Study of alternative building for tsunami evacuation in Kuta Alam sub-district Banda Aceh

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Abstract. Kuta Alam Sub District has many potential hazards, especially from the sea. The location of the area that is directly adjacent to the sea causes it to be very vulnerable to tsunami. Its topography is lowland less than 1 meter above the sea-level. Tsunami in 2004 had taken a great number of people lives in the area about 14.95 % of the total number of inhabitants which is 55,030 people that time. However, there is still no any evacuation building available in Kuta Alam to escape from Tsunami. We know tsunami which might be occurred anytime unpredictable. In order to save people’s lives, it is needed to conduct a study to find alternatives buildings to be used for evacuation and rescue in the area. The aim of this study to identify the locations and number of alternative buildings that are potential as the tsunami evacuation building in Kuta Alam Sub-district. The study used the survey system toward the buildings with qualitative and quantitative approaches. Data analyzing is conducted spatially through geographic information systems. Based on observation results toward evacuation building in Kuta Alam Sub-district, there are some buildings renovated in order to be functioned as tsunami evacuation buildings. The renovation should be done on roof, school, and ladder evacuation of the mosque that are selected as evacuation buildings. Until today, those buildings have not been renovated to be eligible as evacuation places. The result found that there are 45 public buildings that can be used for alternative evacuation buildings in Kuta Alam Sub-district. That can accommodate 94.06 % of the total number of people this time which is 49,011 people.

1. Introduction
A region will potentially risk whether from natural or unnatural disasters. The condition of topography and geography of the area potentially impacted by the natural disaster [1]-[3]. For the area that is bordered on the ocean like Kecamatan Kuta Alam is very vulnerable toward the disaster come from the sea such as a hurricane, sea abrasion, and tsunami.

Tsunami in 2004 caused massive destruction and killed so many people in almost every area of Banda Aceh. One of the impacted areas was Kuta Alam Sub District. There were 8,227 people killed or 15% of the inhabitants [4]. There are some factors why there were so many people killed at that time, such as lack of information or knowledge of the people about the disaster potential risk and how to reduce the risk [5]-[7]. Moreover, there was no clear evacuation direction. For the overcrowd area, was conducted by running, however for the target location, more than 4 km would be hard to reach on foot if the golden time less than 30 minutes [8]-[10].
From the ancient history (paleo tsunami), a tsunami occurred in 1000 AD, between 1350 -1550 AD and after 1800 AD in Aceh that washed away Aceh coastal area [11][12]. While this information was never known by Acehnese people that caused how unprepared people when the tsunami strike. In order to avoid that, National Disaster Management Coordinating Board (BNPB) has stated that Aceh Province is disaster-prone area [13]. Aceh, located near to the subduction zone in the Northern of Sumatera island, the convergence of two very active tectonic plates, Indo-Australia and Eurasia that potentially cause earthquakes and tsunami.

As the vulnerable tsunami impacted, it is very important to have mitigation base site planning and urban design program that is integrated with disaster mitigation principles [14][15]. Actually, in Qanun Banda Aceh District Government No. 4 in 2009 about Urban Planning in Banda Aceh city has included the problem of tsunami threat and mitigation. According to the Qanun, city planning design in the future must give safety and less vulnerable to the communities. It can be done by providing evacuation space and escape buildings to save more lives [16][17]. In fact, there is not all of this implemented in reality for example in Kuta Alam Sub District which isn’t any escape building yet to anticipate the inevitable tsunami attack.

In order to apply the standard requirements of the buildings in the tsunami vulnerable area, it needs a very high cost. The government as the funder should decide to prioritize providing public building as the alternative for escape building in order to reduce the risk of life loss [18][19]. So that public buildings with two floors such as school and government offices expectedly can be alternative as evacuation place however with the calculated and measured standard capacity resistance of the buildings [20][21].

Based on [22] the research’s result shows that the dominant criteria of the potential escape building could be applied in Banda Aceh are it is located in the position > 500 from the coastline with distance range < 1 km and adapted to the building capacity; road access to the building; evacuation signs clearly seen; it can be accessed by the community 24 hours without any obstacles; it has the emergency stairs outside the building and can be used as the access toward the safe place located above the tsunami water average (run-up) predicted.

This study aims to identify the locations and number of alternative buildings that are potential as the tsunami evacuation building in Kuta Alam Sub-district. Before that, the study conducted with observation toward the number of public buildings in Kuta Alam District area. Literature research conducted in order to know how the exposure of hazards to the buildings in vulnerable tsunami areas. The vulnerability of the buildings can be identified from the study. Basic assumptions of determination of building exposure depend on buffer zone in the seashore. For the building, vulnerability is based on its height and numbers of floor and material construction.

2. Design of Experiment
This study used qualitative and quantitative approachment. This method measures the level of building resistance toward the hazard threat of tsunami with primary reference toward the tsunami on December 26th, 2004. The survey activity conducted directly toward every public building in Kecamatan Kuta Alam. The endurance level decided based on an initial survey which is determined by building structure and the height of the building. Based on initial survey of structure, there five types of building available in Kuta Alam. Table 1 explains in detail endurance assessment from building type as the reference to conduct survey.
Table 1. Type of buildings based on structure endurance level and its height [23]

| Type of Building | Structure | Level of building endurance | Classification (Fcb) |
|------------------|-----------|-----------------------------|---------------------|
| Type A           | - Reinforced concrete ≥ 3 floors  
                  - Reinforced concrete column diameter ≥ 30 cm  
                  - Brick wall  
                  - Reinforced concrete foundation | - Tsunami-resistant buildings  
                  - Good column structure condition and connected with the reinforcement on the foundation  
                  - The height of the building > 9 m | Very good (1) |
| Type B           | - Reinforced concrete ≥ 2 floors  
                  - Reinforced concrete column diameter ≥ 30 cm  
                  - Brick wall  
                  - Reinforced concrete foundation | - Tsunami-resistant buildings  
                  - Good column structure condition and connected with the reinforcement on the foundation  
                  - The height of the building 3 - 9 m | Good (2) |
| Type C           | - Concrete floor 1  
                  - Reinforced concrete column diameter ≤ 20 cm  
                  - Brick wall  
                  - Rock foundation | - Buildings are less tsunami-resistant  
                  - Good column structure condition and connected with the reinforcement on the foundation  
                  - The height of the building < 3 m | Not good (3) |

3. Experimental Procedure

There are three parameters used as a benchmark for determining level of building vulnerability toward tsunami threat; they are (i) building condition, (ii) inundation zones, and (iii) sea defense [24]. Each has different values toward the effect of building vulnerability as displayed in Table 2.

Table 2. Parameters of building tsunami vulnerability [24]

| Parameter       | Score |
|-----------------|-------|
| Building condition | $F_{wb} = 3$ |
| Inundation zones | $F_{wi} = 2$ |
| Sea defence      | $F_{ws} = 1$ |

The selection of alternative evacuation building is based on tsunami vulnerability analysis. The proper tsunami evacuation buildings are not the ones classified into high vulnerability. For inundation zones based on the condition Aceh tsunami in 2004. The height of inundation reference taken from tsunami height memorial poles [25]. The damaging impact of the building caused by the height of tsunami struck referred to the Master Plan of tsunami impact risk reduction, which was published by National Board for Disaster Management [26], as presented in Table 3.

Table 3. Indicator of building vulnerability for inundation zones [26]

| Type of inundation | The risk level of inundation | Inundation height | Power failure | Vulnerability (Fci) |
|--------------------|------------------------------|-------------------|---------------|---------------------|
| Type A              | Low                          | ≤ 1 m             | Little        | 1                   |
| Type B              | Medium                       | 1 – 3 m           | Medium        | 2                   |
| Type C              | High                         | ≥ 3 m             | Big           | 3                   |

Buffer zones can be functioned as a natural brigade that would reduce tsunami wave pressure [27]. There two types of buffer zones conditions in Kuta Alam, first, the areas with mangroves and the other
without mangroves. So that the assessment indicator for tsunami vulnerability buildings involved by buffer zone condition as displayed in table 4.

Table 4 Indicator of building vulnerability for sea defense [24]

| Sea defense | Characteristic                    | Level of defense ability | Vulnerability factors (Fcs) |
|-------------|----------------------------------|--------------------------|----------------------------|
| Mangrove    | The presence of Mangrove vegetation | Good                     | 1                          |
| Cultivated land | Dryland and aquaculture pond | Bad                      | 2                          |

The data obtained were analyzed using the equation building tsunami vulnerability (BTV) against tsunami hazard by using building condition inundation zones parameters and sea defense [24]. Based on the parameter above, the equation for calculating the level of vulnerability of the public buildings assessed used equation 1 as followed.

\[
BTV \% = \left( \frac{F_{wb} \times F_{cb}}{\sum_{k=1}^{k} (F_{cmaks} \times F_{w})} \right) \times 100
\]

Where \( F_{wb} \) = building weigh factor; \( F_{cb} \) = building condition factor; \( F_{wi} \) = inundation weigh factor; \( F_{ci} \) = inundation factor; \( F_{ws} \) = sea defence weigh factor; \( F_{cs} \) = sea defence factor; \( k \) = constant; and \( F_{cmaks} \) = indicator maximum.

4. Results and Discussion
A map of the spread of tsunami alternative evacuation buildings in Kuta Alam Sub-district areas can be seen in Figure 1.

![Figure 1. Map distribution of evacuation buildings in Kuta Alam Subdistrict](image)

Results obtained were analyzed further in spatial using Geographic Information System (GIS) for Kuta Alam Sub-district with scale 1: 250,000 following the requirements stated by BNPB for
describing the areas in detail in small scope of the area. Furthermore, followed creating map to spot tsunami alternative evacuation building in Kuta Alam Sub-district.

Evacuation buildings alternative was able to accommodate 46,100 people, while the total number of Kuta Alam population is 49,011. Based on the result above, evacuation buildings in Kuta Alam can accommodate 94.06% of the total number of population. The calculation of evacuation building capacity in each area in Kuta Alam in detail can be seen from Table 5.

### Table 5. The capacity of alternative evacuation buildings

| No. | Name of Village | Building Capacity | Population Number | Difference | Description |
|-----|----------------|-------------------|-------------------|------------|-------------|
| 1   | Lampulo        | 500               | 5,071             | -4,571     | Not enough  |
| 2   | Lamdingin      | 200               | 2,738             | -2,538     | Not enough  |
| 3   | Lambaro Skep   | 1,700             | 4,855             | -3,155     | Not enough  |
| 4   | Mulia          | 7,300             | 3,295             | 4,005      | more        |
| 5   | Peunayong      | 3,200             | 4,658             | -1,458     | Not enough  |
| 6   | Laksana        | 1,200             | 5,096             | -3,896     | Not enough  |
| 7   | Keuramat       | 3,600             | 4,816             | -1,216     | Not enough  |
| 8   | Kuta Alam      | 8,500             | 6,617             | 1,883      | More than enough |
| 9   | Bandar Baru    | 8,400             | 4,348             | 4,052      | More than enough |
| 10  | Beurawe        | 3,000             | 5,864             | -2,864     | Not enough  |
| 11  | Kota Baru      | 8,500             | 1,653             | 6,847      | More than enough |
| **Total** | **Kuta Alam Subdistrict** | **46,100** | **49,011** | **-2,911** | **Not enough** |

Based on observation results toward evacuation building in Kuta Alam Sub-district, there are some buildings renovated in order to be functioned as tsunami evacuation buildings. The renovation should be done on roof, school, and ladder evacuation of the mosque that are selected as evacuation buildings. Until today, those buildings have not been renovated to be eligible as evacuation places.

Alternative tsunami evacuation buildings are public buildings which are appropriate as safe building. They are determined according to vulnerability building assessment results. The vulnerability which is classified to be middle and low would be used for evacuation. There 45 units of building in Kuta Alam that can be as tsunami evacuation buildings, such as school, government office, hospital, etc.

The capacity of evacuation buildings available in Kuta Alam is still less in some areas, especially in high-risk tsunami areas. The area was tsunami puddles $> 3$ meters, such as Lamdingin, Lambaro Skep, and Lampulo. So that the evacuation process should be appropriately designed to prevent more casualties, vulnerable communities such as senior citizens, disable, and children should be priority to be evacuated to public buildings in the area while the ones who are physically good would be evacuated to other safe areas.

Kuta Alam Sub-district is included as prone to tsunami disaster because it borders directly with the sea; besides it has the greatest number of populations in Banda Aceh. Despite not having any particular evacuation building, but there are adequate public buildings available to accommodate 94.06% of population as alternative for tsunami disaster evacuation.

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Acknowledgments
This research was supported by Aceh government. The authors would like to be obliged to Muhammadiyah Aceh University for providing laboratory facilities and financial assistance under project.