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# Evaluation of Public Buildings as Tsunami Evacuation Vertical Based on Tsunami History

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**Keywords:**
Public building; Vertical Evacuation Sites; Disaster; Tsunamis; Coastal Area.

**Abstract**
The research method was carried out through a survey of a number of buildings in the coastal area of Banda Aceh City. The analysis was carried out by comparing the floor heights of buildings with the historical height of the tsunami that occurred in 2004. Based on the survey results, it was found that there were 319 public buildings spread across the coastal area of Banda Aceh City. The percentage of each is known by the number of government office buildings (31.7%), educational facilities (40.8%), health services (5.6%), places of worship (16.6%), trade (2.2%), and other facilities (3.1%). From the analysis of building floor heights, a total of 194 buildings, or 60.81% of the total existing public buildings could function as alternative vertical evacuation sites for the tsunami disaster. This amount can accommodate 43.95% of the total population living in the surrounding area. Thus, part of the population can carry out vertical disaster evacuation. While others are planned through horizontal evacuation scenarios. Public buildings designated as vertical evacuation sites are only calculated from the safe height of the building floor. In contrast, in terms of the resilience of the building structure, it can be re-evaluated.

## INTRODUCTION

The tsunami disaster is a severe catastrophe with profound impacts on community life. The sea waves generated by a tsunami event can devastate residential homes and existing facilities and infrastructure. The experience of the tsunami disaster that occurred on December 26, 2004, resulted in a significant loss of lives and injuries. Tsunami waves, reaching heights of tens of meters, swept inland up to 6 km, causing a substantial loss of life, with 127,720 fatalities and 93,285 individuals reported missing (Syahbudin et al., 2009).

The need for Vertical Evacuation Facilities in tsunami-prone areas imposes a substantial financial burden on developing countries such as Indonesia. Rehabilitation and reconstruction efforts following the 2004 tsunami successfully led to the construction of several self-rescue buildings (escape buildings) in the Aceh region, with support from donor countries such as Japan. However, over the 18 years since the tsunami event, there has been no increase in the number of escape buildings, despite the insufficient evacuation capacity in residential areas, particularly in Banda Aceh. This reality results in a low capacity of a region to cope with the potential disaster.

In areas with flat topography, the idea of creating evacuation mounds must also be supported by soil conditions and the availability of adequate space. Therefore, in the near future, existing public buildings present an opportunity as an alternative Tsunami Evacuation Vertical (TEV). Public buildings that serve as gathering places for a large number of people can be utilized by the surrounding community as temporary TEV when tsunami disaster warnings are issued, and evacuation directives are provided by the authorities.

Temporary TEV can be determined by fulfilling certain criteria to ensure they serve as safe locations for tsunami disaster evacuation. Public buildings must adhere to aspects of safety, accessibility, functionality, and self-sufficiency (Permenpu, 2006). One of the criteria that must be fulfilled by Temporary TEV is that they should be designed with the strength to withstand the effects of tsunami waves and have a height that cannot be surpassed by the tsunami waves (FEMA, 2019; Rahayu & Anita, 2013). Similar to existing escape buildings, even though they were constructed post-tsunami disaster, reinforcing measures are required for the structural safety of the buildings (Idris et al., 2021).

The emergence of concerns regarding the safety of escape buildings has led many individuals to prefer horizontal evacuation during the earthquake event on April 11, 2012, in the city of Banda Aceh (McCaughey et al., 2017). However, horizontal evacuation can save lives if the available evacuation routes are adequate and the evacuation process proceeds smoothly. Infrequent simulation activities may hinder the effectiveness of disaster evacuation. Therefore, both the government and the community need to consider vertical evacuation activities. Similarly, scenarios for calculating the needs of TEV with the available capacity should also be taken into account.

Analysis of Building Tsunami Vulnerability (BTV) to tsunami disasters has been conducted in Casablanca, Morocco (Omira et al., 2010). The vulnerability level is calculated using a building type model, tsunami run-up height, and the existing coastal defense system. In general, the assessment of these building structures classifies the vulnerability level of existing buildings. The method for assessing the vulnerability level of these buildings is employed to select public buildings in the Kuta Alam district, Banda Aceh, as alternative TEV (Soviana & Rani, 2019). However, the calculation of the building's capacity takes into account the capacity of buildings specifically designed for evacuation, such as escape buildings, which may lack infrastructure such as chairs and tables. Therefore, the accuracy of the capacity calculations remains somewhat inadequate.

Modifications to the BTV analysis were conducted to assess a number of buildings in the city of Banda Aceh (Syamsidik et al., 2023). The building vulnerability calculations incorporated numerical simulations from a hydrodynamic perspective. These calculations can be performed when there are sufficient expert resources and adequate tools. However, not everyone may have the capability to conduct modeling, especially in government and emergency response agencies (Browning & Thomas, 2016).

This research aims to explore simpler methods for analyzing the potential of public buildings as TEV based on historical tsunami run-up heights reaching inland. The review focuses on the planning of evacuation sites with safe elevations for tsunami disasters (Scheer et al., 2011). The criteria for buildings include reinforced concrete structures, residential or public buildings with a minimum of 3 floors, and earthquake-resistant design. The assumption is made that public buildings scattered throughout the study area have been designed following earthquake-resistant building structure methods. The tsunami run-up height is determined based on the height of the nearby tsunami pole located to the north of the intended public building. This is due to the coastal position, which is the source of the tsunami waves, situated to the north of the city of Banda Aceh.

## RESEARCH METHODS

### *Research Location*

This research was conducted in the city of Banda Aceh, specifically in the four administrative regions directly adjacent to the Malacca Strait, as shown in Figure 1. The identified areas are the Meuraxa, Kuta Raja, Kuta Alam, and Syiah Kuala districts. The Meuraxa district experienced the most severe tsunami disaster in Banda Aceh, as its residential settlements are located very close to the sea. Following disaster rehabilitation and reconstruction, this area now has four evacuation buildings (escape buildings). However, the other three districts do not yet have specialized disaster rescue buildings like those in the Meuraxa district.

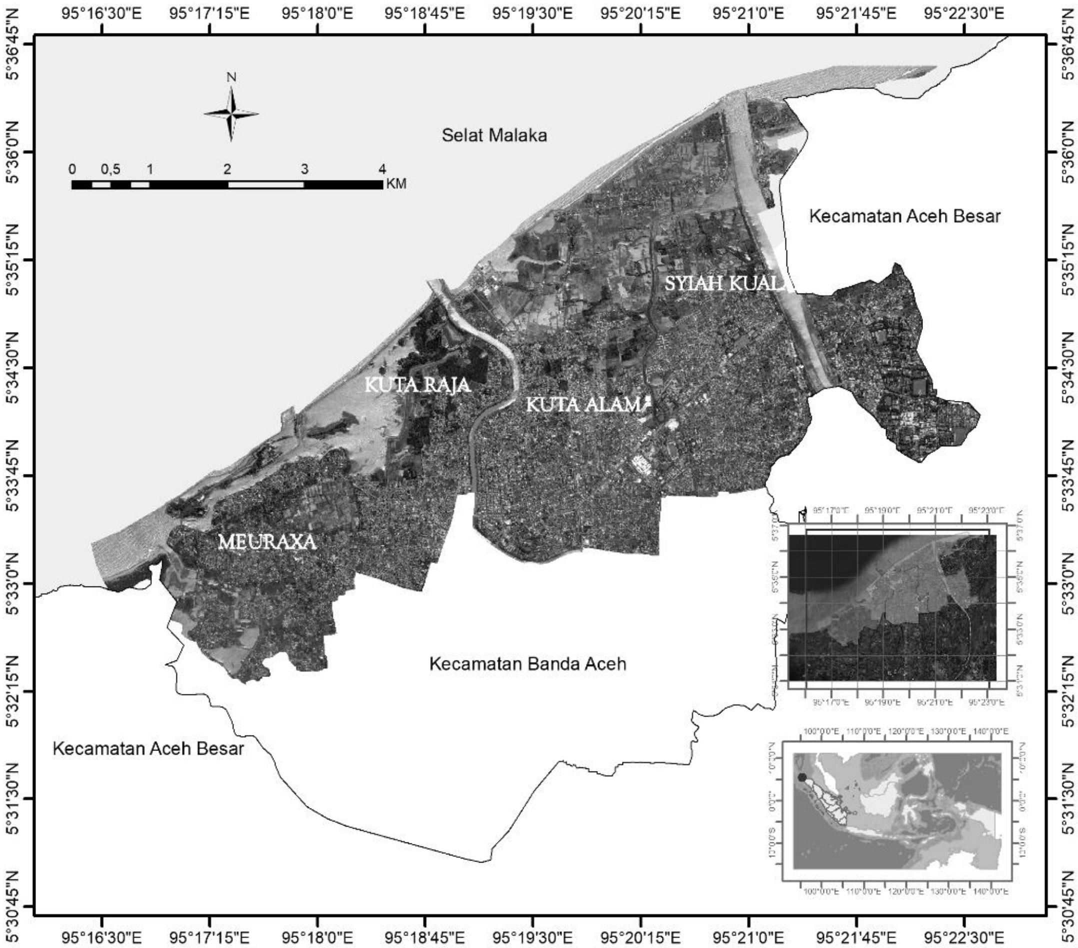


***Figure 1.*** *Research Location (Esri Imagery, 2021)*

*Tsunami Evacuation Vertical (TEV)*

Vertical evacuation is an evacuation activity involving walking to the nearest safe evacuation point during a disaster, while horizontal evacuation is the activity of moving from a hazardous area to a safer one (Dewi, 2012). The process of vertical evacuation is necessary when the available time is insufficient to move people from areas affected by a tsunami disaster to safer regions. Vertical evacuation is recommended for areas near the coast with dense populations, high tsunami risks, limited evacuation time, and congested road networks with low road capacities (Isya et al., 2021).

The need for Tsunami Evacuation Venues (TEV) arises due to the estimated time for evacuation activities (golden time), which is within the range of 10-30 (BNPB, 2012). Therefore, horizontal evacuation from locations with high vulnerability levels is a concern as it may exceed the golden time for evacuation. However, the influence of information circulating within the community can be considered as an option for horizontal evacuation, i.e., moving away from the coast, or vertical evacuation by heading to designated evacuation buildings (McCaughey et al., 2017).

The availability of escape buildings for disaster evacuation in the coastal areas of Banda Aceh is currently limited to four units, distributed in the Meuraxa district. This quantity is insufficient to accommodate the population residing around the escape buildings. From various scenarios examined regarding the tsunami disaster evacuation plan, it was found that out of the four escape buildings, only two, namely those in Ulee Lheu and Deah Geulempang, have sufficient capacity. In contrast, those in Lambung and Alue Deah Teungoh experience an excess capacity of up to 55% of the population expected to evacuate (Nurrady, 2015).

Temporary TEV can be utilized as evacuation sites for residents in disaster-prone areas who may not have sufficient time for horizontal evacuation. According to the Scenarios for Hazard-induced Emergencies Management (SCHEMA) guidelines, evacuation planning, in general, can make use of buildings with sufficient height, specifically those with more than three floors (Scheer, Gardi, Guillande, Eftichidis, Varela, & Vanssay, 2011). However, the calculation of the building height for use as a Temporary Evacuation Venue (TEV) can employ Equation 1 for determining the safe height

$$Safe\ height = (Max\ wave\ heigt\ x\ 1{,}3) + 1\ m \qquad (1)$$

Description: Safe height = Safe height of the vertical evacuation building, Max Wave height = Tsunami run-up height

The space required to accommodate one person is approximately 1 square meter. This area allows an individual to sit without feeling excessively cramped for a relatively short period (Bappenas, 2005).

*Data Collection*

Three variables are used in this research, including the height of public buildings, the tsunami run-up height in 2004, and the population count in 2020. The public buildings assessed include government offices, educational facilities, healthcare services, places of worship, commercial establishments, and other facilities, as shown in Figure 2.


***Figure 2.*** *Public Buildings (a) Syaria Office, Aceh Province (b) Place of worship (c) Community Health Center (d) Higher Eduction Institution and (e) Almahira Tarditional Market*

The tsunami inundation height is based on historical data from the 2004 tsunami, referring to the heights of tsunami poles scattered across the research area. The tsunami poles, constructed with the support of the Japanese community, serve as historical markers for the tsunami disaster that occurred on December 26, 2004, in Banda Aceh. There are a total of 67 tsunami poles in the city of Banda Aceh and 18 in Aceh Besar (Sugimoto et al., 2010). One of the tsunami poles constructed in the courtyard of the Lamgugop Mosque, Syiah Kuala

District, has a height of 1.8 meters and is located at a distance of 3.8 kilometers from the coast, as shown in Figure 3.


***Figure 3.*** *Tsunami Pole*

The population of Banda Aceh in each region is based on the latest and available statistical data from the Central Statistics Agency (BPS) of Banda Aceh. Some areas that experienced a very high population increase after the tsunami disaster are the Meuraxa and Kuta Raja districts. The population figures for each district in Banda Aceh are displayed in Table 1.

***Table 1.*** *The Population Data Based on Districts in Banda Aceh (BPS Banda Aceh, 2022)*

| No. | District | Year | | |
|---|---|---|---|---|
| | | **2005** | **2010** | **2020** |
| 1. | Meuraxa | 2.221 | 16.484 | 26.861 |
| 2. | Jaya Baru | 12.340 | 22.031 | 25.939 |
| 3. | Banda Raya | 24.257 | 20.891 | 25.228 |
| 4. | Baiturrahman | 33.582 | 30.377 | 32.513 |
| 5. | Lueng Bata | 19.284 | 23.592 | 24.336 |
| 6. | Kuta Alam | 35.033 | 42.217 | 42.505 |
| 7. | Kuta Raja | 2.978 | 10.433 | 15.291 |
| 8. | Syiah Kuala | 25.418 | 34.850 | 32.969 |
| 9. | Ulee Kareng | 22.768 | 22.571 | 27.257 |
| | Total | 177.881 | 223.446 | 252.899 |

The public building locations are in the Banda Aceh area, with exposure to tsunami hazards ranging from moderate to high levels in the Meuraxa and Kuta Raja districts, while the hazard levels vary from low to high in the Kuta Alam and Syiah Kuala regions, as illustrated in Figure 4.

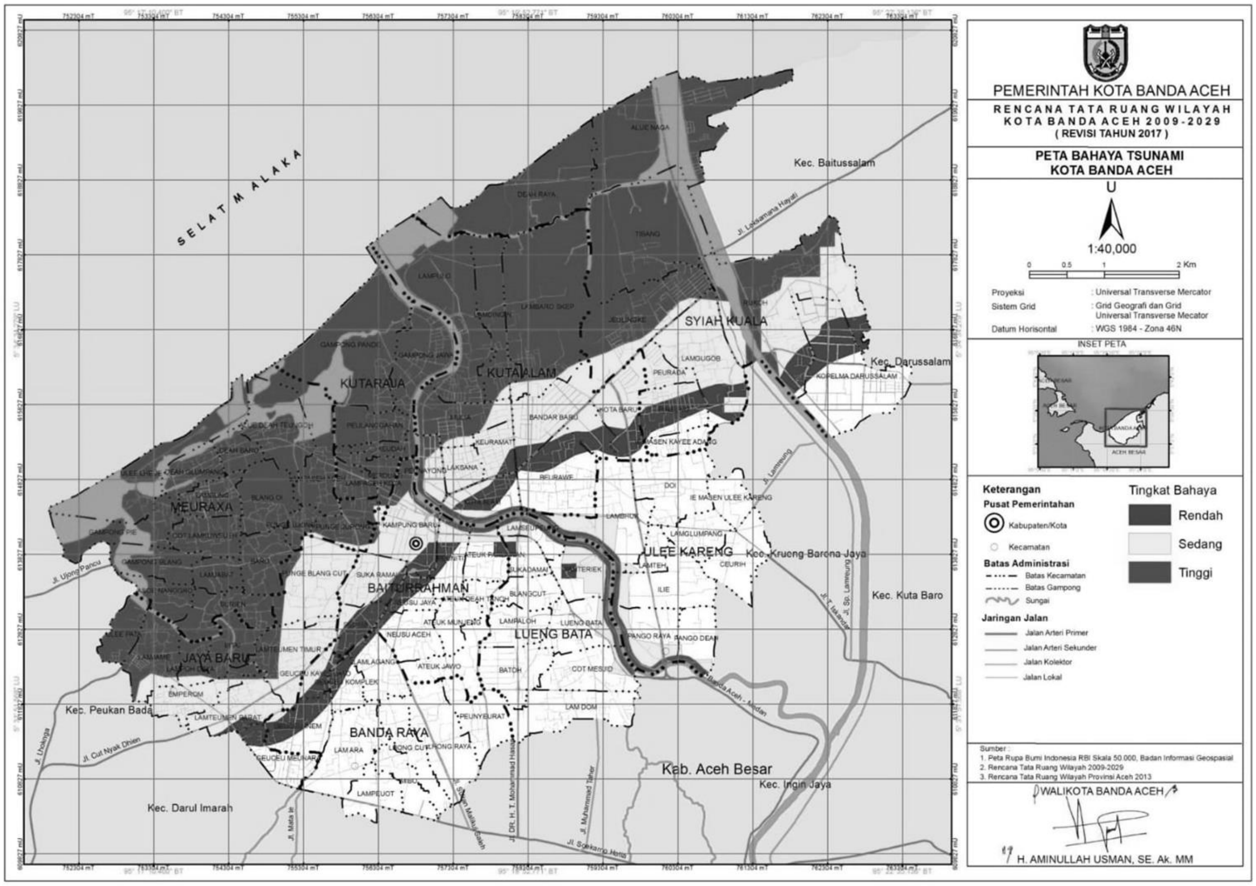


*Figure 4. Hazard Tsunami Map in Banda Aceh (Government of Banda Aceh City, 2021)*

*Survey and Analysis Data*

Data is collected through a survey conducted on a number of public buildings scattered along the coastal areas of Banda Aceh. The survey aims to determine the number of buildings based on the classification of building functions and identify the distribution zoning. The survey data collected includes the floor height and floor area of public buildings in the coastal areas of Banda Aceh, namely in the Meuraxa, Kuta Raja, Kuta Alam, and Syiah Kuala districts. Data on tsunami run-up height comes from historical tsunami data from the 2004 disaster obtained from tsunami poles. Population data for the Meuraxa, Kuta Raja, Kuta Alam, and Syiah Kuala districts are obtained from the Central Statistics Agency of Banda Aceh.

Next, the data is processed by calculating the safe height based on Equation 1. The results obtained from the safe height are used as a reference to determine whether public buildings are suitable or not suitable to be used as alternative TEVs. The survey results are analyzed based on the feasibility parameters of public buildings as vertical evacuation sites for tsunami disasters. Alternative TEVs are those with height values greater than or equal to the calculated safe height. For a clearer analysis, refer to the guidelines shown in Table 2.

***Table 2.*** *TEV alternative (Scheer et al., 2011)*

| **Available** | **Unavailable** |
|---|---|
| The building height ≥ Safe Height | The building height < Safe Height |

Suppose the measured height of a public building is greater than or equal to the safe height based on the calculation in Equation 1. In that case, the building is considered suitable as an alternative tsunami evacuation site. Conversely, if the measured height of the public building is smaller than the safe height, then the building is deemed unsuitable and is subjected to elimination.

After determining the buildings' suitability, public buildings' capacity is calculated using Equation 3. The next step is to calculate the capacity (occupancy) of public buildings deemed feasible based on the safe height. To determine the capacity of a building, data on building capacity is needed, considering the floor area, the number of floors, and the space required for each individual (Dewi et. al., 2012). The average space requirement for each person for standing or sitting activities is 1 m² (Bappenas, 2005). The calculation of building capacity for evacuation is determined by Equation 2.

$$TEBC = \frac{(CS\ x\ BA\ x\ NrF)}{SpP} \qquad (2)$$

Description: TEBC = Tsunami Building Evacuation Capacity (number of populations), CS = Capacity Scor (%), BA = Buildings Areas ($m^2$), NrF = Number of Floors, SpP = Space Required per Person ($m^2$).

Each type of building has a different calibration percentage between one building type and another. The percentage values for each building type are shown in Table 3.

***Tabel 3***. *Percentage Calibration of Building Capacity (Budiarjo, 2006)*

| **No.** | **Type of Building** | **Capacity Scor (%)** |
|---|---|---|
| 1. | Masjid / Place of Worship | 78 |
| 2. | School | 30 |
| 3. | Office | 23,6 |
| 4. | Market Place / Mall | 23 |

## RESULTS AND DISCUSSION

Data from the survey of a number of buildings along the coastal areas of Banda Aceh revealed that there are a total of 319 public buildings, including office buildings, educational facilities, healthcare services, places of worship, trade services, and other facilities (dormitories/hotels). The percentage distribution of the total number of buildings based on these functions is shown in Table 4.

***Table 4.*** *Classification of Building Types*

| No. | Types of Buildings | Number of Buildings (item) | Percentage (%) |
|---|---|---|---|
| 1. | Government Office | 101 | 31,7 |
| 2. | Educational Facilities | 130 | 40,8 |
| 3. | Health Service | 18 | 5,6 |
| 4. | Worship | 53 | 16,6 |
| 5. | Trade Facilities | 7 | 2,2 |
| 6. | Other Facilites | 10 | 3,1 |
| | Total | 319 | 100 |

From the analysis of the floor height of buildings that have a safe height concerning the tsunami run-up that occurred on December 26, 2004, it was found that 194 types of buildings can be used as temporary TEVs. The number and percentage distribution for each classification of buildings that can be used as TEVs are shown in Figure 5.

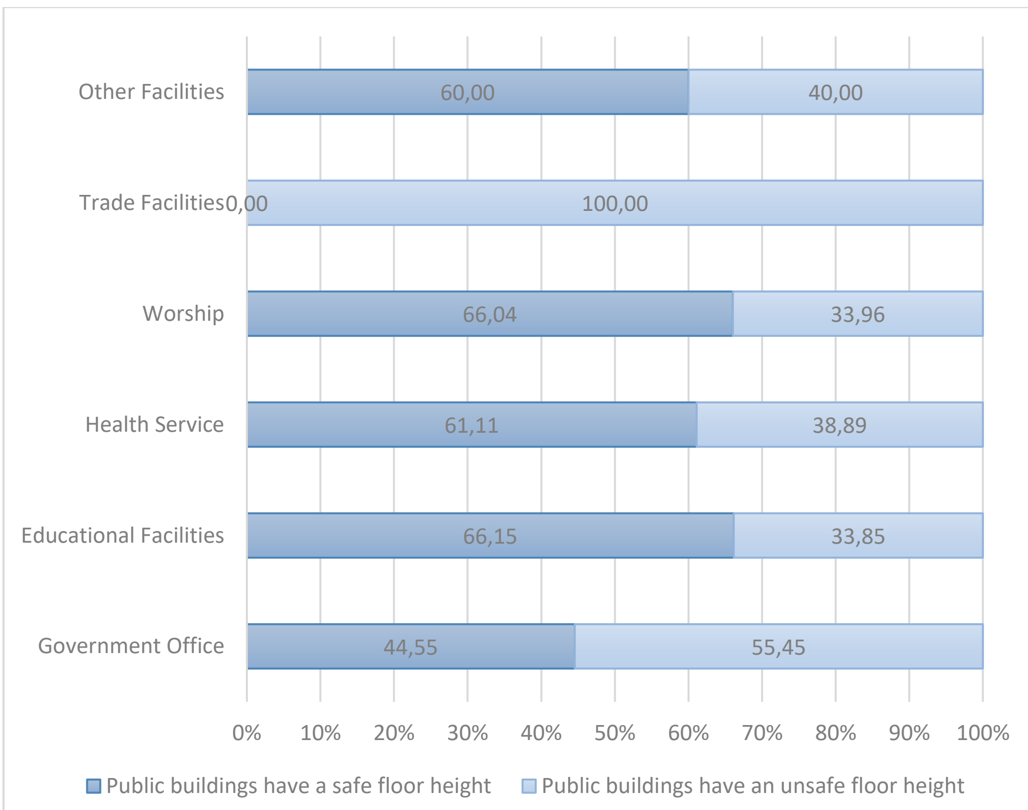


***Figure 5.*** *Percentage of Public Building Height against Tsunami Inundation*

Based on its distribution, public buildings in the coastal areas of Banda Aceh are concentrated in the Kuta Alam and Syiah Kuala districts. This is because Kuta Alam is the central office area, while Syiah Kuala is the central education area. As the capital of Aceh Province, Banda Aceh focuses on office activities serving local and national functions in the Kuta Alam district. Additionally, the Syiah Kuala district is the location of two prominent universities in Aceh, namely Syiah Kuala University (USK) and Ar Raniry State Islamic University. Consequently, educational facilities and places of worship dominate potential public buildings for temporary TEVs. There are no multi-story trade facilities in the coastal areas of Banda Aceh. The distribution of public buildings is illustrated in Figure 6.

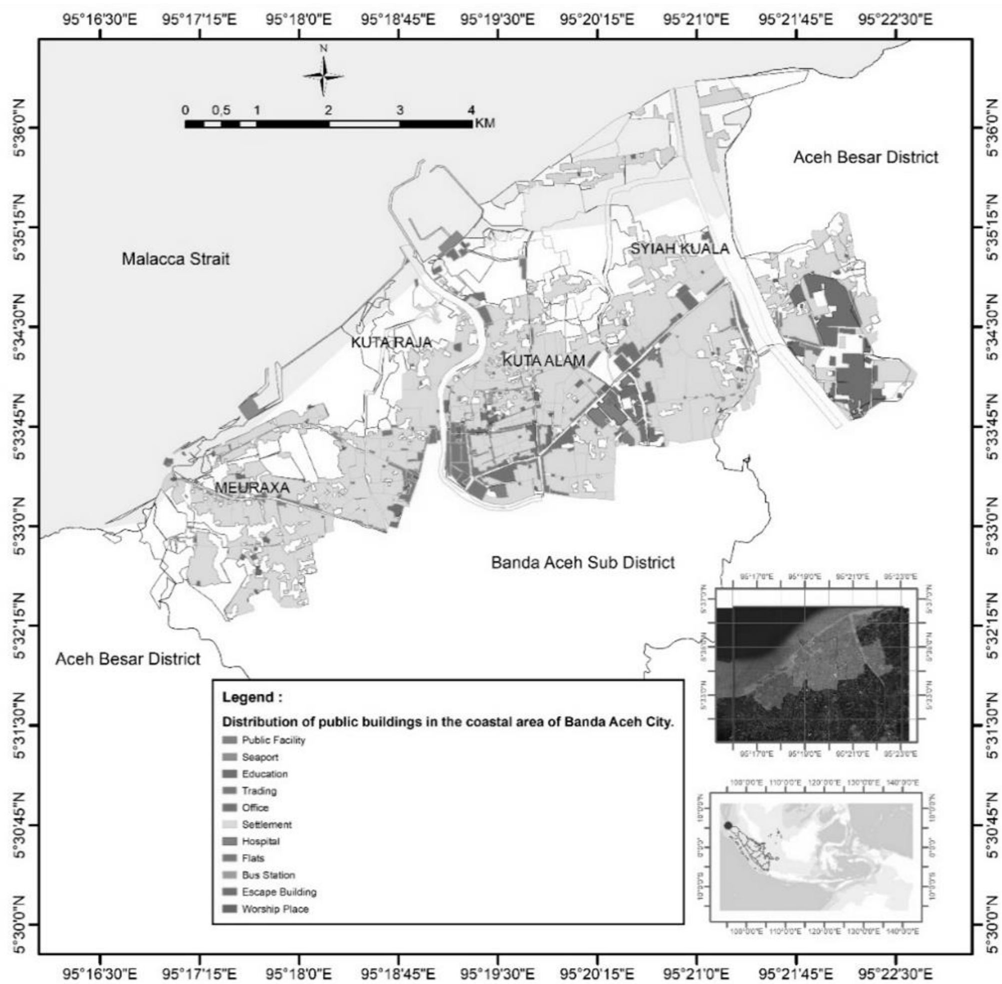


***Figure 6.*** *Map of the Distribution of Public Buildings in the Coastal Areas of Banda Aceh*

The comparison results of the number of public buildings scattered in each coastal area of Banda Aceh against the number of public buildings considered safe for disaster evacuation activities are shown in Figure 7.

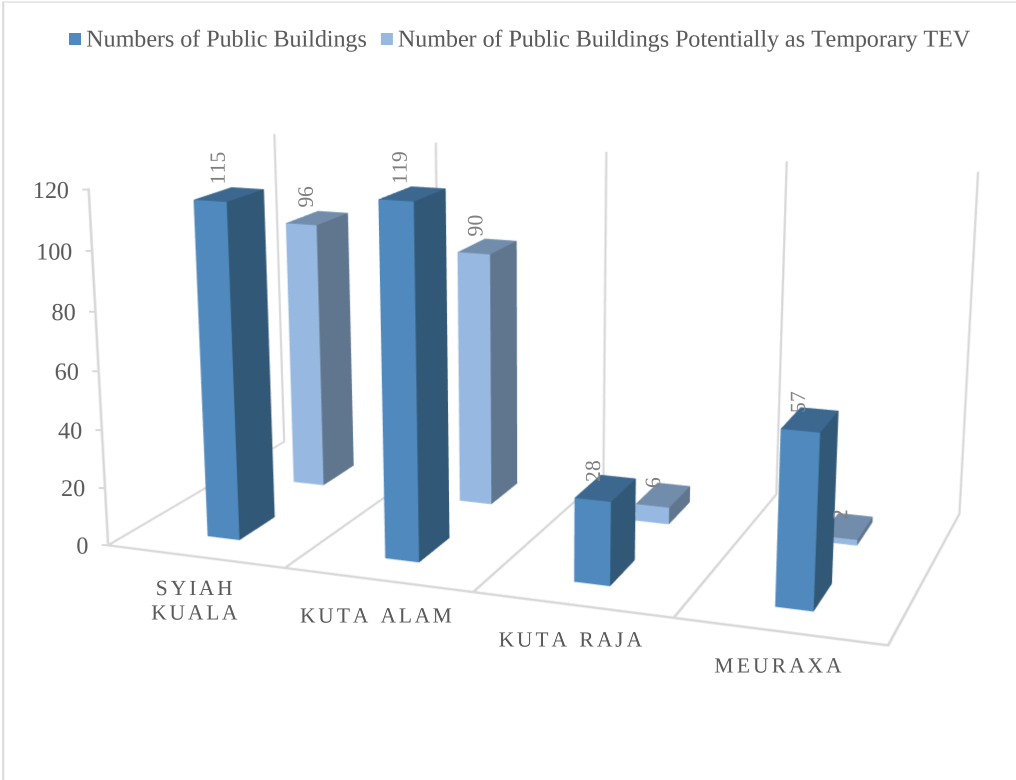


***Figure 7.*** *Distribution of Public Buildings in the Coastal Areas of Banda Aceh*

From Figure 7, it can be observed that among the total number of public buildings scattered in the area, the percentage of public buildings potentially serving as temporary evacuation centers (TEVs) is very high in the Kuta Alam district, reaching 75.63%, and in the Syiah Kuala district, reaching 83.47%. This is due to the characteristics of public buildings in these areas, which are generally 3 to 4 stories high, and some buildings are not located in the tsunami inundation zone during the 2004 disaster. On the other hand, the percentage of public buildings with potential in the Kuta Raja district is 21.42%, and in Meuraxa, it is only 3.50%. The total capacity of temporary TEVs is obtained by calculating the comfort level for each person in a given area. The capacity of public buildings in each region is shown in Table 5.

***Table 5.*** *Capacity of Public Buildings as Temporary TEV*

| No. | District | Population Number in 2020 (person) | Building Capacity (person) | Difference in Capacity (person) | Percentage of Capacity per District (%) |
|---|---|---|---|---|---|
| 1. | Syiah Kuala | 32.969 | 31.015 | -1.954 | 94,07 |
| 2. | Kuta Alam | 42.505 | 16.538 | -25.967 | 38,91 |
| 3. | Kuta Raja | 15.291 | 3.511 | -11.780 | 22,96 |
| 4. | Meuraxa | 26.861 | 643 | -26.218 | 2,39 |
| | Total | 117.626 | 51.707 | -65.919 | 43,96 |

Based on Table 5, the Syiah Kuala district has a relatively very good percentage comparison, with the percentage of alternative TEV capacity for its population reaching 94.07%. The percentage of alternative TEV capacity in the other 3 districts is relatively low, with capacities for each district being 38.91% in Kuta Alam, 22.3% in Kuta Raja, and 2.39% in Meuraxa.

The Meuraxa district is an area with a relatively small number of public buildings, although the exposed population is as high as 26,861 people. Even though there are 3 escape buildings and 1 former tsunami disaster mitigation research center (TDMRC) building available in the area, with each escape building having a capacity of 1000 people, the total capacity for vertical disaster evacuation is only 4,643 people. Therefore, the capacity is still insufficient, with a shortfall of 81.21% for the exposed population.

From the scenarios conducted in the Meuraxa district, only the escape buildings in the Ulee Lheu and Deah Glumpang areas have sufficient capacity to serve with a radius of 900 meters. However, the 2 escape buildings located in the Lambung and Alue Daya Teungoh areas are over capacity, exceeding 55% of the building's capacity (Nuraddy et. al., 2015). As a result, residents are required to evacuate horizontally.

The estimated total population exposed to the tsunami disaster is 117,626 people, and the capacity of public buildings is 51,707 people. With the addition of special escape buildings capable of accommodating 4,000 people, the total capacity of public buildings is 55,707 people. From this total, 46.50% of the coastal population in Kota Banda Aceh has the opportunity for vertical evacuation, while 53.50% must be planned for horizontal evacuation.

## CONCLUSION

From the obtained results, it can be concluded that public buildings in the coastal area of Banda Aceh City can be considered as an alternative for Temporary Evacuation Vertical (TEV). The total number of public buildings in that area reached 319 types, comprising office buildings, educational facilities, healthcare services, places of worship, trade establishments, and other facilities. Out of this total, 194 types of buildings, or 60.81%, meet the required safe height for evacuation and can be designated as TEV temporarily. The TEV, in this case, is predominantly composed of office buildings and educational facilities.

The total capacity of public buildings identified as TEV can accommodate 43.95% of the population in the surrounding area. However, the uneven distribution of these buildings highlights the need for specific attention in planning alternative forms of vertical evacuation in the regions of Meuraxa, Kuta Alam, and Kuta Raja.

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