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Article

Site Suitability of Evacuation Centers in Zamboanga City, Philippines using GIS: Assessing Safety and Accessibility in Hazard-Prone Areas

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ABSTRACT

Climate change is a present-day problem, making areas previously unaffected by natural hazards now vulnerable to disasters. Building resilient cities involves ensuring effective disaster response, which includes providing safe and accessible evacuation centers (ECs). This study evaluates the suitability of ECs in Zamboanga City, Philippines, by assessing their safety and accessibility. Using QGIS, the exposure of ECs to various natural hazards was analyzed. The Analytic Hierarchy Process (AHP) was employed to determine the weights for each criterion. Results revealed that most of the ECs are moderately suitable in terms of safety, with a few highly suitable. However, accessibility ratings varied, highlighting the need for improvements in infrastructure in certain areas. The study emphasizes the reality that not all safe ECs are accessible, and not all accessible ECs are safe.

KEYWORDS

Site suitability; evacuation center; natural hazard; safety; Zamboanga; GIS; AHP.

1. Introduction

The Philippines, a country in Southeast Asia, is highly susceptible to a range of natural hazards, including typhoons, floods, storm surges, landslides, earthquakes, volcanic eruptions, and tsunamis (Nakasu & Amrapala, 2023). These events often result in significant damage to properties and infrastructure, as well as loss of lives. Effective disaster response, including the provision of safe and accessible shelter, is crucial for mitigating these impacts. Evacuation centers (ECs) serve as essential refuges during emergencies, emphasizing the importance of strategically locating them in areas that are hazard-free or controllable and accessible to affected communities within a reasonable time threshold.

However, climate change has intensified the frequency and severity of extreme weather events, causing areas previously unaffected by natural hazards now vulnerable to disasters like floods and

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typhoons. This shifting hazard landscape necessitates a reassessment of existing EC locations to ensure their continued safety and functionality. In practice, many ECs in the Philippines are schools, gymnasiums, government facilities, and private buildings that are often repurposed as ECs due to the lack of dedicated facilities. This makeshift approach poses numerous challenges, such as disruptions to education, inadequate amenities, limited access to utilities, unsafe pathways to the centers, and the potential hazard of situating these centers in high-risk areas. Building resilient cities involves ensuring effective disaster response, which includes providing safe and accessible ECs. The Department of Interior and Local Government (DILG) Memorandum Circular No. 122 series of 2018 mandates that ECs be situated in stable, hazard-free areas with immediate access to basic goods, services, and utilities, and accessible by vehicular transportation before, during, and after a hazard event (DILG, 2018). Such mandates emphasize the need for a holistic approach to disaster resilience, incorporating core dimensions like preparedness, community involvement, and capacity-building among key actors (Milenković & Cvetković, 2025). In this context, community-based disaster risk reduction (CBDRR) strategies offer valuable pathways for overcoming barriers to effective EC planning by fostering local participation and addressing accessibility gaps (Cvetković et al., 2025).

GIS-based site suitability approaches are extensively used to evaluate ECs against multiple hazards, as presented in Table 1. Kar and Hodgson (2008) used a weighted linear combination (WLC) and a pass-or-fail screening technique to determine the physical and social suitability of ECs (Kar & Hodgson, 2008). Mustaffa et al. (2015) combined remote sensing techniques with GIS for site suitability analysis (Mustaffa et al., 2015). Şentürk and Erener (2017) employed a multi-criteria decision analysis (MCDA) with criteria weights determined by the Analytical Hierarchy Process (AHP) (Şentürk & Erener, 2017). Bolanio et al. (2023) created a suitability map for flood ECs using GIS and MCDA with literature-based weights (Bolanio et al., 2023).

Table 1. Summary of site suitability analysis performed in the reviewed literature.

Reference	Software	Hazards considered in the analysis	Methods	Criteria considered in the analysis
(Kar & Hodgson, 2008)	GIS software (brands not indicated)	Flood	GIS-based approach using WLC and Pass/Fail screening technique.	Physical and Social Suitable Criteria
(Mustaffa et al., 2015)	ArcGIS, RS Software	Flood	GIS-based approach and RS technique	Safety, Road Access, Capacity
(Şentürk & Erener, 2017)	ArcGIS, GIS, ERDAS		GIS-based approach using the MCDA method	Proximity to fuel stations, road networks, security centers, existing buildings, electricity transmission lines, fault lines, medical centers, polluting industries, cultural heritage areas, water supply, flood-prone areas, electrical supply, and landslide risk areas, Land Slope, Geological Structure
(Hilvano, 2018)	QGIS. Google Earth	Floods, Storm Surges, Landslides	GIS-based spatial analysis	Exposure to multi-hazards
(Arandia et al., 2019)	Google Map	Flood, Wind, Seismic	RVS, Weights Assignment based on AHP.	Safety + Sustainability + Accessibility = Suitability
(Tsioulou et al., 2021)	*	Flood, Wind, Seismic	GIS-based approach, Weights Assignment based on AHP.	Hazards at Location, Physical Vulnerability, Accessibility, Communications, Living Environment, Access to Supplies
(Alejandria et al., 2021)	GIS software (brands not indicated)	Natural hazards	GIS-based spatial analysis	Exposure to multi-hazards

(Bolanio et al., 2023)	GIS software (brands not indicated); Web application	Flood	GIS-based approach using the MCDA method	Elevation, Slope, Road Network, Land Use, Proximity to Water Supply, Electrical Supply, Fuel Stations
(Morales et al., 2024)	GIS software (brands not indicated)	Not applicable	GIS-based spatial vulnerability analysis	Spatial distribution of population and ECs
(Ahmed & Islam, 2025)	ArcGIS	Seismic	Comprehensive Open Space Suitability Index (COSI)-based Suitability Assessment for Emergency-sheltering (SAFE) framework: a GIS-based multi-criteria framework	Quality, Capacity, and Accessibility

Notes: * Not indicated

Hilvano (2018) conducted a simpler analysis, examining EC exposure to natural hazard zones using GIS-based spatial analysis (Hilvano, 2018). Arandia et al. (2019) evaluated EC suitability using a Safety-Sustainability-Accessibility (SSA) assessment framework, wherein indicators under safety, sustainability, and accessibility were used to determine overall suitability. This multi-dimensional approach provides a useful basis for evacuation center planning and assessment. Alejandria et al. (2021) identified and geotagged ECs across the Philippines, assessing their exposure to natural hazards and presenting their spatial distribution based on building use and hazard exposure (Alejandria et al., 2021). Moreover, Tsioulou et al. (2021) compared the relative suitability of school buildings as ECs using AHP, considering both hard characteristics (hazard location and physical vulnerability) and soft characteristics (accessibility, communications, living environment, access to supplies) (Tsioulou et al., 2021). Morales et al. (2024) proposed a new approach for evaluating disaster shelter vulnerability by incorporating the spatial distribution of both population and ECs, estimating shelter capacity and demand to assess potential imbalances (Morales et al., 2024). Similarly, recent advancements include GIS-based multi-criteria frameworks for assessing urban open spaces as post-earthquake emergency shelters, integrating factors such as accessibility, safety, and hazard exposure to support resilient shelter planning (Ahmed & Islam, 2025). These approaches highlight the critical role of key actors in Disaster Risk Reduction and Management (DRRM), including first responders, whose capacities must be strengthened for effective implementation in vulnerable regions (Cvetković, 2025).

Despite these advancements, Zamboanga City lacks a published map of its ECs. Creating a map of ECs within a city can empower residents by providing vital information on safe shelters and guiding them to the nearest secure locations during emergencies. This study addresses this gap by mapping ECs and categorizing them based on their building use. Using GIS, this study conducts site suitability analysis of the identified ECs, evaluating them based on safety and accessibility criteria. Safety is assessed by analyzing exposure to various natural hazards, while accessibility is evaluated based on proximity to essential services, resources, and infrastructures. GIS is used to map these criteria and calculate the scores for each EC, determining their overall suitability. Given the increasing impact of climate change, this study provides a framework for reassessing EC locations to enhance disaster preparedness and community resilience.

2. Materials and Methods

2.1. Study Area

Zamboanga City, located on Mindanao Island in the Philippines, is a highly urbanized hub with 98 barangays (PhilAtlas, 2024) shown in Figure 1. It covers approximately 1,414.70 square kilometers (546.22 square miles) and, as of the 2024 Census, has a population of 977,081, resulting in a population density of 691 individuals per square kilometer (World Population Review, 2024). The city features a mix of rolling to very steep terrain, with the urban center being relatively flat but surrounded by mountains in the peninsula's center. Heavy rains often cause water to flow from these mountains to the low-lying barangays near the city proper, making areas near the Tumaga and San Jose Gusu River Basins particularly prone to flooding (Rodriguez et al., 2017).

Though Zamboanga City lies outside the typical typhoon belt, it is still vulnerable to hydro-meteorological hazards like droughts, floods, landslides, and storm surges. Floods are considered the most significant threat, followed by storm surges along the coastal areas. Recent years have seen an increase in flooding incidents, as shown in Table 2. In October 2022, Typhoon Paeng caused substantial infrastructure damage and displaced thousands of families in Zamboanga City. Figure 2a shows the flooding along MCLL Highway, blocking vehicular access to the city's east coast, while Figure 2b depicts residents seeking refuge from floodwaters at Ayala Barangay Hall during Typhoon Paeng.

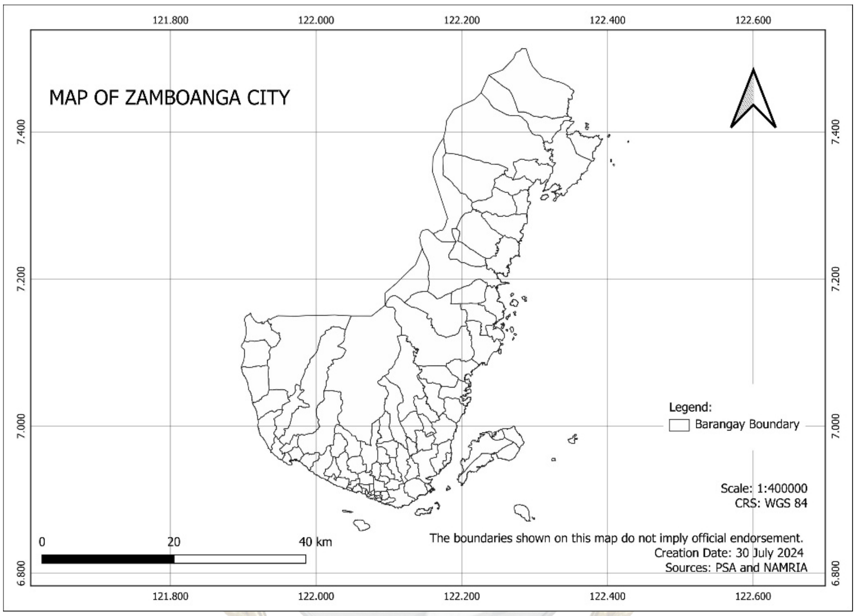


Figure 1. Map of Zamboanga City with 98 barangays.

Table 2. Summary of hazards and impacts on Zamboanga City.

Year	Month	No. Barangay flooded	No. of families affected	Hazard/s	Source
2023	September	2	383	Flood	(DROMIC, 2023b)
2023	August	10	1796	Flood	(NDRRMC, 2023)
2023	January	12	1463	Flood, Landslide	(DROMIC, 2023a)
2022	December	13	507	Flood	(DROMIC, 2022b)
2022	October	14	Estimated 3000 families	Flood, Landslide	(DROMIC, 2022c)
2022	August	1	*	Flood	(Jocson, 2022a)
2022	May	3	659	Flood, Landslide	(DROMIC, 2022a)
2021	May	10	1830	Flood	(NDRRMC, 2021)
2020	October	5	1617	Flood	(DROMIC, 2020)
2019	September	12	700	Flood	(Pareño, 2019)
2018	September	4	200	Flood	(Garcia, 2018)
2017	October	12	1740	Flood, Landslide	(DROMIC, 2017)
2014	July	2	Estimated 500 families	Flood	(Locsin, 2014)

*** No data**

Figure 2. (a) MCLL highway flooded due to Typhoon Paeng (Gomez, 2022);
(b) Ayala barangay hall used as EC during Typhoon Paeng (Jocson, 2022b)

2.2. Data Collection and Processing

For this preliminary study, primary data were sourced from the Zamboanga City Disaster Risk Reduction Management Office (ZCDRRMO) and Alejandria et al. (2021) (Alejandria et al., 2021). The data included a list of ECs with information on their names, coordinates, and types (either purpose-built facilities or makeshift facilities like covered courts and schools). These were added to QGIS as a vector layer and represented as points on the map, with color coding to indicate the type of building use.

Secondary data included a map of Zamboanga City showing administrative boundaries, sourced from the Philippine Statistics Authority (PSA) and the National Mapping and Resource Information Authority (NAMRIA) (PSA & NAMRIA, 2023).

Tertiary data comprised hazard maps showing natural threats within Zamboanga City, including floods, storm surges, landslides, liquefaction, and tsunamis. Cyclone data were obtained by assessing tracks of the top three historically strongest typhoons (Knapp et al., 2010). The nearest active volcano was examined for potential seismic hazards like ground rupture and shaking (DOST-PHIVOLCS, 2020). Secondary hazard map, particularly earthquake-induced landslide data, was excluded from this analysis due to the unavailability of updated and officially validated hazard data at the time of analysis.

Flood hazard maps were sourced from the Nationwide Operational Assessment of Hazards (NOAH) website (*NOAH Flood Hazard Maps*, 2021), along with storm surge and landslide maps, which were drawn from studies documented in journal articles (Alejandrino et al., 2015; Lagmay, 2015; Luzon et al., 2016; Rabonza et al., 2016). Liquefaction and tsunami hazard maps were acquired from the Philippine Institute of Volcanology and Seismology (PHIVOLCS) and converted to GIS format (DOST-PHIVOLCS, 2021). Table 3 summarizes the data collected, their sources, and their applications in this study.

Table 3. Summary of data collected and their sources.

Data Information	Sources	Application
Designated evacuation sites	(Alejandria et al., 2021), ZCDRRMO	S-A Assessment
Boundary data	PSA, NAMRIA	Boundary of the study area
Road network	OSM	Spatial accessibility analysis
Hazard Maps:		
Flood	NOAH	Safety assessments: Spatial distribution analysis

Storm Surge	NOAH	Safety assessments: Spatial distribution analysis
Landslide	NOAH	Safety assessments: Spatial distribution analysis
Liquefaction	PHIVOLCS	Safety assessments: Spatial distribution analysis
Tsunami	PHIVOLCS	Safety assessments: Spatial distribution analysis
Volcanic Hazard	thinkhazard.org, hazardhunter.georisk.gov.ph	Safety assessment
Seismic Hazard	thinkhazard.org, hazardhunter.georisk.gov.ph	Safety assessment
Cyclone (Wind) Hazard	thinkhazard.org hazardhunter.georisk.gov.ph	Safety assessment
Accessibility Criteria	Openstreetmap.org	Accessibility assessment

2.3. Site Suitability Analysis

The site suitability analysis for ECs in Zamboanga City was conducted using GIS technology, guided by a framework that defines overall suitability based on two primary categories: safety and accessibility, as illustrated in Figure 3. Safety was evaluated based on EC exposure to selected natural hazards, while accessibility was assessed in terms of proximity to essential services, utilities, and ease of access. Each category was analyzed independently using a set of indicators derived from relevant guidelines (DILG, 2018) and literature (Arandia et al., 2019; Bolanio et al., 2023; Kar & Hodgson, 2008; Morales et al., 2024; Şentürk & Erener, 2017; Tsioulou et al., 2021), ensuring they were comprehensive and applicable to the local context.

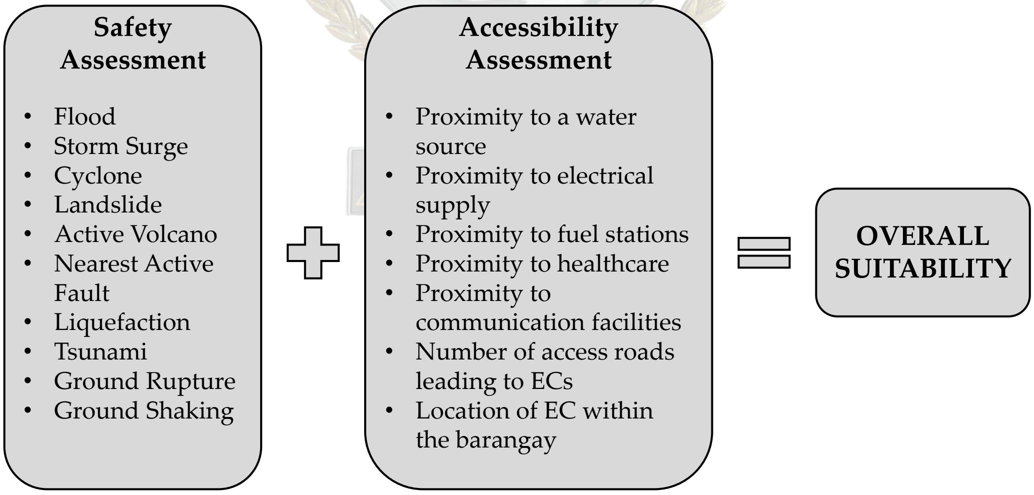


Figure 3. Proposed site suitability framework considering safety and accessibility criteria.

Each criterion was reclassified into classes based on its impact on safety and accessibility. The reclassification process involved assigning values to different levels of exposure or proximity, which were then rated on a scale to facilitate comparison. All spatial analyses and map outputs were conducted in the WGS 84 geographic coordinate reference system (EPSG:4326), consistent with the local projection of the primary hazard and administrative boundary datasets used. The core GIS processing steps included data preprocessing, spatial overlay, and intersection operations to extract hazard exposure attributes for each EC point location, buffer, and proximity analysis for accessibility criteria, supplemented by the ORS Tools plugin, and attribute reclassification before AHP scoring. For safety criteria, exposure was scored directly at EC points: no to low exposure was assigned a rating of 5, medium exposure a rating of 3, and high exposure a rating of 1. For accessibility criteria, graduated proximity classes were applied based on the computed distances. A hybrid method, which was explained in the subsequent section, was employed to provide a realistic and comparable measure of accessibility. The weights of each criterion were determined using the Analytical Hierarchy Process (AHP). Due to compatibility issues with the EasyAHP plugin in QGIS version 3.36.3, an Excel application (Barnard, 2012) was used instead to perform the pair-wise comparison and generate the weights. The criteria, ratings, and weights were used to generate a composite suitability score for each EC in Zamboanga City.

An EC was considered suitable only if it attained a high suitability rating (a score > 4.50) in both safety and accessibility. The > 4.50 threshold represents 90% of the maximum possible score (5.00) and was intentionally adopted to reflect a near-optimal performance requirement for ECs, given their critical life-safety function, during disaster response. The primary outputs of this analysis are suitability maps that visually identify ECs meeting both safety and accessibility requirements. To assess the robustness of this threshold choice, a sensitivity analysis is conducted in a subsequent section to examine how alternative threshold values influence the number and distribution of suitable sites.

2.3.1. Analytical Hierarchy Process

The analytical hierarchy process (AHP) is a multi-criteria decision-making method developed by Saaty (1980) that is widely used to support complex decision problems by incorporating both quantitative data and expert judgement (Saaty, 1980; Sharma et al., 2025; Tsioulou et al., 2021). AHP simplifies decision-making by a complex problem into a hierarchical structure of goals, criteria, and sub-criteria, and by deriving relative weights through pairwise comparisons (Sharma et al., 2025; Tsioulou et al., 2021).

In this study, AHP was employed to derive the weights for the safety and accessibility criteria used in the site suitability analysis of evacuation centers. Expert judgment was collected through pairwise comparisons using the Saaty fundamental scale of relative importance. A total of thirteen experts participated in the assessment and were grouped into three sectors to capture diverse perspectives relevant to disaster risk reduction: five engineers from the academe, five professionals from private institutions, including engineers and geologists, and threelocal government personnel involved in disaster-related planning and decision-making.

Pairwise comparisons were performed independently by each expert, and individual priority weights for each criterion were derived from their respective comparison matrices. The final weights for the safety and accessibility criteria, as presented in Table 4, were obtained by computing the geometric mean of the individual weights across all experts, assuming equal importance among respondents. The resulting weights were normalized so that their sum equals one and were subsequently used in the GIS-based site suitability analysis. The final weights obtained from the AHP were used as inputs in the GIS-based safety and accessibility assessments of the evacuation centers.

Table 4. Summary of parameter weights.

Parameters	Weights
Safety Parameters	
Flood	0.2401
Storm Surge	0.1516
Cyclone	0.1559
Landslide	0.1417
Active Volcano	0.0328
Nearest Active Fault	0.0430

Liquefaction	0.0517
Tsunami	0.0657
Ground Rupture	0.0474
Ground Shaking	0.0701
Accessibility Parameters	
Proximity to water source	0.2079
Proximity to electrical supply (power line)	0.1009
Proximity to fuel stations	0.0398
Proximity to healthcare facilities	0.1341
Proximity to communication facilities	0.0927
Number of access roads leading to ECs	0.1678
Location of EC within the barangay	0.2569

The derived weights reflect expert consensus on the relative importance of each parameter in the Zamboanga City context. For safety parameters, flood exposure received the highest weight (0.2401) due to its frequent occurrence and widespread impact in low-lying and coastal areas. Cyclone (0.1559) and storm surge (0.1516) were also prioritized, reflecting the city's exposure to tropical cyclones and associated coastal hazards. Lower weights were assigned to rarer or more localized hazards such as active volcanoes (0.0328) and the nearest active fault (0.0430), consistent with the absence of active volcanoes and limited fault proximity in most areas.

Within accessibility parameters, the location of EC within the barangay received the highest weight (0.2569) because experts emphasized its critical role in facilitating immediate administrative coordination, equitable local access, and reducing evacuation delays. This aligns with DILG Memorandum Circular No. 122 series of 2018, which stresses that ECs should be situated to serve barangay-level needs efficiently. Proximity to water source (0.2079) ranked second, reflecting its essential role in sustaining evacuees, while the number of access roads (0.1678) was also highly weighted to ensure logistical viability. These differential weights strongly influence the overall suitability rankings.

Consistency of expert judgments was evaluated using the consistency ratio (CR), with values of CR ≤ 0.10 considered acceptable. As shown in Table 5, consistency ratios for all expert judgement matrices were below the acceptable threshold of 0.10, indicating satisfactory consistency across expert evaluations.

Table 5. Summary of expert consistency ratios.

Experts	Consistency Ratio	
	Safety Parameter	Accessibility Parameter
1	0.05	0.04
2	0.02	0.06
3	0.06	0.10
4	0.05	0.04
5	0.06	0.06
6	0.04	0.03
7	0.06	0.02
8	0.10	0.03
9	0.10	0.06

10	0.06	0.06
11	0.00	0.01
12	0.04	0.02
13	0.05	0.03

2.3.2. Safety Assessment

Safety is assessed by analyzing the exposure of ECs to various natural hazards, including flooding, storm surges, landslides, liquefaction, and tsunamis. The impact of a natural hazard depends on its magnitude or strength; for example, a higher flood level poses a greater threat to exposed structures. All ECs were evaluated for their exposure to these hazards.

To conduct the assessment, the identified ECs were loaded into QGIS and represented as points, while the hazard maps were loaded as vector layers. Using the intersection geoprocessing tool in QGIS, the ECs intersecting with hazards were identified.

Table 6 summarizes the safety criteria considered in the assessment, along with their corresponding ratings and weights. Some safety parameters, including flood, storm surge, landslide, liquefaction, and tsunami, were evaluated based on hazard maps. In contrast, cyclone or wind hazard was assessed using data from the top three historically strongest typhoons in the Philippines and the National Structural Code of the Philippines (NSCP) wind contour map. Parameters such as active volcanoes, the nearest active fault, ground rupture, and ground shaking were assessed using data from hazardhunter.georisk.gov.ph, the Philippines' one-stop shop for hazard assessment (Hazard Hunter PH, 2024).

Table 6. Summary of safety criteria, rating, and weights.

	Safety Parameter	Low (1)	Medium (3)	High (5)	Weight
1.	Hydro-Meteorological Hazard:				
1.1	Flood[a]	High susceptibility: Exposed to 5-year and 25-year rainfall return period flood	Moderate susceptibility: Exposed to a 100-year rainfall return period flood	Safe	0.2401
1.2	Storm Surge[a]	High susceptibility: Exposed to SSA 1,2, and 3	Moderate susceptibility: Exposed to SSA 4	Safe	0.1516
1.3	Cyclone[b,c]	Wind speed > 250 kph	Wind speed between 150 kph to 250 kph	Wind speed < 150 kph	0.1559
1.4	Landslide[a]	Exposed to a landslide	*	Not exposed to a landslide	0.1417
2.	Volcanic Hazard:				
2.1	Active Volcano[c]	Distance to active volcano < 11 km	Distance to active volcano between 11 km to 50 km	Distance to active volcano > 50 km	0.0328
3.	Seismic Hazard:				
3.1	Nearest Active Fault[c]	Distance to nearest active fault < 11 km	Distance to nearest active fault is between 11 km to 50 km	Distance to nearest active fault > 50 km	0.0430
3.2	Liquefaction[a]	Exposed to liquefaction	*	Not exposed to liquefaction	0.0517
3.3	Tsunami[a]	Exposed to a tsunami	*	Not exposed to a tsunami	0.0657
3.4	Ground Rupture[c]	Unsafe	*	Safe	0.0474

3.5	Ground Shaking[c]	Prone	*	Not prone	0.0701

[a] Based from the hazard maps
[b] Based on the top 3 historically strongest typhoons in the Philippines and the NSCP wind contour map
[c] Based on hazardhunter.georisk.gov.ph
* Choices between Low and High only

Each safety parameter was classified into either Low and High, or Low, Medium, and High, with corresponding ratings of 1, 3, and 5, respectively. The weights of each parameter were derived using the AHP. The overall safety score is obtained through the equation shown below:

$$S_j = \sum (SP_i \times w_i) \quad (1)$$

where S_j is the safety score for each EC, SP_i is the rating of each safety parameter, and w_i is the weight for safety parameters. The safety score is classified into ratings based on its classes, as shown in Table 7.

Table 7. Safety Rating for each EC.

	Safety Classes	Safety Ratings
Safety Scores	0 – 2.99	Not Suitable
	3.0 – 4.50	Moderately Suitable
	>4.50	Highly Suitable

2.3.3. Accessibility Assessment

The accessibility of ECs in Zamboanga City was assessed to ensure that affected residents could reach these facilities efficiently during emergencies. The evaluation considered proximity to essential resources and infrastructure, specifically water sources, electrical supply, healthcare facilities, communication facilities, fuel stations, and access roads. Table 8 presents the accessibility criteria, distance-based class ranges (in meters), corresponding ratings, and weights derived through the AHP.

Table 8. Summary of accessibility criteria, rating, and weights.

	Accessibility Parameter	Unit	Class Ranges	Class Remarks	Class Ratings	Weights
1	Proximity to a water source	m	< 31 or > 3,000	Low	1	0.2079
			1,001 - 3,000	Medium	3	
			31 - 1,000	High	5	
2	Proximity to electrical supply (power line)	m	< 31 or > 3,000	Low	1	0.1009
			1,001 - 3,000	Medium	3	
			31 - 1,000	High	5	
3	Proximity to fuel stations	m	< 31 or > 3,000	Low	1	0.0398
			1,001 - 3,000	Medium	3	
			31 - 1,000	High	5	
4	Proximity to healthcare facilities	m	> 5,000	Low	1	0.1341
			2,001 - 5,000	Medium	3	
			< = 2,000	High	5	
5	Proximity to communication facilities	m	< 31 or > 3,000	Low	1	0.0927
			1,001 - 3,000	Medium	3	
			31 - 1,000	High	5	

6	Number of access roads leading to ECs	road	1	Low	1	0.1678
			2	Medium	3	
			> 2	High	5	
7	Location of EC within the barangay	-	near the edge boundary of the barangay	Low	1	0.2569
			between the edge boundary and the center of the barangay	Medium	3	
			near the center of the barangay	High	5	

To conduct the assessment, the identified ECs were loaded into QGIS and represented as points, while the accessibility parameters were loaded as vector layers. Proximity was evaluated using a hybrid approach that distinguished between network-constrained and straight-line distance measurement to reflect realistic travel paths. For water sources, fuel stations, and healthcare facilities, where actual travel must follow the road network, the ORS Tool plugin was used to generate distance-based isochrones from each EC point, drawing on the OpenRouteService API and OpenStreetMap road data. Isochrones were computed in distance mode (not in travel time) with fixed range intervals of 30 meters, 1000 meters, 2000 meters, 3000 meters, and 5000 meters, representing the reachable area along roads within each threshold under pre-disaster conditions (no road restrictions, standard routing profile). The intersection geoprocessing tool in QGIS was then applied to determine the proximity class by checking which isochrone polygon contained the nearest service point. Buffer analysis was employed to assess the proximity of ECs to electrical supply, communication facilities, and the presence of access roads leading to the ECs. The buffer tool in QGIS creates polygon layers by generating circular buffer zones with specified diameters around the ECs, based on accessibility criteria. This method approximates the distance between ECs and essential facilities like electrical supply and communication towers. Additionally, the number of roads leading to each EC within the buffer zone was identified.

Each accessibility parameter was classified as Low, Medium, and High, with corresponding ratings of 1, 3, and 5, respectively. The weights of each parameter were derived using the Analytical Hierarchy Process (AHP). The overall safety score is obtained using the equation shown below:

$$A_i = \sum (AP_i \times w_i) \tag{1}$$

where A_i is the accessibility score for each EC, AP_i is the rating of each accessibility parameter, and w_i is the weight for accessibility parameters. The accessibility score is classified into ratings based on its classes, as shown in Table 9.

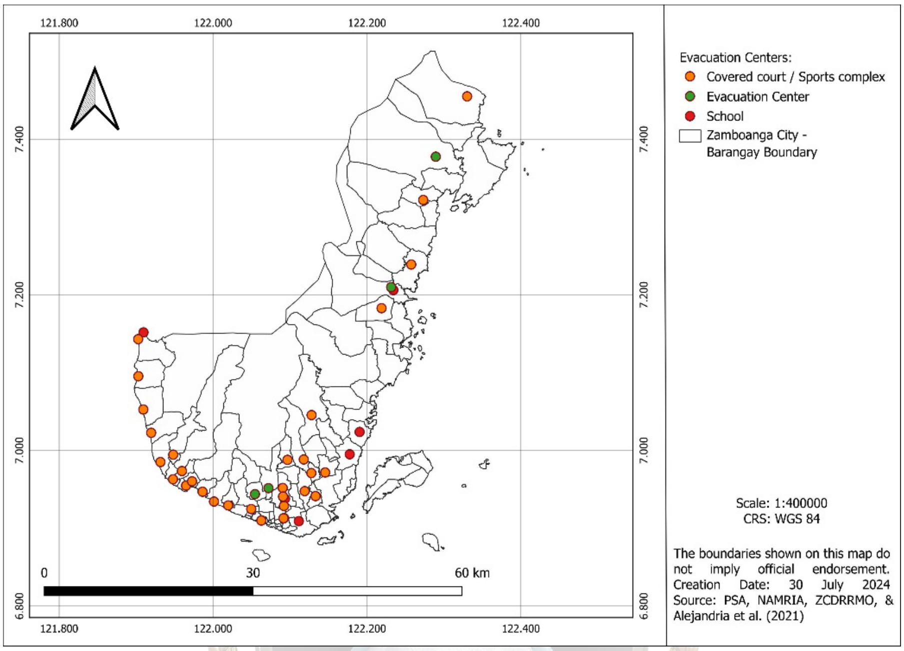
Table 9. Accessibility Rating for each EC.

	Accessibility Classes	Accessibility Ratings
Accessibility Scores	0 – 2.99	Not Suitable
	3.0 – 4.50	Moderately Suitable
	>4.50	Highly Suitable

3. Results and Discussion

3.1. Distribution and Classification of ECs in Zamboanga City

There were 41 identified ECs in Zamboanga City, as illustrated in Figure 4. These centers were further classified based on their type of building use, including schools, covered courts or sports complexes, and purpose-built evacuation centers. Specifically, there were 4 purpose-built ECs, 6 schools, and 31 covered courts or sports complexes, as shown in Figure 5. Based on this information, there seems to be a discrepancy between the number of ECs and the demographic and geographic coverage of the city. Specifically, the ratio of ECs to the city's population is approximately 1:24,000, and the ratio of ECs to geographic coverage is roughly 1:35 square kilometers. These ratios indicate an imbalance in the distribution of ECs relative to the densely populated and expansive geographical area of the highly urbanized city. Such a discrepancy suggests that there may be inadequate provision of evacuation facilities for the city's population and land area.



The boundaries shown on this map do not imply official endorsement. Creation Date: 30 July 2024 Source: PSA, NAMRIA, ZCDRRMO, & Alejandria et al. (2021)

Figure 4. Spatial distribution of ECs in Zamboanga City.

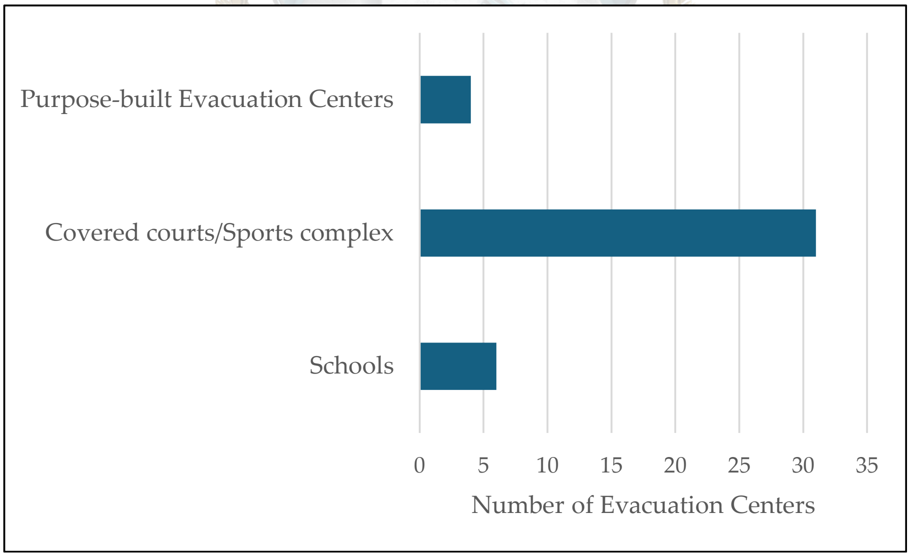


Figure 5. Number of ECs per Type of Building Use

Figure 6 shows that the population is higher in the city proper area, as expected. It was also observed that more ECs are located in this area. However, not all barangays have their ECs. Barangays with larger areas and higher populations, especially those far from the city proper, often have only one EC, and it is not always centrally located within the barangay. This might mean that the EC is not easily accessible to most residents. However, without knowing the exact population distribution within each barangay, it's possible that the areas near highways, where ECs are commonly located, have higher populations. Therefore, an EC not being centrally located doesn't necessarily mean it is inaccessible to the majority of the population.

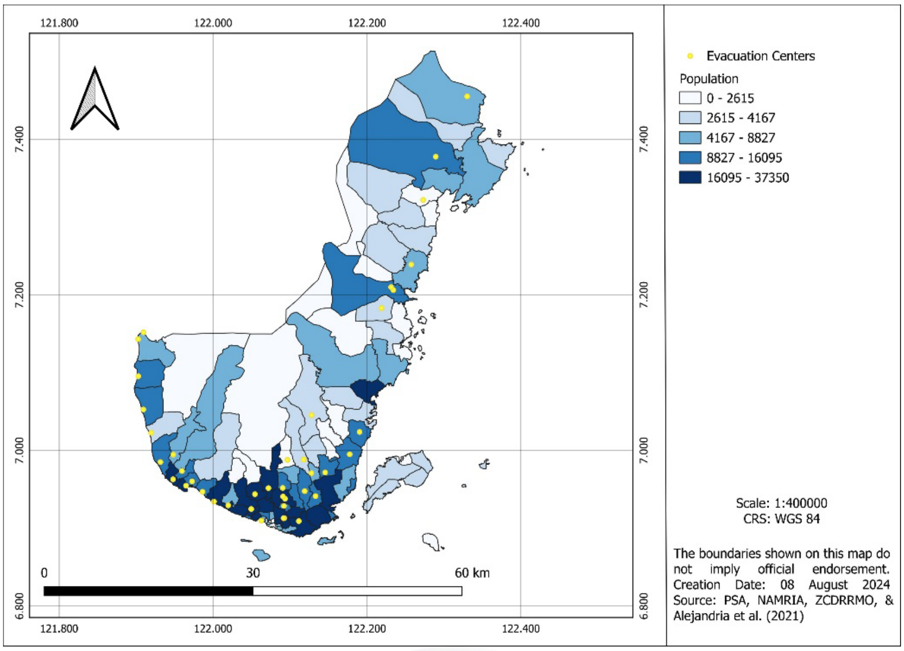


Figure 6. Distribution of population and ECs in Zamboanga City.

Nevertheless, relating the EC distribution to barangay-level population estimates reveals potential imbalances in coverage relative to demand. The barangay with the highest population (Barangay Talon-talon, approximately 38,000) has only one EC, while barangays with the lower populations (for example, Barangay Quiniput, approximately 4,000) also typically have only one EC. This pattern suggests that a simple one-EC-per-barangay approach may not adequately address varying population sizes. Rather than treating one EC per barangay as sufficient, local authorities should examine the population distribution to establish the appropriate EC-to-population ratio and determine the number of ECs required per barangay accordingly. Although detailed population distribution data within each barangay are currently unavailable, acquiring and mapping these patterns should be a priority in future planning to identify optimal locations for new or additional ECs within each barangay and thereby improve equity and effectiveness in disaster response.

3.2. Safety Assessment

The exposure of evacuation centers (ECs) to various natural hazards, including four advisory levels of storm surge, three return periods of flooding, landslide, liquefaction, and tsunami, were assessed using QGIS. Figure 7 illustrates the ECs intersecting with 8 to 11 hazards, 4 to 7 hazards, 1 to 3 hazards, and those not intersecting with any hazards. Notably, none of the ECs intersected more than 7 hazards, which is a positive outcome, as shelters should ideally be resistant to multiple natural hazards. Specifically, 10 ECs intersected with 4 to 7 hazards, 18 ECs intersected with 1 to 3 hazards, and 13 ECs did not intersect with any hazards. Additionally, it was found that only 2 out of 4 purpose-built ECs intersected with a single hazard, while the remaining purpose-built ECs were safe and not exposed to any natural hazards. This indicates that natural hazard risks were considered in the planning and construction of purpose-built ECs.

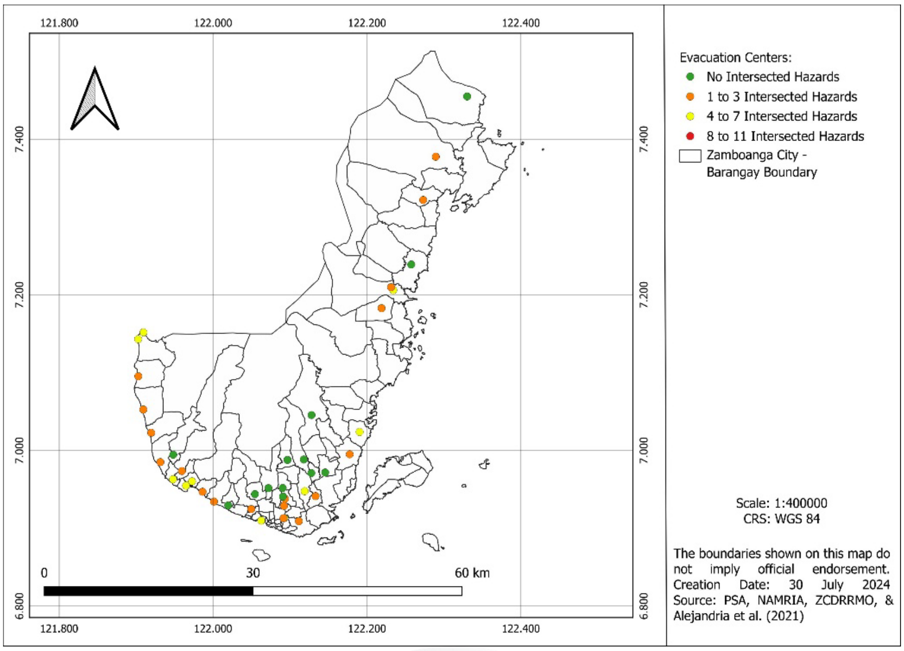


Figure 7. Multi-hazard assessment of ECs in Zamboanga City.

The summary of safety scores and ratings is shown in Table 10. Figure 8 displays the spatial distribution of ECs based on their safety ratings, while Figure 9 shows the number of ECs per safety rating class. Figure 8 indicates that the highly suitable ECs are generally located away from the coastal area, and, although not explicitly shown, these ECs are also distant from water bodies. Given that flooding is the prevalent hazard in Zamboanga City, it is no surprise that the highly suitable ECs are situated away from both coastal areas and water bodies. Furthermore, as illustrated in Figure 9, only 1 out of 41 ECs is rated as not suitable. Most ECs are rated as moderately suitable, which is understandable since 37 out of the 41 ECs are makeshift and not purpose-built. This makes them more susceptible to natural hazards compared to purpose-built ECs. Additionally, 2 out of 4 purpose-built ECs are rated highly suitable, while the rest are moderately suitable.

Table 10. Summary of safety scores and ratings of each EC.

EC ID	F	SS	LS	LQ	T	GS	GF	NAF	NAV	C	**Safety Score**	**Safety Rating**
EC-001	5	1	1	1	1	1	5	5	5	5	3.0768	Moderately Suitable
EC-002	5	5	5	5	5	1	5	3	5	5	4.6336	Highly Suitable
EC-003	5	5	1	5	5	1	5	3	5	5	4.0668	Moderately Suitable
EC-004	5	5	5	5	5	1	5	5	5	5	4.7196	Highly Suitable
EC-005	3	1	5	1	1	1	5	5	5	5	3.1634	Moderately Suitable
EC-006	3	5	5	5	5	1	5	5	5	5	4.2394	Moderately Suitable
EC-007	1	5	5	1	1	1	5	5	5	5	3.2896	Moderately Suitable
EC-008	5	5	5	1	1	1	5	5	5	5	4.2500	Moderately Suitable
EC-009	5	5	5	5	5	1	5	5	5	5	4.7196	Highly Suitable
EC-010	5	5	5	5	5	1	5	5	5	5	4.7196	Highly Suitable
EC-011	5	5	5	5	5	1	5	5	5	5	4.7196	Highly Suitable
EC-012	5	5	5	5	5	1	5	5	5	5	4.7196	Highly Suitable
EC-013	5	5	5	1	1	1	5	5	5	5	4.2500	Moderately Suitable
EC-014	1	5	5	1	1	1	5	5	5	5	3.2896	Moderately Suitable

EC-015	5	5	5	5	5	1	5	5	5	5	4.7196	Highly Suitable
EC-016	5	5	5	5	5	1	5	5	5	5	4.7196	Highly Suitable
EC-017	5	5	5	5	5	1	5	5	5	5	4.7196	Highly Suitable
EC-018	5	5	5	5	5	1	5	5	5	5	4.7196	Highly Suitable
EC-019	5	5	5	1	1	1	5	5	5	5	4.2500	Moderately Suitable
EC-020	1	1	5	1	1	1	5	5	5	5	2.6832	Not Suitable
EC-021	3	5	5	1	1	1	5	5	5	5	3.7698	Moderately Suitable
EC-022	3	5	5	1	1	1	5	5	5	5	3.7698	Moderately Suitable
EC-023	3	5	5	1	1	1	5	5	5	5	3.7698	Moderately Suitable
EC-024	5	5	5	5	5	1	5	5	5	5	4.7196	Highly Suitable
EC-025	5	3	5	1	1	1	5	5	5	5	3.9468	Moderately Suitable
EC-026	5	5	5	1	1	1	5	5	5	5	4.2500	Moderately Suitable
EC-027	5	1	5	1	1	1	5	5	5	5	3.6436	Moderately Suitable
EC-028	5	1	5	1	1	1	5	5	5	5	3.6436	Moderately Suitable
EC-029	3	1	5	1	1	1	5	5	5	5	3.1634	Moderately Suitable
EC-030	3	5	5	1	1	1	5	5	5	5	3.7698	Moderately Suitable
EC-031	5	5	5	1	1	1	5	5	5	5	4.2500	Moderately Suitable
EC-032	5	5	5	5	5	1	5	5	5	5	4.7196	Highly Suitable
EC-033	5	5	5	1	1	1	5	5	5	5	4.2500	Moderately Suitable
EC-034	5	1	5	1	1	1	5	5	5	5	3.6436	Moderately Suitable
EC-035	5	3	5	1	1	1	5	5	5	5	3.9468	Moderately Suitable
EC-036	5	5	5	1	1	1	5	5	5	5	4.2500	Moderately Suitable
EC-037	5	1	5	5	5	1	5	5	5	5	4.1132	Moderately Suitable
EC-038	5	5	5	5	5	1	5	5	5	5	4.7196	Highly Suitable
EC-039	5	5	5	5	5	1	5	5	5	5	4.7196	Highly Suitable
EC-040	5	3	1	5	5	1	5	5	5	5	3.8496	Moderately Suitable
EC-041	5	5	5	5	1	1	5	3	5	5	4.3708	Moderately Suitable

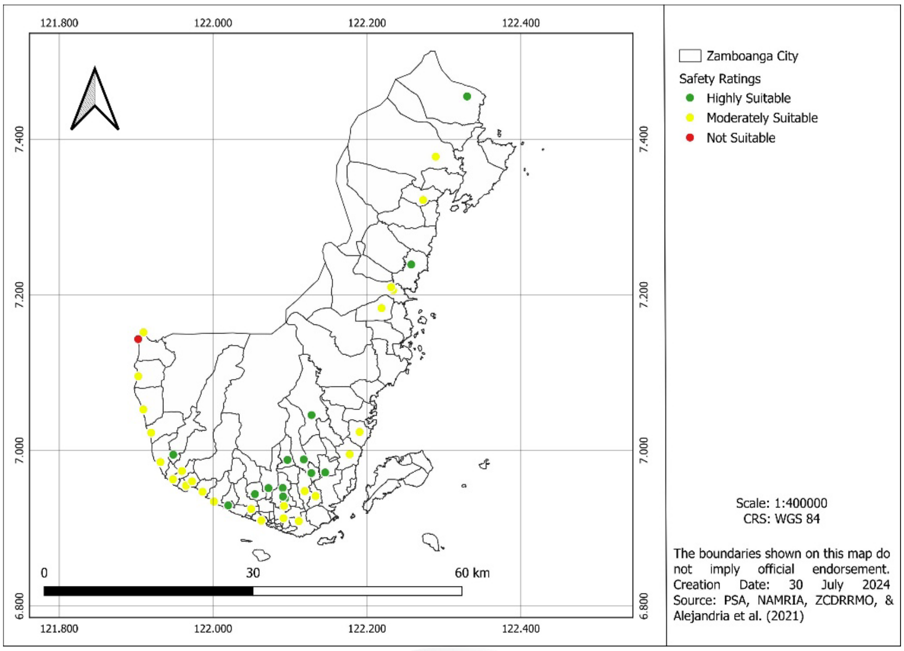


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Figure 8. Safety rating of ECs in Zamboanga City.

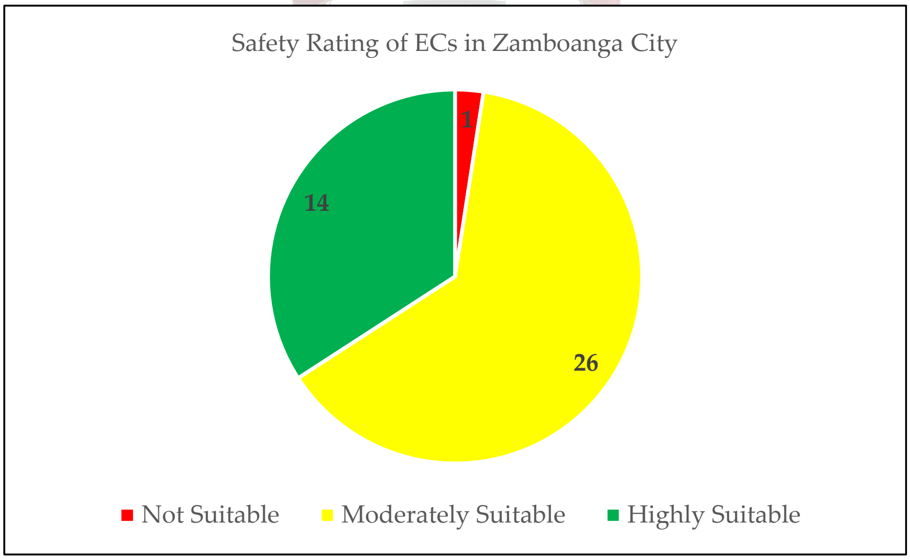

Figure 9. Number of ECs per safety rating.

3.3. Accessibility Assessment

The summary of the accessibility scores and ratings is shown in Table 11. Figure 10 displays the spatial distribution of ECs based on their accessibility ratings. Figure 11 shows the number of ECs per accessibility rating.

As shown in Figure 11, 8 out of 41 ECs are rated as not suitable. Most ECs, 31 out of 41, are rated as moderately suitable. Finally, 2 out of 41 ECs are rated as highly suitable. Most of the ECs have low scores for proximity to communication facilities (CF). This is because all the communication facilities in Zamboanga City are located near the city proper. The average score for CF is only 1.93.

Another parameter with low average scores is proximity to fuel stations (FS) and healthcare facilities (HF), with average scores of 2.51 and 2.76, respectively. This is due to most fuel stations and healthcare facilities being situated near the city proper. The reason why the average scores for FS and HF are higher than those for CF is that there are fewer CFs in Zamboanga City.

Compared to the safety assessment, more ECs are rated as not suitable under the accessibility assessment. However, this does not mean that these ECs can never be suitable for use. The results suggest that the specific areas where these ECs are located should be developed and improved, with the addition of essential facilities such as communication towers, fuel stations, and hospitals.

Table 11. Summary of accessibility scores and ratings of each EC.

EC ID	WS	PL	FS	HF	CF	AR	LEC	Accessibility Score	Accessibility Rating
EC-001	5	5	1	1	1	1	1	2.2353	Not Suitable
EC-002	3	5	1	1	1	5	3	3.0045	Moderately Suitable
EC-003	3	5	1	1	1	3	3	2.6689	Not Suitable
EC-004	3	3	1	1	1	5	5	3.3165	Moderately Suitable
EC-005	5	5	1	1	1	5	3	3.4203	Moderately Suitable
EC-006	1	5	1	5	1	3	5	3.3033	Moderately Suitable
EC-007	5	5	1	5	1	5	5	4.4705	Moderately Suitable
EC-008	3	3	3	3	1	5	5	3.6643	Moderately Suitable
EC-009	5	3	3	5	1	5	3	3.8345	Moderately Suitable
EC-010	3	1	1	1	1	3	5	2.7791	Not Suitable
EC-011	5	3	1	3	1	5	3	3.4867	Moderately Suitable
EC-012	3	5	3	5	1	5	3	3.6205	Moderately Suitable
EC-013	5	3	3	3	3	5	5	4.2655	Moderately Suitable
EC-014	1	3	5	3	3	5	5	3.5135	Moderately Suitable
EC-015	1	3	1	1	1	3	5	2.5651	Not Suitable
EC-016	3	3	3	5	3	5	3	3.6041	Moderately Suitable
EC-017	5	3	5	5	5	5	5	4.7987	Highly Suitable
EC-018	5	3	5	5	5	5	5	4.7987	Highly Suitable
EC-019	3	1	5	3	3	5	3	3.2137	Moderately Suitable
EC-020	5	5	1	3	1	5	3	3.6885	Moderately Suitable
EC-021	5	5	1	5	1	5	3	3.9567	Moderately Suitable
EC-022	5	5	1	3	1	5	3	3.6885	Moderately Suitable
EC-023	5	5	3	1	1	3	3	3.1643	Moderately Suitable
EC-024	3	5	1	1	1	3	3	2.6689	Not Suitable
EC-025	5	5	3	1	1	3	3	3.1643	Moderately Suitable
EC-026	5	5	3	1	1	5	5	4.0137	Moderately Suitable
EC-027	5	5	5	1	1	5	5	4.0933	Moderately Suitable
EC-028	5	5	5	1	1	5	1	3.0657	Moderately Suitable
EC-029	5	5	3	1	1	5	5	4.0137	Moderately Suitable
EC-030	1	5	1	1	1	5	3	2.5887	Not Suitable
EC-031	5	5	1	1	1	5	3	3.4203	Moderately Suitable
EC-032	3	5	1	3	3	5	1	2.9443	Not Suitable
EC-033	5	1	5	5	3	5	5	4.4115	Moderately Suitable
EC-034	5	1	3	5	3	5	3	3.8181	Moderately Suitable

EC-035	5	1	3	5	3	5	3	3.8181	Moderately Suitable
EC-036	5	3	5	3	5	5	1	3.5029	Moderately Suitable
EC-037	3	1	5	5	5	5	1	3.1535	Moderately Suitable
EC-038	5	5	3	3	3	5	5	4.4673	Moderately Suitable
EC-039	3	5	3	3	5	5	5	4.2369	Moderately Suitable
EC-040	3	5	1	1	1	3	3	2.6689	Not Suitable
EC-041	5	5	1	3	1	5	3	3.6885	Moderately Suitable

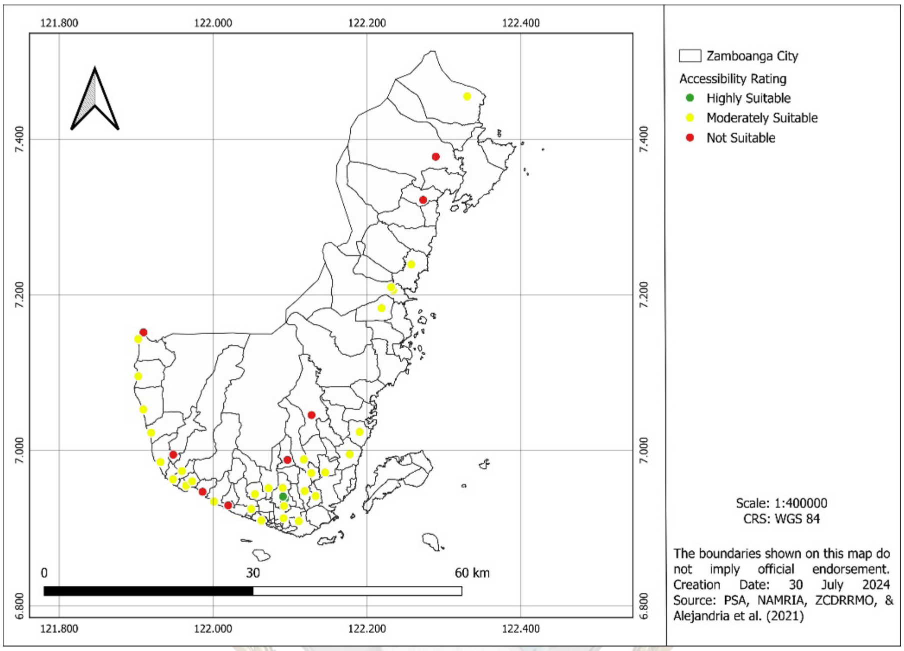

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Figure 10. Accessibility rating of ECs in Zamboanga City.

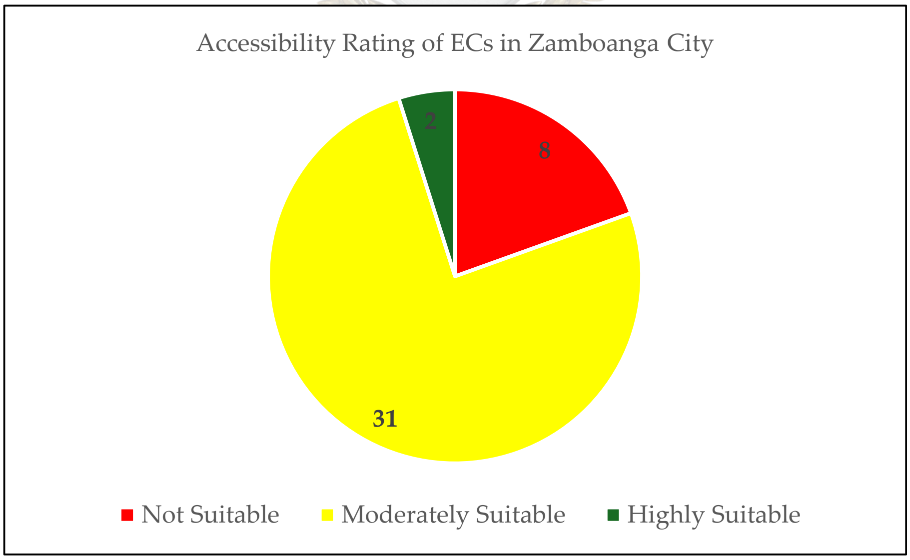

Figure 11. Number of ECs per accessibility rating.

3.4. Safety-Accessibility Assessment of ECs

Table 12 summarizes the safety and accessibility ratings of the evacuation centers (ECs). It is observed that an EC could be highly suitable in terms of safety but not suitable in terms of accessibility, vice versa. This highlights the importance of considering both criteria when evaluating overall suitability. Although safety and accessibility are externally defined spatial conditions, their influence on EC suitability provides actionable inputs for local authority decision-making, particularly in prioritization, infrastructure upgrading, and future site selection.

Table 12. Summary of the safety and accessibility rating of each EC.

EC ID	Safety Rating	Accessibility Rating
EC-001	Moderately Suitable	Not Suitable
EC-002	Highly Suitable	Moderately Suitable
EC-003	Moderately Suitable	Not Suitable
EC-004	Highly Suitable	Moderately Suitable
EC-005	Moderately Suitable	Moderately Suitable
EC-006	Moderately Suitable	Moderately Suitable
EC-007	Moderately Suitable	Moderately Suitable
EC-008	Moderately Suitable	Moderately Suitable
EC-009	Highly Suitable	Moderately Suitable
EC-010	Highly Suitable	Not Suitable
EC-011	Highly Suitable	Moderately Suitable
EC-012	Highly Suitable	Moderately Suitable
EC-013	Moderately Suitable	Moderately Suitable
EC-014	Moderately Suitable	Moderately Suitable
EC-015	Highly Suitable	Not Suitable
EC-016	Highly Suitable	Moderately Suitable
EC-017	Highly Suitable	Highly Suitable
EC-018	Highly Suitable	Highly Suitable
EC-019	Moderately Suitable	Moderately Suitable
EC-020	Not Suitable	Moderately Suitable
EC-021	Moderately Suitable	Moderately Suitable
EC-022	Moderately Suitable	Moderately Suitable
EC-023	Moderately Suitable	Moderately Suitable
EC-024	Highly Suitable	Not Suitable
EC-025	Moderately Suitable	Moderately Suitable
EC-026	Moderately Suitable	Moderately Suitable
EC-027	Moderately Suitable	Moderately Suitable
EC-028	Moderately Suitable	Moderately Suitable
EC-029	Moderately Suitable	Moderately Suitable
EC-030	Moderately Suitable	Not Suitable
EC-031	Moderately Suitable	Moderately Suitable

EC-032	Highly Suitable	Not Suitable
EC-033	Moderately Suitable	Moderately Suitable
EC-034	Moderately Suitable	Moderately Suitable
EC-035	Moderately Suitable	Moderately Suitable
EC-036	Moderately Suitable	Moderately Suitable
EC-037	Moderately Suitable	Moderately Suitable
EC-038	Highly Suitable	Moderately Suitable
EC-039	Highly Suitable	Moderately Suitable
EC-040	Moderately Suitable	Not Suitable
EC-041	Moderately Suitable	Moderately Suitable

In this study, an EC is considered suitable if it achieves a high suitability rating in both safety and accessibility, corresponding to scores greater than 4.50 for each criterion. A high safety score indicates that the EC is not exposed to the assessed natural hazards, while a high accessibility score reflects ease of access and proximity to essential services and utilities. ECs meeting both thresholds are recommended for continued use and priority designation during disaster response. ECs rated as moderately suitable (3.0 to 4.50) are not discarded but are recommended for targeted improvements, while ECs rated below 3.0 require substantial interventions before being used as ECs.

Out of the 41 ECs assessed, only EC-017 and EC-018 were rated highly suitable in both safety and accessibility, meaning they fully meet the criteria for suitability based on the recommended Safety-Accessibility (SA) assessment and can be prioritized during disaster response. Eight ECs scored highly suitable in safety but only moderately suitable in accessibility; these are generally located in remote areas, explaining the lower accessibility rating. Meanwhile, four ECs scored highly suitable in safety but not suitable in accessibility, as they are situated in mountainous areas far from the city proper. While these ECs are not exposed to the assessed hazards, it is crucial to ensure they are also accessible. If a safe EC is not easily accessible, its usefulness diminishes as residents may struggle to reach it promptly.

To enhance the practical utility of these results, the ECs can be grouped into four priority categories based on binary safety and accessibility ratings (High = Highly Suitable, scores > 4.50, Low = Moderately Suitable or Not Suitable, scores ≦ 4.50). Table 13 presents the 2×2 prioritization matrix, which identifies readily viable ECs or "quick wins" and sites requiring targeted upgrades.

Table 13. Prioritization matrix for EC suitability.

	High Accessibility (> 4.50)	Low Accessibility (≦ 4.50)
High Safety (> 4.50)	Readily viable ECs: EC-017, EC-018	Accessibility upgrades needed: EC-002, EC-004, EC-009, EC-010, EC-011, EC-012, EC-015, EC-016, EC-024, EC-032, EC-038, EC-039
Low Safety (≦ 4.50)	Safety upgrades needed: None	Major interventions required: All remaining ECs

ECs rated highly suitable in both safety and accessibility represent "quick wins" that fully meet the recommended criteria and should be prioritized immediately for continued use and designation during disaster response. ECs rated highly suitable in safety but low in accessibility are generally located in remote or poorly connected areas; these offer high potential for improvement through targeted infrastructure upgrades, such as enhanced road connectivity and transport routes, which could elevate their overall suitability relatively quickly. No ECs were rated highly suitable in accessibility but low in safety. The remaining ECs, rated low in both criteria, require more substantial interventions in either domain or both. For near-miss ECs, those rated moderately suitable in one or both criteria, a phase upgrade pathway should generally be addressed first, as they often involve quicker, lower-cost interventions with high impact on usability. Priority should be given to proximity to communication facilities and fuel stations, which recorded the lowest average scores across all ECs and are critical for emergency coordination and logistical support, respectively. This should be followed by enhancements in proximity to healthcare facilities, which had the third-lowest average score, and is essential for medical response during evacuations. Proximity to the number of access roads, water sources, and electrical supply can be addressed subsequently as supportive measures. For safety near-miss, those that scored moderately suitable in the safety assessment, further technical evaluation is recommended rather than outright exclusion. In particular, a rapid visual screening (RVS) or similar structural assessment may be conducted to evaluate the vulnerability of the EC structure to the identified hazards. Exposure to a hazard does not necessarily imply that an EC is unsafe; rather, its actual risk depends on the structural vulnerability of the facility when subjected to that hazard. By combining information on hazard exposure with structural vulnerability, a more accurate estimation of risk can be achieved. Further studies may therefore strengthen the safety assessment by explicitly incorporating vulnerability evaluation as an additional component. Overall, the differentiated results of the SA assessment provide actionable guidance for local authorities in prioritizing interventions and allocating resources to strengthen disaster risk management.

3.5. Sensitivity Analysis

The present study adopted a threshold score of 4.50 to classify ECs as highly suitable. To examine the robustness of this decision rule, a sensitivity analysis was conducted by varying the high-suitability threshold. Alternative threshold values of 4.00, 4.25, and 4.75 were evaluated to determine whether minor or substantial adjustments would affect the classification outcomes for both safety and accessibility parameters.

The threshold for highly suitable ECs is critical because it directly determines which ECs can be regarded as readability implementable or immediately viable. Table 14 presents the rating intervals for the baseline and alternative thresholds.

Table 14. Classification ranges under baseline and alternative thresholds.

Ratings	Present Study	Alternative		
		1	2	3
Not Suitable	0 - 2.99	0 - 2.99	0 - 2.99	0 - 2.99
Moderately Suitable	3.00 - 4.50	3.00 - 4.00	3.00 - 4.25	3.00 - 4.75
Highly Suitable	> 4.50	> 4.00	> 4.25	> 4.75

3.5.1. Safety Parameter

Table 15 and Figure 12 summarized the effect of threshold variation on the safety parameter classification. When the threshold was adjusted slightly to 4.25, minimal changes were observed in the number of ECs classified as Moderately Suitable and Highly Suitable. The specific ECs assigned to each category remained largely unchanged, indicating that this modest relaxation (− 0.25) has a negligible impact on the overall classification outcome.

Table 15. Distribution of ECs across safety classifications under different threshold scenarios.

Alternatives	No. of Not Suitable ECs	No. of Moderately Suitable ECs	No. of Highly Suitable ECs
Present Study	1	26	14
1	1	15	25
2	1	25	15
3	1	40	0

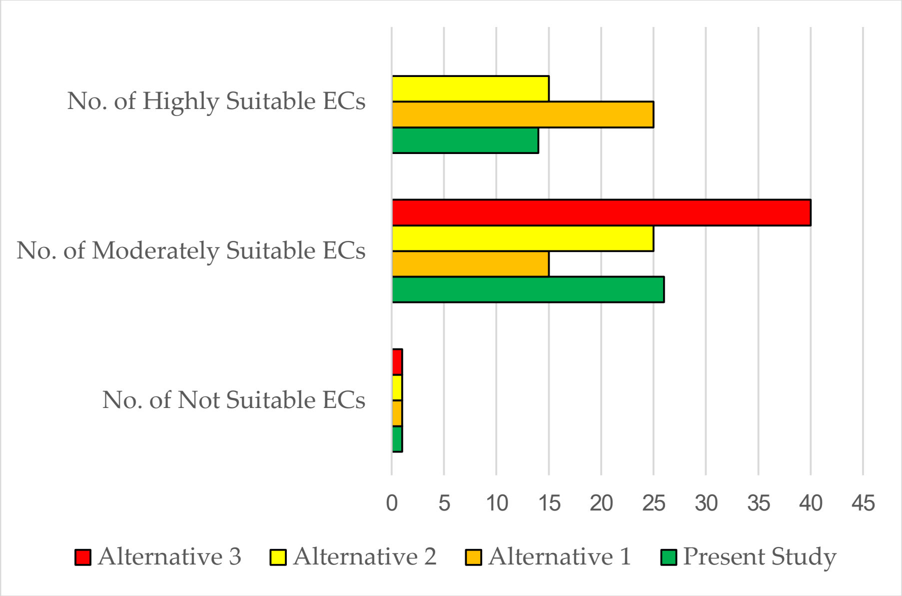

Figure 12. Sensitivity analysis of EC suitability to safety threshold variations.

A substantial reduction to 4.00, however, markedly expanded the highly suitable category from 14 to 25, with a corresponding decrease in moderately suitable ECs from 26 to 15. This substantial shift illustrates that considerably lowering the threshold relaxes the classification boundary and broadens the set of ECs deemed highly suitable, potentially reducing the model's precautionary approach.

Conversely, raising the threshold to 4.75 produced significant contractions, eliminating the highly suitable category (from 14 to 0 ECs) and shifting all 14 of these ECs into the moderately suitable category. This stricter boundary substantially limits the number of ECs qualifying as immediately viable.

These results demonstrate that the baseline threshold of 4.50 remains stable under minor downward adjustments but exhibits sensitivity to even minor upward adjustments and to larger deviations in either direction. This asymmetric response confirms that 4.50 serves as a balanced and appropriately cautious boundary, ensuring that only the most reliable ECs are prioritized as highly suitable while minimizing the risk of over-classification in a high-stakes disaster response context.

3.5.2. Accessibility Parameter

A different trend was observed for the accessibility parameter, as shown in Table 16 and Figure 13. A minor upward adjustment to 4.75 produced no change in the classification results relative to the baseline. The distribution of ECs across suitability categories remained identical.

Table 16. Distribution of ECs across accessibility classifications under different threshold scenarios.

Alternatives	No. of Not Suitable ECs	No. of Moderately Suitable ECs	No. of Highly Suitable ECs
Present Study	8	31	2
1	8	23	10
2	8	27	6
3	8	31	2

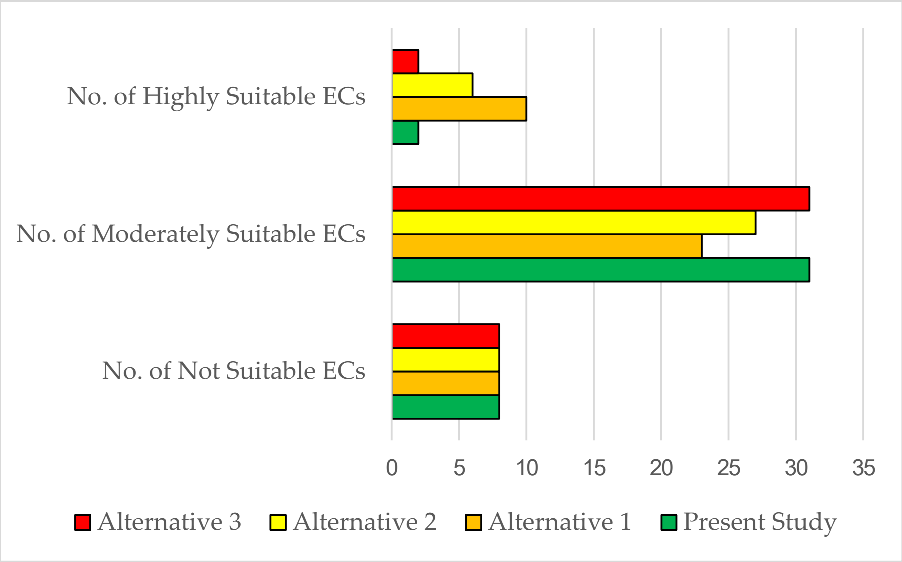

Figure 13. Sensitivity analysis of EC suitability to accessibility threshold variations.

In contrast, downward adjustments to 4.00 and 4.25 resulted in a noticeable increase in the highly suitable category. At the threshold of 4.25, the number of highly suitable ECs rose from 2 to 6, with a corresponding decrease in moderately suitable ECs. At the threshold of 4.00, the highly suitable category expanded further from 2 to 10, with moderately suitable ECs decreasing from 31 to 23. These shifts demonstrate that lowering the threshold relaxes the classification boundary.

The results indicate that the baseline threshold of 4.50 is highly stable under minor upward adjustments but sensitive to downward changes, particularly when the reduction exceeds 0.25. This relative insensitivity to stricter boundaries, combined with controlled expansion under more permissive thresholds, reinforces that 4.50 provides a balanced and appropriately cautious cutoff for accessibility classification.

4. Conclusions and Recommendations

This study presents a comprehensive GIS-based evaluation of evacuation center (EC) suitability in Zamboanga City, focusing on safety and accessibility. The results demonstrate that while many ECs exhibit moderate safety levels, their accessibility varies considerably across locations. Crucially, the findings reveal a fundamental mismatch: not all evacuation centers that are safe are accessible, and not all accessible evacuation centers are safe. This disconnect highlights the limitations of evaluating EC suitability using a single criterion and highlights the necessity of an integrated, multi-criteria approach in disaster preparedness planning.

The application of QGIS proved effective in spatially identifying hazard-prone areas and assessing EC proximity to essential services, enabling a clear visualization of exposure patterns and accessibility gaps. These outputs support evidence-based decision-making by local authorities and emphasize the importance of simultaneously considering both safety and accessibility in the designation and management of evacuation centers.

The safety assessment presented here is exposure-based, quantifying the spatial intersection of EC locations with mapped natural hazards. While this approach effectively identifies sites with low or no exposure to the assessed hazards, it does not constitute a full risk evaluation. Full risk assessment requires integrating hazard exposure with structural vulnerability and capacity considerations. The current exposure-based suitability, therefore, represents a necessary but preliminary step in determining EC suitability.

Based on the findings, several recommendations are proposed. First, the integration of structured database management tools such as SQL is recommended to improve data organization, consistency, and analytical efficiency. Second, while this study focused on exposure-based safety assessment, future research should incorporate risk-based evaluation by integrating hazard exposure with structural vulnerability assessments of EC buildings. Such assessments should examine the susceptibility of the entire structure to multiple hazards, thereby providing a more accurate representation of EC safety.

In addition, future studies should incorporate secondary and cascading hazard layers, particularly earthquake-induced landslide data, into the safety assessment. During the conduct of this study, updated and officially validated earthquake-induced landslide maps were not publicly available, limiting the inclusion of this secondary hazard mechanism. However, earthquake-induced landslides can significantly alter ground stability and intensify potential damage during seismic events, particularly in topographically varied areas. Excluding such cascading effects may result in partial characterization of hazard exposure. As updated and comprehensive multi-hazard data become available in the Philippines, especially for Zamboanga City, these layers should be integrated into future suitability analyses to enhance the robustness and reliability of safety assessment.

Expanding the framework to include a sustainability assessment is strongly recommended. A combined Safety, Sustainability, and Accessibility (SSA) framework would allow for a more holistic evaluation of EC functionality. Sustainability indicators should assess the EC’s capacity to support evacuees over time, including the availability of essential amenities such as separate sanitary facilities, breastfeeding and prayer areas, kitchens, and adequate floor area based on recommended space per occupant.

Evaluating population distribution at the barangay level, together with demographic characteristics such as age and gender, will further refine EC planning by identifying areas with higher demand for accessible and adequately sized evacuation facilities. When combined with sustainability-based capacity estimates, these variables can guide authorities in determining where additional ECs are most urgently needed.

Importantly, ECs classified as unsuitable under accessibility criteria should not be automatically excluded. Rather, these results signal the need for broader infrastructure and service improvements, including enhanced access to healthcare facilities, fuel stations, and communication infrastructure. Lastly, future studies should integrate safety, sustainability, and accessibility scores into a single composite suitability index, with carefully derived weights that reflect the principle that effective evacuation centers must be simultaneously safe, accessible, and capable of meeting basic human needs.

Overall, this study reinforces the critical insight that evacuation center effectiveness cannot be determined by safety or accessibility alone. By adopting a multi-dimensional assessment framework, future EC planning and policy interventions can be more resilient and responsive to the evolving risks intensified by climate change.

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