The total coverage for the 33-shelter scenario is also relatively limited, with a 900-meter distance yielding only 48.58% coverage, and 45 shelters covering about 50.9%.

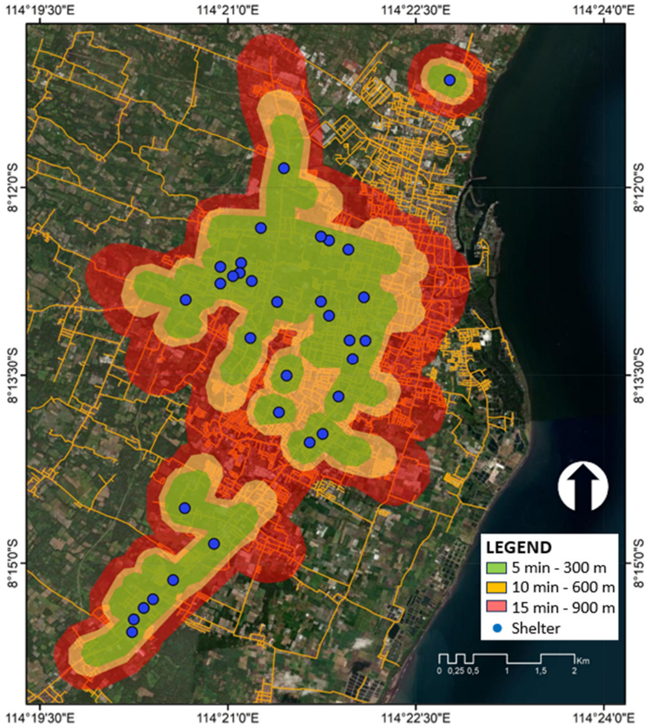

Fig. 4. Coverage area of 33 shelters in scenario #2.

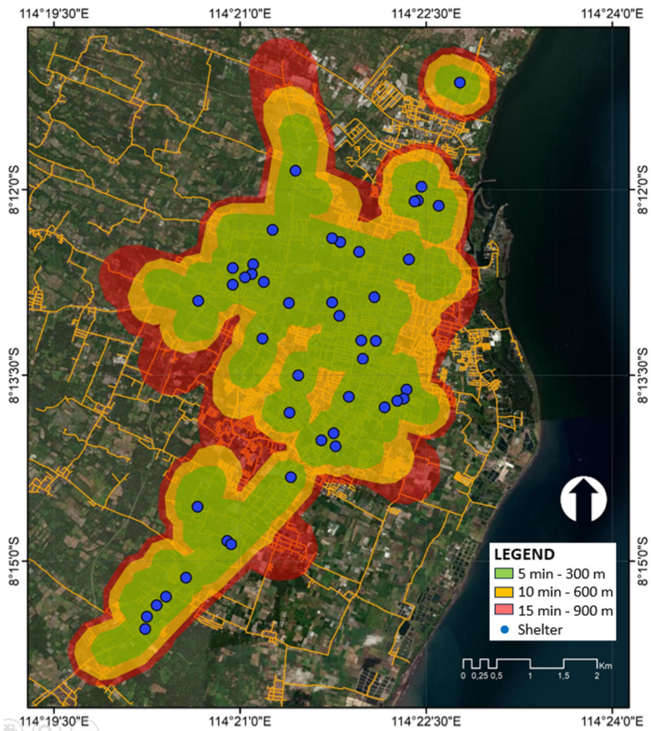

Fig. 5. Coverage area of 45 shelters in scenario #3.

TABLE III. SCORING RESULT OF POTENTIAL BUILDINGS

No	Scenario	300 m	600 m	900 m
1	21 shelters	664.34	1,099.41	2,176.19
	Coverage area	11.49%	19.01%	37.63%
2	33 shelters	1,035.23	1,614.03	2,808.84
	Coverage area	17.90%	27.91%	48.58%
3	45 shelters	1,506.41	2,254.47	2,942.50
	Coverage area	25.71%	39.01%	50.90%

Therefore, an in-depth study is needed to expand shelter distribution to locations outside the coverage area with available shelters. The distribution of proposed shelter buildings may include those in high-risk areas, provided they are constructed under supervised conditions. The number of shelters remains inadequate, with an average capacity of only 1,500–2,500 people. Consequently, 21 shelters can accommodate about 40,000 people, 33 can hold 60,000, and 45 can serve 90,000. However, if using the shelter standard as temporary housing at a need of 4 m² per person, 21 shelters can accommodate 10,000 people, 33 shelters can accommodate 15,000 people, and 45 shelters can accommodate 21,500 people.

Figure 6 shows a vulnerable area within the settlement with 45 shelters. The map indicates that shelters are located only in the yellow and green zones, with none in the red zone. According to data from the Banyuwangi City Central Statistics Agency, the city's population is approximately 120,000, and the red zone in Figure 6 covers only about 17.8% of the City's area. Meanwhile, the built-up area in the red zone accounts for approximately 15.88% of the total built-up area in Banyuwangi. If the build area is converted into the number of residents in the red zone, the number is around 19,000 people, which means 45 shelters are expected to accommodate all refugees from the red zone in a safer zone.

Discussion of these results emphasizes the importance of integrating disaster mitigation strategies into regional spatial planning, especially in areas at high risk of tsunami impacts. Based on current findings, without adequate structural and non-structural mitigation measures, the coastal communities of Banyuwangi remain vulnerable to tsunamis. This research is necessary because Indonesia, as a developing country, lacks the financial resources to build mega-structures to block tsunami waves or sturdy shelters like those in Japan. By assessing the suitability of existing buildings for use as shelters, communities have a reasonable chance of surviving by evacuating to nearby public buildings, such as schools, mosques, and other structures.

Although this study offers valuable insights into the spatial distribution and capacity of tsunami evacuation shelters in Banyuwangi City, several research gaps remain. First, the current analysis primarily focuses on structural and spatial parameters, such as capacity, accessibility, and location, while socio-behavioral factors that affect evacuation compliance, such as community trust, awareness, and decision-making under stress, have not been examined in depth. Second, the model does not yet incorporate dynamic simulation of evacuation scenarios that consider real-time congestion, mobility differences among vulnerable groups, and uncertainties in tsunami arrival times. Finally, economic feasibility and policy implementation, which are essential for the long-term sustainability of evacuation planning, remain insufficiently explored.

Future research should focus on integrating agent-based evacuation simulations with GIS-based spatial analysis to capture realistic evacuation dynamics better. Additionally, interdisciplinary approaches that combine engineering, social science, and policy perspectives are necessary to develop comprehensive mitigation strategies. Studies could also include comparative analyses across various coastal cities in Indonesia and beyond to identify context-specific and transferable best practices for tsunami evacuation planning.

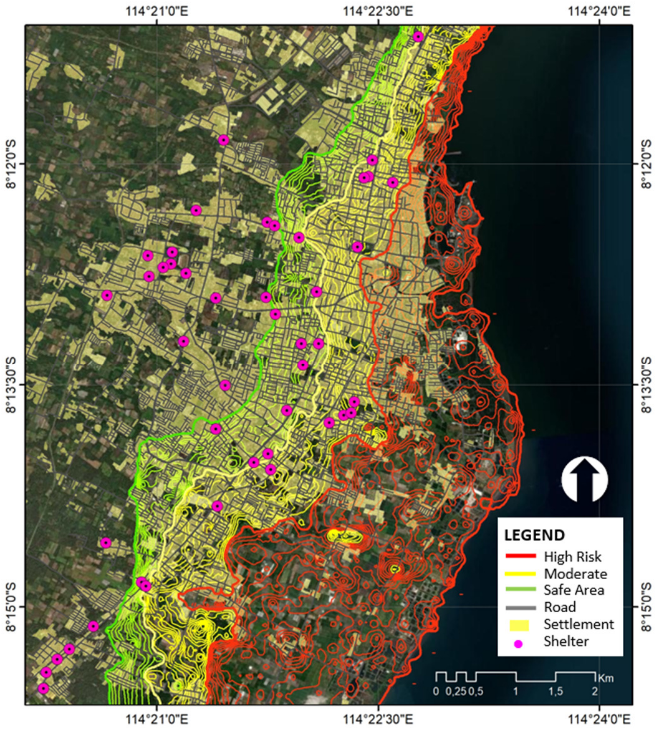

Fig. 6. Vulnerable zone of 45 shelters in the settlement area.

V. CONCLUSION AND RECOMMENDATION

The availability of tsunami evacuation sites in Banyuwangi City remains inadequate, both in terms of capacity and spatial distribution. Existing shelters cannot accommodate the entire at-risk population, and access to evacuation sites faces various obstacles. Recommendations include increasing the number of shelters in densely populated areas on the south coast, using strategic public buildings as alternative temporary evacuation sites, strengthening evacuation route infrastructure by providing signs, lighting, and road access, and integrating tsunami mitigation policies into the Banyuwangi Regency spatial plan. These efforts are expected to increase the community's capacity to respond to the threat of a tsunami and minimize the risk of loss of life.

ACKNOWLEDGMENT

The author gratefully acknowledges the support from Universitas Brawijaya. This research was conducted without external funding. The author also appreciates the editorial insights from academic reviewers and fellow scholars that contributed to the clarity and rigor of the manuscript.

REFERENCES

[1] L. Y. Irawan *et al.*, "Multi-hazard detection in the southern part of Banyuwangi Regency using a geomorphological approach," *Jàmbá: Journal of Disaster Risk Studies*, vol. 16, no. 1, July 2024, Art. no. 11, https://doi.org/10.4102/jamba.v16i1.1586.

[2] T. Trisnawati, S. Surjono, and L. Hakiem, "Model of Tsunami Mitigation and Evacuation Routes in Pancer Banyuwangi," *Jurnal Penelitian Pendidikan IPA*, vol. 10, no. SpecialIssue, pp. 604–613, Aug. 2024, https://doi.org/10.29303/jppipa.v10iSpecialIssue.8358.

[3] R. E. Abercrombie, M. Antolik, K. Felzer, and G. Ekström, "The 1994 Java tsunami earthquake: Slip over a subducting seamount," *Journal of Geophysical Research: Solid Earth*, vol. 106, no. B4, pp. 6595–6607, 2001, https://doi.org/10.1029/2000JB900403.

[4] A. Maramai and S. Tinti, "The 3 June 1994 Java Tsunami: A Post-Event Survey of the Coastal Effects," *Natural Hazards*, vol. 15, no. 1, pp. 31–49, Jan. 1997, https://doi.org/10.1023/A:1007957224367.

[5] Y. Xia *et al.*, "Marine forearc structure of eastern Java and its role in the 1994 Java tsunami earthquake," *Solid Earth*, vol. 12, no. 11, pp. 2467–2477, Nov. 2021, https://doi.org/10.5194/se-12-2467-2021.

[6] H. Srinivas and Y. Nakagawa, "Environmental implications for disaster preparedness: Lessons Learnt from the Indian Ocean Tsunami," *Journal of Environmental Management*, vol. 89, no. 1, pp. 4–13, Oct. 2008, https://doi.org/10.1016/j.jenvman.2007.01.054.

[7] J. León, A. Ogueda, L. Hurtado, A. Gubler, and N. Zamora, "An integrated framework for analysing horizontal and vertical tsunami evacuation. A case study of Iquique, Chile," *International Journal of Disaster Risk Reduction*, vol. 116, Jan. 2025, Art. no. 105137, https://doi.org/10.1016/j.ijdrr.2024.105137.

[8] G. Nakano, K. Yamori, T. Miyashita, L. Urra, E. Mas, and S. Koshimura, "Combination of school evacuation drill with tsunami inundation simulation: Consensus-making between disaster experts and citizens on an evacuation strategy," *International Journal of Disaster Risk Reduction*, vol. 51, Dec. 2020, Art. no. 101803, https://doi.org/10.1016/j.ijdrr.2020.101803.

[9] F. Dall'Osso, D. Dominey-Howes, C. Tarbotton, S. Summerhayes, and G. Withycombe, "Revision and improvement of the PTVA-3 model for assessing tsunami building vulnerability using 'international expert judgment': introducing the PTVA-4 model," *Natural Hazards*, vol. 83, no. 2, pp. 1229–1256, Sept. 2016, https://doi.org/10.1007/s11069-016-2387-9.

[10] S. Bera *et al.*, "Assessment of shelter location-allocation for multi-hazard emergency evacuation," *International Journal of Disaster Risk Reduction*, vol. 84, Jan. 2023, Art. no. 103435, https://doi.org/10.1016/j.ijdrr.2022.103435.

[11] M. A. Ferreira, C. S. Oliveira, and R. Francisco, "Tsunami risk mitigation: the role of evacuation routes, preparedness and urban planning," *Natural Hazards*, vol. 121, no. 6, pp. 6719–6751, Apr. 2025, https://doi.org/10.1007/s11069-024-07061-7.

[12] 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 Conference Series: Earth and Environmental Science*, vol. 328, no. 1, July 2019, Art. no. 012039, https://doi.org/10.1088/1755-1315/328/1/012039.

[13] Syamsidik, Tursina, A. Suppasri, M. Al'ala, M. Luthfi, and L. K. Comfort, "Assessing the tsunami mitigation effectiveness of the planned Banda Aceh Outer Ring Road (BORR), Indonesia," *Natural Hazards and Earth System Sciences*, vol. 19, no. 1, pp. 299–312, Jan. 2019, https://doi.org/10.5194/nhess-19-299-2019.

[14] B. Kar and M. E. Hodgson, "A GIS-Based Model to Determine Site Suitability of Emergency Evacuation Shelters," *Transactions in GIS*, vol. 12, no. 2, pp. 227–248, 2008, https://doi.org/10.1111/j.1467-9671.2008.01097.x.

[15] Y. Ma, W. Xu, L. Qin, and X. Zhao, "Site Selection Models in Natural Disaster Shelters: A Review," *Sustainability*, vol. 11, no. 2, Jan. 2019, Art. no. 399, https://doi.org/10.3390/su11020399.

[16] V. Bayram and H. Yaman, "A joint demand and supply management approach to large scale urban evacuation planning: Evacuate or shelter-in-place, staging and dynamic resource allocation," *European Journal of Operational Research*, vol. 313, no. 1, pp. 171–191, Feb. 2024, https://doi.org/10.1016/j.ejor.2023.07.033.

[17] K. Shiwaku, A. Sakurai, and R. Shaw, Eds., *Disaster Resilience of Education Systems*. Tokyo: Springer Japan, 2016.

[18] F. Usman, Eddi Basuki Kurniawan, M. Fathoni, and M. Rozikin, "Tsunami Disaster Preparedness in Tambakrejo Village, Sumbermanjing Wetan Distric, Malang, Indonesia," *Evergreen*, vol. 11, no. 2, pp. 1182–1189, June 2024, https://doi.org/10.5109/7183421.

[19] Z. Chen, X. Chen, Q. Li, and J. Chen, "The temporal hierarchy of shelters: a hierarchical location model for earthquake-shelter planning," *International Journal of Geographical Information Science*, vol. 27, no. 8, pp. 1612–1630, Aug. 2013, https://doi.org/10.1080/13658816.2013.763944.

[20] A. Suppasri *et al.*, "A Decade After the 2004 Indian Ocean Tsunami: The Progress in Disaster Preparedness and Future Challenges in Indonesia, Sri Lanka, Thailand and the Maldives," *Pure and Applied Geophysics*, vol. 172, no. 12, pp. 3313–3341, Dec. 2015, https://doi.org/10.1007/s00024-015-1134-6.

[21] P. González-Riancho, B. Aliaga, S. Hettiarachchi, M. González, and R. Medina, "A contribution to the selection of tsunami human vulnerability indicators: conclusions from tsunami impacts in Sri Lanka and Thailand (2004), Samoa (2009), Chile (2010) and Japan (2011)," *Natural Hazards and Earth System Sciences*, vol. 15, no. 7, pp. 1493–1514, July 2015, https://doi.org/10.5194/nhess-15-1493-2015.

[22] T. Fraser *et al.*, "Trust but verify: Validating new measures for mapping social infrastructure in cities," *Urban Climate*, vol. 46, Dec. 2022, Art. no. 101287, https://doi.org/10.1016/j.uclim.2022.101287.

[23] A. Sakurai and T. Sato, "Promoting Education for Disaster Resilience and the Sendai Framework for Disaster Risk Reduction," *Journal of Disaster Research*, vol. 11, no. 3, pp. 402–412, June 2016, https://doi.org/10.20965/jdr.2016.p0402.

[24] M. S. Kappes, M. Papathoma-Köhle, and M. Keiler, "Assessing physical vulnerability for multi-hazards using an indicator-based methodology," *Applied Geography*, vol. 32, no. 2, pp. 577–590, Mar. 2012, https://doi.org/10.1016/j.apgeog.2011.07.002.

[25] M. Papathoma, D. Dominey-Howes, Y. Zong, and D. Smith, "Assessing tsunami vulnerability, an example from Herakleio, Crete," *Natural Hazards and Earth System Sciences*, vol. 3, no. 5, pp. 377–389, Oct. 2003, https://doi.org/10.5194/nhess-3-377-2003.

[26] F. Usman, K. Murakami, F. Shoimah, and M. A. Nabila, "Evacuation route during a disaster with health protocol in the new normal era," *IOP Conference Series: Earth and Environmental Science*, vol. 916, no. 1, Aug. 2021, Art. no. 012028, https://doi.org/10.1088/1755-1315/916/1/012028.

[27] A. Masuya, A. Dewan, and R. J. Corner, "Population evacuation: evaluating spatial distribution of flood shelters and vulnerable residential units in Dhaka with geographic information systems," *Natural Hazards*, vol. 78, no. 3, pp. 1859–1882, Sept. 2015, https://doi.org/10.1007/s11069-015-1802-y.

[28] M. Kako, M. Steenkamp, B. Ryan, P. Arbon, and Y. Takada, "Best practice for evacuation centres accommodating vulnerable populations: A literature review," *International Journal of Disaster Risk Reduction*, vol. 46, June 2020, Art. no. 101497, https://doi.org/10.1016/j.ijdrr.2020.101497.

[29] F. Usman, K. Murakami, A. D. Wicaksono, and E. Setiawan, "Application of Agent-Based Model Simulation for Tsunami Evacuation in Pacitan, Indonesia," *MATEC Web of Conferences*, vol. 97, 2017, Art. no. 01064, https://doi.org/10.1051/matecconf/20179701064.

[30] H. Boone and D. Boone, "Analyzing Likert Data," *The Journal of Extension*, vol. 50, no. 2, Apr. 2012, Art. no. 48, https://doi.org/10.34068/joe.50.02.48.

[31] S. Jamieson, "Likert scales: how to (ab)use them," *Medical Education*, vol. 38, no. 12, pp. 1217–1218, Dec. 2004, https://doi.org/10.1111/j.1365-2929.2004.02012.x.

[32] R. Likert, " A technique for the measurement of attitudes," *Archives of Psychology*, vol. 22, no. 140, pp. 55–55, 1932.

[33] F. Usman *et al.*, "Assessing coastal population capacity in Tsunami-prone areas: A grid-based approach," *Jàmbá: Journal of Disaster Risk Studies*, vol. 16, no. 1, July 2024, Art. no. 10, https://doi.org/10.4102/jamba.v16i1.1685.

[34] T. Takabatake, N. Hasegawa, K. Yamaguchi, and M. Esteban, "Comparative Analysis of Tsunami Casualty Estimation Approaches: Agent-Based Modeling versus Simplified Approach in Japanese Coastal Cities," *International Journal of Disaster Risk Science*, vol. 15, no. 5, pp. 719–737, Oct. 2024, https://doi.org/10.1007/s13753-024-00586-2.