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Preparedness of Tsunami Disaster in Pandeglang Region Due to The Activity of Mount Krakatau

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ABSTRACT

Pandeglang Regency is one of the areas with the most building damage in The 2018 Anak Krakatau Tsunami. The tsunami in 2018 was caused by the activity of Anak Krakatau Volcano in the form of an avalanche of material on the volcano's cliffs. The subdistricts in Pandeglang Regency affected by the tsunami were Carita Subdistrict, Labuan Subdistrict, and Panimbang Subdistrict. This research evaluates potential damage to buildings to determine the condition of the existing land, determines an evacuation route to a temporary evacuation site (TES), and simulates a tsunami evacuation using this evacuation route. Parameters of run-up height and building type are used as parameters for assessing building damage. The determination of TES is influenced by run-up height, elevation, and distance from the shoreline. Evacuation route planning and evacuation simulation are based on the assumed number of evacuees and the scenario of a tsunami evacuation. The results showed moderate damage to buildings in Carita Subdistrict, Labuan Subdistrict, and Panimbang Subdistrict. The examination of existing land as TES, namely Carita Vacant Land, Carita 1 Middle School, LDII Labuan Mosque, Labuan Shelter Building, Panimbang Vacant Land. According to the tsunami evacuation scenario during the day, evacuation time results for 25-30 minutes with an average speed of > 1 m/s. The tsunami evacuation time at night is free of obstacles or with obstacles for 50-85 minutes with an average speed of 1 m/s. The tsunami evacuation time at night is full of free and obstacle-free tours for 60-100 minutes with an average speed of 0.5 m/s. Evacuation time based on simulation results is compared with evacuation time calculated by ETA and other studies as data validation to determine the probability of community preparedness in the Pandeglang Regency. The preparedness community in Pandeglang Regency is in the ready category by 25% in the Carita subdistrict, Labuan subdistrict, and Panimbang Subdistrict.

1. Introduction

The last Sunda Strait tsunami occurred on December 22, 2018 caused by the material collapse of Anak Krakatau Volcano. The material collapse triggers an underwater avalanche, so it is classified as a rare phenomenon. The height of Anak Krakatau Volcano was originally 338 m and the height after the eruption was 110 m above sea level. Anak Krakatau Volcano formed when there is a composite eruption sequence Alkaline magma was seen at the Krakatau Complex Center on 29 December 1927-18 February 1929, until finally in 1929 it was declared the birth of Anak Krakatau Volcano. After the emergence of Anak Krakatau Volcano, the mountain grew rapidly due to frequent eruptions almost every year. The resting period for the eruption of Anak Krakatau Volcano ranges from 1 to 8 years. Eruption occurs on average once every 4 years. Based on the history of the eruption, period eruptions always move around the body of the mountain cone [1].

The process of the avalanche of Anak Krakatau Volcano is similar to the cliff slide of Mount Stromboli, where the slide entered the water body quickly and triggered a tsunami wave as high as 8 m in 2002 in Italy [2]. Tsunamis caused by volcanic activity are difficult to predict and monitor because events generally occur quickly. The coast of the Sunda Strait in Banten Province is a tsunami-prone area originating from the avalanche of the body of Mount Anak Krakatau, material from the eruption of Anak Krakatau. The characteristics of the coast in the Sunda Strait in the Banten area are generally sloping beaches where there are rarely coastal barriers in the form of beach

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walls or coastal embankments and vegetation, making them prone to tsunamis [3].

Based on data from the National Disaster Management Agency (BNPB), the Sunda Strait Tsunami on December 22, 2018, hit the coasts of Banten and Lampung Provinces with more than 430 fatalities and damaged infrastructure. The worst infrastructure damage occurred in Pandeglang Regency, Banten Province. Based on these conditions, the west coast of Pandeglang Regency faces the Sunda Strait. The west coast areas of Pandeglang Regency which were the most severely affected by the tsunami were the Labuan Subdistrict, Panimbang Subdistrict, and Sumur Subdistrict. The height of the tsunami waves reached 1-6 m with an inundation reach of up to 200 m from the coastline [4]. Therefore, this study links the influence of the height of the tsunami waves with the determination of existing land as TES and evacuation simulations using the right evacuation route to TES.

1.1 Tsunami Caused by a Volcanic Eruption

Volcanic eruptions under the sea or above the sea can cause tsunamis. When it erupts, the mountain releases various earth materials. Then the materials that are on the mountain can scatter towards the beach and can cause a tsunami. One example of a tsunami that occurred as a result of a volcanic eruption was the Sunda Strait Tsunami in December 2018, the eruption of Anak Krakatau Volcano was suspected of causing seawater to rise to result in a tsunami [5]. The activity of Mount Tambora in West Nusa Tenggara was the cause of a tsunami with more than 10,000 fatalities in 1815.

Volcanic tsunamis can occur as a result of caldera collapse, tectonic movement from volcanic activity, or pyroclastic decay in the form of volcanic ash and bor pumice composed of very large amounts of dacite-rhyolite that a volcano with the influence of seawater. The damage caused by the tsunami waves mainly occurred in the bay area due to the narrowing of the wave motion which affected the speed of the wave motion. Tsunami waves are shallow water waves because they depend on speed.

The process of causing a tsunami due to a volcano, where the first stage of the original summit of a volcano is the initial peak of the volcano. The volcano started collapsing and the magma was uncovered, and it showed explosive smoke down the side of the mountain. Debris from the volcanic avalanche is moving towards the sea. The stages of tsunami form are the process by which a tsunami begins to form and there are high waves that hit the area around the volcano. The final stage of the wave travels out to distant coastlines where the waves move quickly towards the edges of the coast around the volcano [6].

1.2 Run-Up Wave

When an incident wave hits a structure, the water carried by its momentum is pushed up and creeps up the surface of the structure. The vertical height of the SWL that the incoming waves achieve is called wave run-up. Waves that propagate toward the coast when they hit a breakwater will experience run-up on the surface of the building. Wave run-up is related to the effectiveness of the building because the building structure must be able to withstand water friction on the building surface [7]. Buildings with rough structural surfaces produce run-ups with lower heights than those with fine structures. Friction is one of the factors causing the surface of the rough structure to be greater than the surface of the fine structure [8].

1.3 Building Damage Evaluation

There are 2 major groups of evaluation of building damage, namely evaluation of buildings that are still standing and damaged as a result of an evaluation of buildings that have suffered damage due to a natural disaster. The categories of building damage are as follows.

1. Minor damage, i.e. the building is still standing and there is no structural damage.
2. Moderate damage, i.e. the building is still standing and there is minor damage to the structural components.
3. Serious damage i.e. collapsed building

FEMA 302 states that buildings can be divided into three groups of buildings, among others.

1. Building group III is a group of public facility buildings, where buildings can be used for emergencies after an earthquake occurs. Group III buildings contain a very large amount of hazardous materials and the buildings are fire departments, police stations, hospitals, and power plants.
2. Building Group II is a group of public facility buildings with the capacity for many community activities. For example, buildings for education, or buildings with more than 300 people having activities in them. The performance level of group II buildings after an earthquake occurs must be able to continue operating, although not fully.
3. Building group I is a group of buildings not included in groups II and III, where buildings have a large plastic response due to disasters. The performance level of this group of buildings in the aftermath of the

earthquake is divided into two levels of performance, namely the level of occupant safety or life safety and the level of collapse prevention or near collapse which can also be called collapse prevention [9].

Several classifications of building damage used to determine damage classification are satellite remote sensing and field surveys, which are often used in combination. Building damage by the remote survey is mostly classified into two main conditions, safe or collapse, depending on the condition of the roof of the building. The post-tsunami field survey classified the level of damage into 4 to 6 classes depending on the level of damage and the part of the building that was damaged [10]. Four statuses of damage (minor, moderate, major, and complete) are used to describe damage to windows up to columns [11]. Suppose, et al. classified the damage into four states, from minor to total, for the 2011 Greater East Japan tsunami [12]. Reese, et al. Surveyed 201 buildings and classified the damage into five conditions based on consideration of non-structural damage by resolving structural collapse after the Pacific tsunami south 2009, where the classification of damage is minor, minor, moderate, severe, and complete [13].

1.4 Existing Building

Existing buildings generally can use Adaptive Reuse, where the building can be modified from a public building to suit the existing function. Studies related to the benefits of Adaptive Reuse can provide three benefits, including environmental aspects, social aspects, and economic aspects. Adaptive Reuse is an alternative strategy for providing temporary housing. Adaptive reuse in providing shelter for refugees in the context of disaster mitigation is used to provide an assessment of the potential of buildings that can be transformed into temporarily habitable buildings as an advanced stage in disaster mitigation. Adaptive Reuse (AR) applies the concept of reusing unused buildings. According to Ideman [14].

Evaluating the vulnerability of existing buildings can be carried out in two stages [15]. The first stage is in the form of a rapid assessment called Rapid Visual Screening (RVS) using the FEMA 154-2002 assessment procedure. If in the first stage the building is considered at risk, then it can be continued in the second stage, namely in the form of a detailed evaluation using the assessment procedures in FEMA 310 and FEMA 356. The results of the assessment in the second stage can be used as a basis for subsequent disaster risk reduction actions, whether the building can be strengthened (retrofitting) or torn down (demolish). Rapid Visual Screening (RVS) is a visual inspection of the condition of the building, including structural and non-structural, architectural, and utility buildings. Rapid Visual Screening (RVS) evaluation is carried out by filling out the available form and calculating a score by identifying the level of vulnerability of the building. Score assessment is done by circling the score at the bottom of the building type according to the building evaluation. Scores are added up after being circled. The results of the assessment of the building's vulnerability score identified that the building has a value of more than 2 including a low level of vulnerability to earthquakes and a building with a value of 2 includes buildings with a high vulnerability to earthquakes [15].

1.5 Evacuation Route

Evacuation routes are routes that can be used for direct and fast transfers, whereby refugees stay away from tsunami hazard areas. There are 2 types of routes, namely small-scale evacuation and large-scale evacuation. An example of a small-scale evacuation route is the rescue of a building caused by a bomb or fire threat. An example of a large-scale evacuation route would be rescued from an area prone to flooding, volcanic eruptions, and storms. The conditions for proper and adequate evacuation routes are as follows [16]:

1. Pathway safety is used for the safe evacuation of potentially dangerous objects.
2. The distance traveled by the evacuation route is used for evacuating from the original residence to a safer place with a short distance to a safe place.
3. The feasibility of the route must be suitable for use during evacuation so that it does not hinder the evacuation process.

Not all the estimated time of arrival of a tsunami or ETA (estimated time of arrival) can be used as an evacuation time. While there is time to detect a tsunami, time to prepare, and time to get to safety. Empirical calculations for the analysis of evacuation time, speed, and distance. Factors that affect the calculation are the maximum distance of the evacuation site based on the warning time. Formula calculation The ETA used is as follows [17]:

$$ETA = \frac{L}{V} \tag{1}$$

where ETA is estimated time of arrival (s), L is the evacuation route length (m), V is slow walking speed (m/s).

Evaluate evacuation routes using numerical simulations based on Dijkstra's Algorithm. Numerical simulation based on capacity and suitability by the reality in the field. Dijkstra's Algorithm is an algorithm that can be used to determine the shortest path to a predetermined shelter. Dijkstra's algorithm (1959) is similar to the A* algorithm but without the heuristic features. The heuristic feature is a feature used to guess the shortest possible path to the target. This A* algorithm serves to determine smooth paths and turns. Dijkstra's algorithm requires a longer computation time to check all nodes up to the target because it is the result of an increase in computational algorithms [18].

1.6 Running Speed and Assumptions of Running Behavior and Constraints

According to Steudel-Numbers et al. [19], taller people can run faster. The male volunteers (179.6 cm) were an average higher than the female volunteers (168.2 cm) with the most efficient running speed at 3.7 m/s in men, while female volunteers ran at 2.9 m/s s while the test ran for 5 minutes. The average height of male and female Indonesian citizens is 158 and 147 respectively Therefore, the average Indonesian population (healthy but not athlete running speed is much slower). Imamura et al. simulated evacuation during a tsunami event in Indonesia using a constant average running speed of 1.67 m/s, which is slightly faster than the preferred walking speed of 1.42 m/s [20]. Goto et al. used a slower running speed of 1.5 m/s for the average person when no one else is within 1 m^2 [21]. Factors that affect the speed of a refugee running to a safe place are as follows:

1. Evacuee’s physical condition (gender, age, health, disability).
2. Preparedness (shoes, clothing, any items, or baby to bring).
3. Distance of run.
4. Crowd density.
5. Road conditions (soft sand, hard sand, paved road, steep slope, stairs, slippery road, rocky road, road with obstacles, visibility).

The running speed considering age and gender factors can be determined based on world running records. The following equations were prepared to represent the impact of age and gender on running speed:

$$Vc = C(kA/A_0)^k \, e^{-(kA/A_0)} \quad (2)$$

where Vc is the individual running speed capacity (speed run unhindered on paved roads) for certain running distance; C and K is the constants related to gender, age, and running distance; A is the age of evacuee; A_0 is the optimum age for maximum running speed capacity [22].

2. Method

This research activity was carried out in several subdistricts of Pandeglang Regency, Banten Province. The results of the observation in the field are (1) Carita Subdistrict, (2) Laban Subdistrict, and (3) Panimbang Subdistrict.

The data or materials in this study are primary data and secondary data. Primary data is data obtained directly during research in the form of field observations to determine TES and evacuation routes. Secondary data is data obtained from research that has been done in the form of data on run-up height, the distance of tsunami inundation, type of building, and population density.

This research activity aims to determine the evacuation route by using the damage assessment of the building and the condition of the existing building. Based on this, the researcher prepared a research procedure by considering several parameters to achieve the desired results. In solving the problem, the researcher conducted field observations to find out the condition of preparedness in the Pandeglang area.

Determination of run-up height is done by weighting. The weighting results are classified into several categories of building damage. Examination of existing land in Pandeglang Regency as TES with the results of observations in the field. The determination of TES is based on elevation, distance from the shoreline and the area of the building to accommodate the number of evacuees. Determination of the assumed number of refugees taking into account Perka BNPB No. 7 of 2008 concerning Guidelines for the Provision of Assistance to Fulfill Basic Needs where the assumed number of refugees is 1% of the total population, tourists, and the time of disaster occurrence both during the day and at night. Therefore, the assumed number of refugees is set at 1000-2000 people from the total population. The total number of people is based on population data according to BPS (2019). The last stage is to determine and simulate evacuation with the right evacuation route to TES. The results of the evacuation simulation are the evacuation time and the average speed of the evacuees walking, where the evacuation time of the simulation results is compared with the evacuation time based on the ETA calculation to determine the feasibility of the evacuation route. The stages in this study are shown in Figure 1.

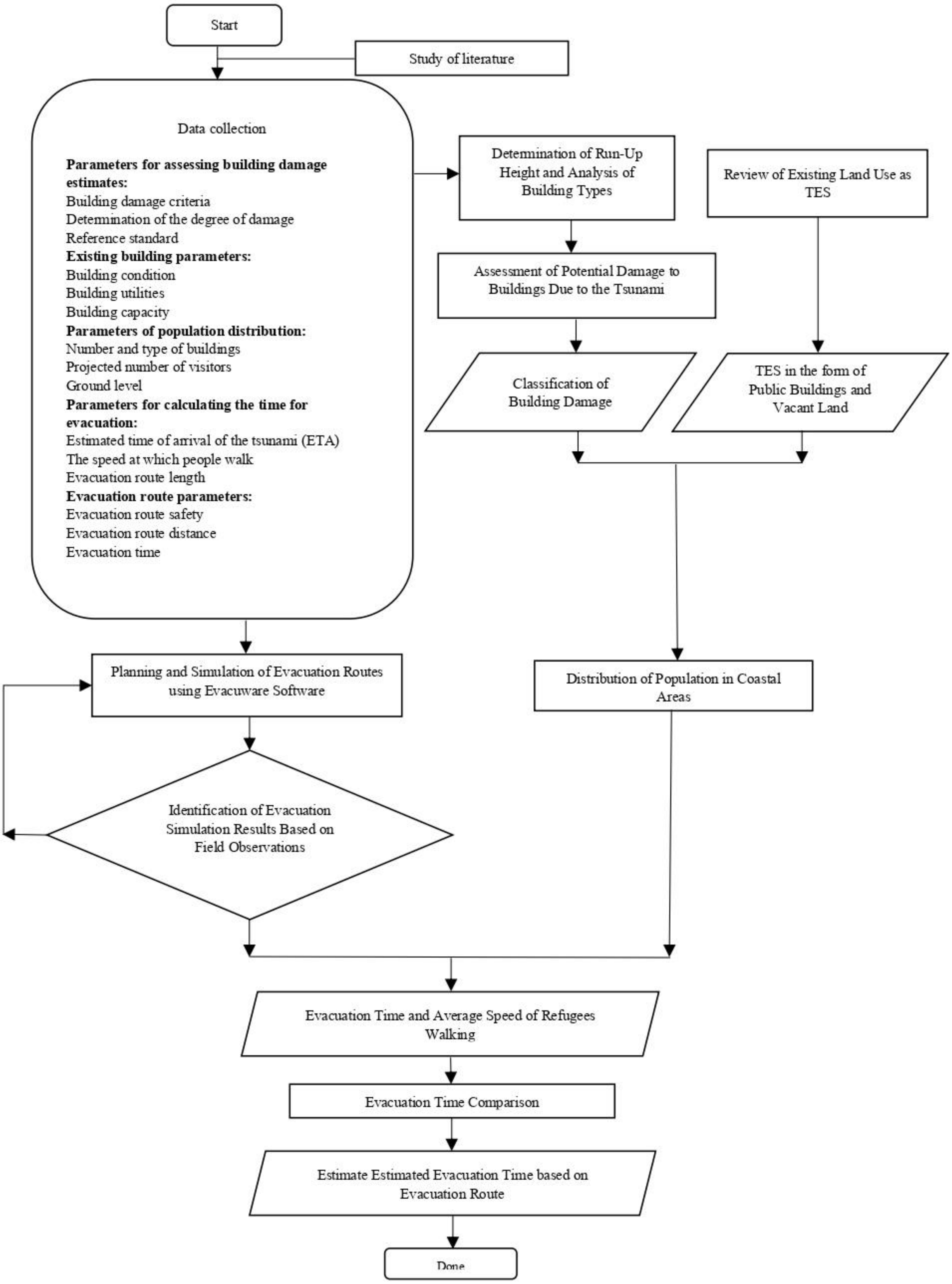

Figure 1. Research Methodology

3. Results

The location of this research is in Pandeglang Regency. The subdistricts in Pandeglang Regency that were affected by the 2018 Anak Krakatau tsunami with the highest amount of damage and field observations have been carried out are Carita Subdistrict, Labuan Subdistrict, and Panimbang Subdistrict.

3.1. Determination of Run-Up Height

Assessment of run-up height as a basis for planning evacuation routes about the results of research conducted by [23] and [24]. The run-up height in Carita Subdistrict is 4.5-5.3 m and the inundation distance is 110-175 m. In Labuan Subdistrict, the run-up height is 0.7-2.3 m and the inundation distance is 1.2-160 m. The run-up height is 0.8 m-12.8 m, and the inundation distance is 0.7-260 m in Panimbang Subdistrict. The run-up height and the area of inundation area were caused by the tsunami waves from the Anak Krakatau Volcano avalanche moving to the southeast and hitting Tanjung Lesung Beach, so the highest run-up height was in Panimbang Subdistrict.

Run-up height data is marked with an R-coded balloon and inundation distance data is marked with a dot-coded balloon according to Muhari, et al., while data on run-up height and inundation distance according to [24] are marked with a balloon with code C for Carita District, and balloon with code L for Labuan District. Data on run-up height and inundation distance are shown in Figure 2.

Building damage to inundation distance in Carita Subdistrict is included in the Moderate category with a weight of 2, Labuan Subdistrict is included in the moderate category with a weight of 2, and Panimbang Subdistrict is included in the high category with a weight of 3. The indicator of the distance of inundation to building damage is shown in Table 1.

Table 1. Indicator of Inundation Distance to Building Damage

Inundation Distance	Building Damage	Weight
≤87m	Low	1
87-174 m	Currently	2
≥174m	Tall	3

Building damage to run-up height in Carita Subdistrict is included in the moderate category with a weight of 2, Labuan Subdistrict is included in the low category with a weight of 1, and Panimbang Subdistrict is included in the high category with a weight of 3. The distance indicator of inundation to building damage is shown in Table 2.

Table 2. Indicator of Run-Up Height to Building Damage

Run-Up Height	Building Damage	Weight
≤4m	Low	1
4-8 m	Currently	2
≥8m	Tall	3

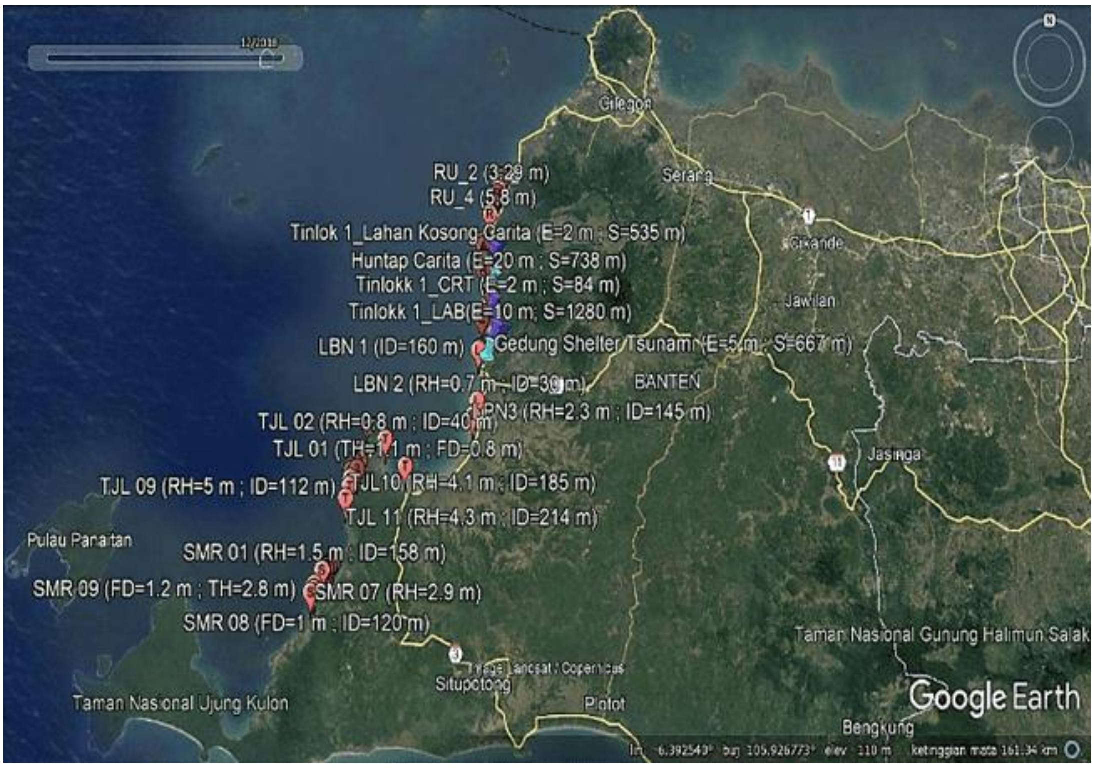

Figure 2. Combined Distribution of Run-up Heights, Flow Depth, Inundation, Field Observations, and Existing Land as TES

Building damage to the depth of tsunami inundation in Carita Subdistrict is included in the moderate classification with a weight of 3, Labuan Subdistrict is included in the moderate classification with a weight of 2, and Panimbang Subdistrict is included in the high classification with a weight of 3. The flow depth indicator to building damage is shown in Table 3.

Table 3. Indicator of Flow Depth to Building Damage

Flow Depth	Building Damage	Weight
≤2 m	Low	1
2-4 m	Moderate	2
≥4 m	High	3

3.2 Building Type Analysis

Determination of building types is based on field observations and adapted to building types according to Soviana, et al. [26]. Existing buildings in Carita Subdistrict are dominated by old buildings which are included in Type D buildings (Table 4). Building Type D is a building with a high level of damage and an incomplete building structure, which is given a weight of 4 (four) according to Soviana, et al. [26].

Existing buildings in Labuan Subdistrict are dominated by old buildings which are included in type C buildings (Table 4). Building Type C is a building with a moderate level of damage and has a complete building structure, which is given a weight of 3 (three), according to Soviana, et al. (2015). Existing buildings in Panimbang Subdistrict are dominated by old buildings where the determination of Building Type C is based on field observations and adapted to building types according to [26].

Table 4. Building Type Indicators for Building Vulnerability

Type	Damage Type	Weight
Type A	Very low	1
Type B	Low	2
Type C	Moderate	3
Type D	High	4
Type E	Very high	5

3.3 Potential Analysis of Building Damage Assessment

Determination of potential damage to buildings based on the total weight of indicators of run-up height to damage to buildings, distance of inundation to damage to buildings, and type of building based on the vulnerability of buildings. Building damage in Carita Sub District was given a total weight of 15 (Table 5), where the highest weight was 4 based on the building type indicator of building vulnerability (Table 4). Building damage in the Labuan Subdistrict was given a total weight of 12 (Table 5), where the highest weight of 4 is the same as the Carita Subdistrict based on building type indicators on building vulnerability (Table 4). Building damage in the Panimbang Subdistrict was given the highest total weight, namely 16 (Table 5), where the highest weight was 3 based on the run-up height indicator to damage and the building type indicator to building vulnerability (Table 4). Based on the total weight in Table 5, the building damage is classified into 3 classes with the ranges: (1) Low Damage: ≤ 8; (2) Moderate Damage: 8-16; (3) High Damage: ≥ 16.

Based on the range of building damage, it can be indicated the classification of building damage that dominates Carita Subdistrict is moderate class damage (Table 6), where the total weight of building damage is 15, which means that the total weight of the building damage in Carita Subdistrict is in the range 8-16. The building type indicator is one indicator that most influences the damage to buildings in the Carita Subdistrict. Building Type D is a permanent building with an incomplete structure in the coastal area of the Carita Subdistrict. Building type D, if it is at a total building height (building height and building elevation) of 7-10 m, results in building damage with a probability of 55-80% due to the depth of the tsunami inundation in Figure 2 of 0.1-5.5 m [25] and the run-up height in Figure 2 is 4.5-5.3 m [24].

The vegetation between buildings in Carita Subdistrict reduces the impact of waves on building damage, so the total weight of damage to buildings in the Carita Subdistrict is lower than in Panimbang Subdistrict. The number of damages to Moderate-class buildings in the Carita District during the 2018 Anak Krakatau Volcano Tsunami was 15 houses out of the total damage to 28 buildings.

Table 6. Classification of Building Damage

Subdistrict	Weight	Classification
Carita	15	Moderate
Labuan	12	Moderate
Panimbang	16	Heavy

Table 5. Building Damage Indicator

Subdistrict	Run-up height	Flow Depth	Inundation	Building Type	Probability Damage	Total Building Height	Total Weight
Carita	1	2	2	4	3	3	15
Labuan	1	2	2	3	2	2	12
Panimbang	3	3	3	3	2	2	16

Based on the range of building damage, it can be indicated that the classification of building damage that dominates Labuan Subdistrict is medium class damage (Table 6), where the total weight of building damage is 13, which means the total weight of building damage in Labuan Subdistrict is in the range 8-16. The building type indicator is one indicator that most influences the damage to buildings in the Labuan Subdistrict. Building Type C is a permanent building with a complete structure in the coastal area of the Labuan Subdistrict. Building type C, if it is at a total building height (building height and building elevation) of 10-12 m, results in building damage with a probability of 30-45% due to the depth of the tsunami inundation (Figure 2) of 0.3-3.1 m [25] and is included in the inundation area of up to 160 m while the distance between settlements and the coastline is 80 m. Labuan Subdistrict is the subdistrict with the densest settlements and population, so the number of damage to Moderate class buildings in Labuan Subdistrict during the 2018 Anak Krakatau Volcano Tsunami was 46 houses out of a total of 108 damaged buildings.

Damage to buildings in Panimbang Subdistrict is included in the middle class of building damage classification (Table 6), with a total weight of building damage of 13. The total damage to buildings in Panimbang Subdistrict is in the range of 8-16. Damage to high-class buildings in Panimbang Subdistrict was due to the highest run-up height of up to 14.9 m [25] in Panimbang Subdistrict and the highest tsunami inundation depth of up to 6.6 m [25] even though buildings in Panimbang Subdistrict is dominated by Building Type C. Building Type C is a permanent building with a complete structure in the coastal area of the Panimbang Subdistrict. Building type C, if it is at a total building height (building height and building elevation) of 10-12 m, will result in building damage with a probability of 35-50% due to the depth of the tsunami inundation (Figure 2) of 04-6.6 m [25] and a run-up height of 12.8 m. The maximum run-up height and maximum inundation depth without breakwaters and seawalls in the coastal area and the boundary wall in the mainland area in Panimbang Subdistrict cause the waves to reach land as far as 260 m [24]. The amount of damage to high-class buildings during the 2018 Anak Krakatau Volcano Tsunami was 29 houses out of 52 buildings damaged.

3.4 Review of Existing Land Use as TES

TES locations are based on field observations and research results by [23] and [24]. Examination of existing land as TES uses parameters such as holding capacity, existing land topography, and distance of existing land from the shoreline. Shelter capacity is based on the space requirement for tsunami evacuation is 0.5 m^2 per person or every 1m^2 can accommodate 2 people [17]. Existing land topography considering the height of the run-up value. The distance of the existing land from the shoreline considering the distance of the inundation is shown in Figure 2.

Existing land review data in the form of buildings are marked with a yellow pin, vacant land is marked with a green pin, buildings constructed by BPBD Pandeglang are marked with a blue pin, and site review is marked with a purple pin. Location review data in Carita Subdistrict are SMPN 1 Carita and Carita Vacant Land as TES. Location overview in Labuan Subdistrict is the LDIII Labuan Mosque and the Labuan Shelter Building as TES. Location overview in Labuan Subdistrict is Panimbang Vacant Land as TES. The results of a review of existing land in the Carita Subdistrict, Labuan Subdistrict, and Panimbang Subdistrict are shown in Figure 2.

3.5 Population Distribution

The distribution of population in coastal areas based on BPS Pandeglang 2018 is as follows.

1. The coastal area of Sukanagara Village, Carita Subdistrict with a population of 4,301 people living in the village. The total population includes 2,232 men and 2,069 women.
2. The coastal area of Labuan Village, Labuan Subdistrict with the highest population density is 1137 people per km2, whereas the total population of Labuan District is 14,596 people. A sex ratio of 100:105 means that for every 100 female population there are 105 male populations.
3. The coastal area of Tanjungjaya Village, Panimbang Subdistrict with a population of 7,200 people inhabits the village. The ratio of the total population is 3,727 male and 3,473 female residents.

Determination of the number of refugees taking into account Perka BNPB No. 7 of 2008 concerning Guidelines for the Provision of Assistance to Fulfill Basic Needs where the assumed number of refugees is 1% of the total population, tourists, and the time of disaster occurrence both during the day and at night [27]. Therefore, the assumed number of refugees is set at 1000-2000 people from the total population. The assumed number of refugees is used for community input in evacuation simulations with Evacuware Software.

3.6 Planning and Simulation of Evacuation Routes

The planning of the evacuation route is based on data from field observations of existing land and buildings built by BPBD Pandeglang with data parameters of run-up height and inundation distance from the shoreline. The merging of the two data is modeled on the Google Earth Software with the parameter data included in Figure 2. The results of combining the data on Google Earth Software are shown in Figure 2.

Evacuation route planning in Carita Subdistrict is represented by modeling evacuation routes in Sukanagara Village. The selection of the evacuation route in Sukanagara Village with moderate damage classification is shown in Table 5. The evacuation route in Carita Subdistrict was directed towards two alternatives TES because the second TES was located farther away, so the first TES alternative was needed with a closer distance of 838 m with an elevation of 20 m. The first TES is an empty field marked with a green pin and the second TES is SMPN 1 Carita with a yellow pin. The width of the local road leading to TES is 7-10 m while the width of the collector road is 10-15 m. The evacuation route in Carita Subdistrict is shown in Figure 3.

The results of the tsunami evacuation simulation in the Carita Subdistrict indicated the percentage of evacuees who safely arrived at TES against the time of evacuation. The number of refugees who survived arriving at TES within 0-15 minutes showed a significant increase with the percentage of refugees surviving TES 0-90% during the daytime tsunami, 0-70% at night tsunami, 0-80% at night tsunami with obstacles, 0-65% for tourist-heavy night tsunamis and 0-60% for tourist-heavy night tsunamis with obstacles. This increase was influenced by factors such as optimal walking speed, optimal capacity of TES, the response of refugees to evacuation situations, the number of refugees, and optimal lighting of evacuation routes.

The time frame of 15–25 minutes during the day saw a decrease in the number of survivors arriving at TES from 11% of refugees out of 1,000 people. The 15-30 minute time frame saw a decrease in the number of survivors arriving at TES compared to the first 15 minutes, with as many as 14% of 1,000 refugees at night and 4% of 1,000 refugees at night with obstacles. The 15-30 minute time frame saw a decrease in the number of survivors arriving at TES compared to the first 15 minutes, as many as 30% of the 2,000 refugees during the tourist-packed night tsunami and as many as 26% of the 2,000 refugees at night tsunami densely traveled with obstacles. The percentage of refugees who safely arrived at TES was influenced by the factor that TES's capacity almost reached the maximum limit, the density of refugees, limited lighting, and obstacles at several points along the evacuation route.

Figure 3. Evacuation Route in Carita Subdistrict

The time frame of 30-50 minutes during the night saw an increase in the number of survivors arriving at TES compared to the second 15 minutes, as many as 17% of the last 1,000 refugees. The time frame is 30-56 minutes at night with as many as 19% of the last 1000 evacuees being hindered. The time frame of 30-60 minutes on a busy touristic night saw a decrease in the number of survivors arriving at TES compared to the second 15 minutes, as many as 8% of the last 2,000 refugees. The time frame of 30-65 minutes at night with obstacles experienced an increase in the number of survivors arriving at TES compared to the second 15 minutes, as many as 17% of the last 2000 refugees. The percentage reduction is influenced by the factor that the capacity of TES has reached its maximum limit, the density of refugees, the behavior of refugees in evacuation situations, limited lighting, and obstacles that require a longer time for tsunami evacuation. The graph of the difference in the percentage of survivors at TES against the evacuation time in Carita Subdistrict is shown in Figure 4.

Evacuation route planning in Labuan Subdistrict is represented by modeling the evacuation route in Teluk Village. The selection of evacuation routes in Teluk Village with high damage classification is shown in Table 5. The evacuation route for the tsunami disaster was planned to consider the number of residents, tourists, and the road corridor leading to the TES location. The evacuation route in Carita Subdistrict was directed towards two alternative TES because the second TES was a building constructed by BPBD but did not attract the public to go to the TES so the first TES alternative was recommended in the form of a public building (LDII Labuan Mosque). The first TES is the Labuan LDII Mosque marked with a yellow pin and the second TES is the Labuan Shelter Building with a blue pin (Figure 2). The width of the local road to TES is 4-7 m and the width of the collector road is 7-10 m. The evacuation route in Labuan Subdistrict is shown in Figure 5.

The results of the tsunami evacuation simulation in the Labuan Subdistrict indicate the percentage of evacuees who safely arrived at TES against the time of evacuation in Figure 6. The number of refugees who survived arriving at TES within 0-15 minutes showed a significant increase with the percentage of survivors arriving at TES 0-85% during daytime tsunamis, 0-55% at night tsunamis, 0-75% at night tsunamis with obstacles, 0-65% for tourist-heavy night tsunamis and 0-65% for tourist-heavy night tsunamis with obstacles. This increase was influenced by factors such as optimal walking speed, optimal capacity of TES, the response of refugees to evacuation situations, the number of refugees, and optimal lighting of evacuation routes.

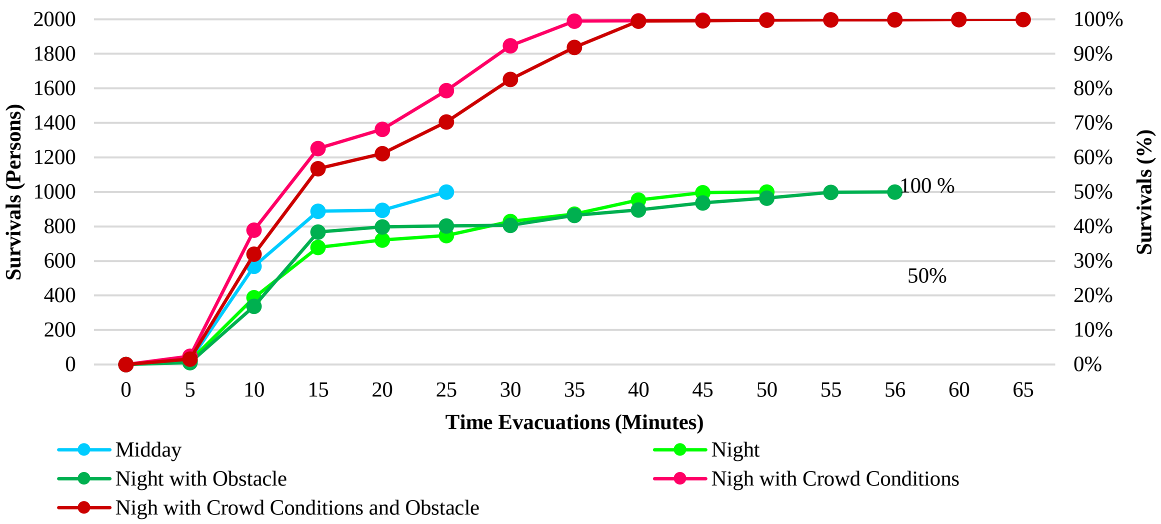

Figure 4. Graph of The Difference in The Percentage of Survivors at TES Against the Time of Evacuation in Carita Subdistrict

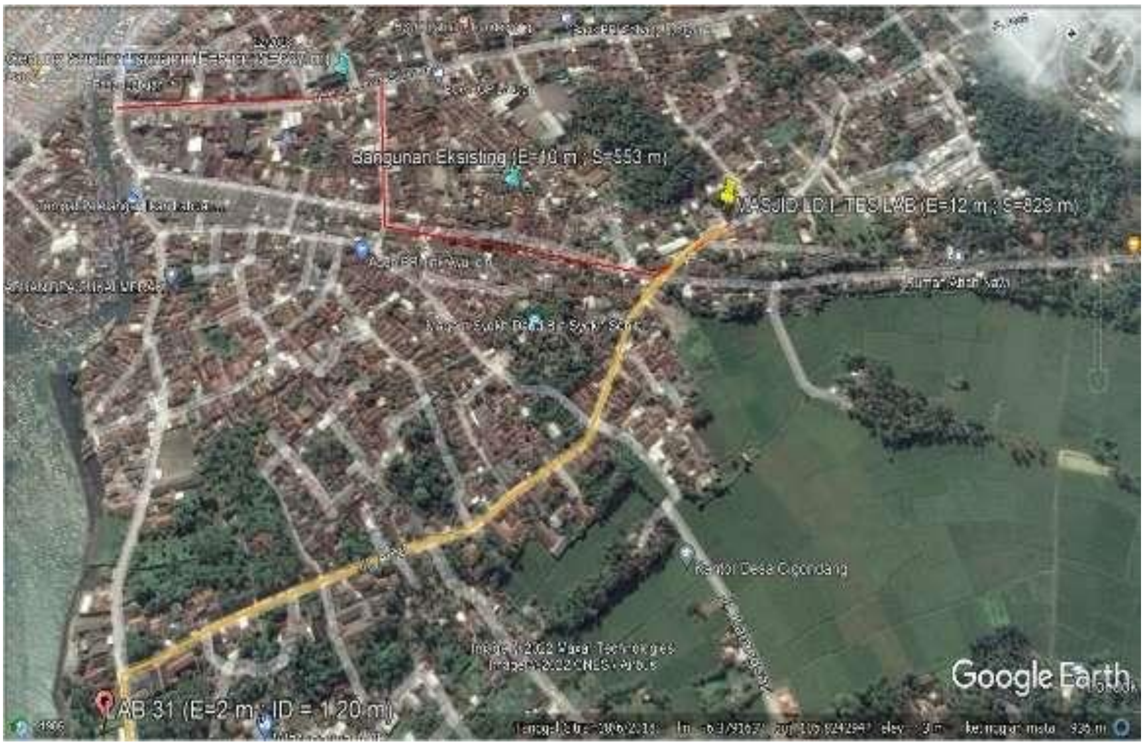

Figure 5. Evacuation Route in Labuan Subdistrict

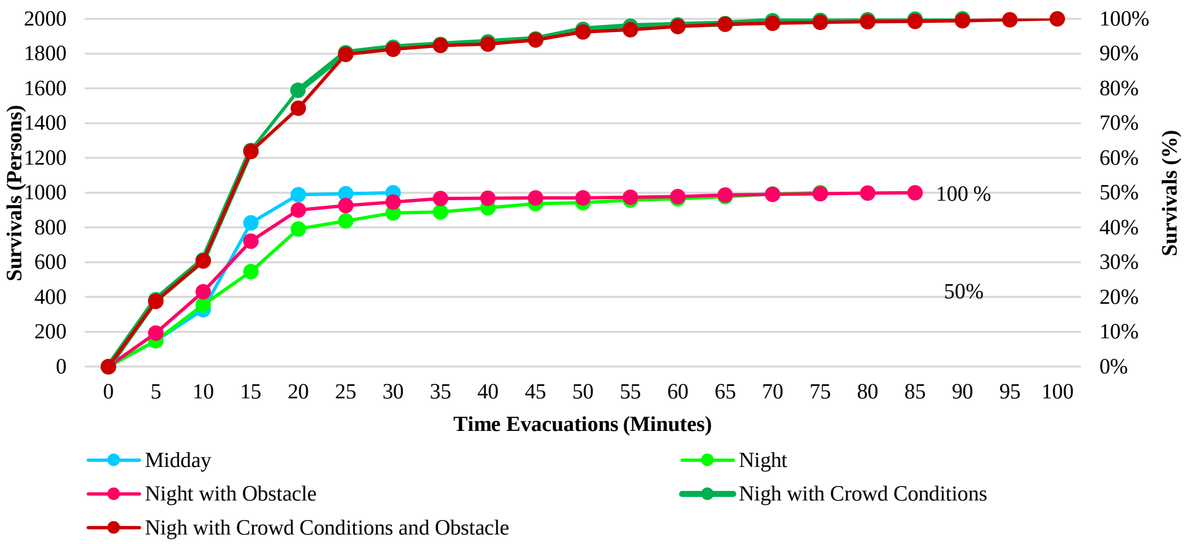

Figure 6. The Difference in The Percentage of Survivors at TES Against the Evacuation Time in Labuan Subdistrict

The time frame of 15-30 minutes during the day saw a decrease in the number of survivors arriving at TES from 17% of refugees out of 1,000 people. The 15-30 minute time frame saw a decrease in the number of survivors arriving at TES compared to the first 15 minutes, with as many as 34% of 1,000 refugees at night, and 22% of 1,000 refugees at night with obstacles. The 15-30 minute time frame saw a decrease in the number of survivors arriving at TES compared to the first 15 minutes, as many as 60% of the 2,000 refugees during the tourist-packed night tsunami and as many as 59% of the 2,000 refugees at night tsunami dense travel with obstacles. The percentage of refugees who safely arrived at TES was influenced by the factor that TES's capacity almost reached the maximum limit, the density of refugees, limited lighting, and obstacles at several points along the evacuation route.\

The time frame of 30-75 minutes during the night saw an increase in the number of survivors arriving at TES compared to the second 15 minutes, as many as 12% of the last 1,000 refugees. The time frame is 30-56 minutes at night with as many as 5% of the last 1000 evacuees being affected. The time frame of 30-90 minutes on a busy touristic night saw a decrease in the number of survivors arriving at TES compared to the second 15 minutes, as many as 16% of the last 2,000 refugees. The time frame of 30-100 minutes at night with obstacles experienced an increase in the number of survivors arriving at TES compared to the second 15 minutes, as many as 17% of the last 2000 refugees. The percentage reduction is influenced by the factor that the capacity of TES has reached its maximum limit, the density of refugees, the behavior of refugees in evacuation situations, limited lighting, and obstacles that require a longer time for tsunami evacuation. The graph of the difference in the percentage of survivors at TES against the evacuation time in Carita Subdistrict is shown in Figure 6.

The evacuation route in Panimbang Subdistrict (Figure 7) is planned by modeling the evacuation route in Tanjungjaya Village. The selection of evacuation routes in Tanjungjaya Village with a high level of damage classification is shown in Table 5. The evacuation route for the tsunami disaster was planned to take into account the number of residents, tourists, and the road corridor leading to the TES location. The evacuation route in Panimbang Subdistrict is directed towards vertical TES because TES is in a tsunami-prone area with a distance of 290 m from the shoreline. The TES in the form of the Panimbang Vacant Land is marked with a yellow pin in Figure 2 and the second TES is in the form of the Labuan Shelter Building with a blue pin in Figure 2. The local road leading to TES is 4-8 m wide with coconut trees along the road corridor.

The results of the tsunami evacuation simulation in Panimbang District indicate the percentage of evacuees who safely arrived at TES against the time of evacuation. The number of refugees who survived arriving at TES within 0-15 minutes showed a significant increase with the percentage of survivors arriving at TES 0-45% during the daytime tsunami, 0-40% at night tsunami, 0-40% at night tsunami with obstacles, 0-25% in tourist-dense night tsunamis and 0-30% in tourist-dense night tsunamis with obstacles. This increase was influenced by factors such as optimal walking speed, optimal capacity of TES, the response of refugees to evacuation situations, the number of refugees, and optimal lighting of evacuation routes.

The time frame of 15-30 minutes during the day saw an increase in the number of survivors arriving at TES from 56% of refugees out of 1000 people. The 15-30 minute time frame saw a decrease in the number of survivors arriving at TES compared to the first 15 minutes, with as many as 35% of 1,000 refugees at night and 34% of 1,000 refugees at night with obstacles. The 15-30 minute time frame saw an increase in the number of survivors arriving at TES compared to the first 15 minutes, as many as 38% of the 2,000 refugees during the tourist-packed night tsunami and as many as 60% of the 2,000 refugees at night tsunami dense travel with obstacles. The percentage of refugees who safely arrived at TES was influenced by the factor that TES's capacity almost reached the maximum limit, the density of refugees, limited lighting, and obstacles at several points along the evacuation route.

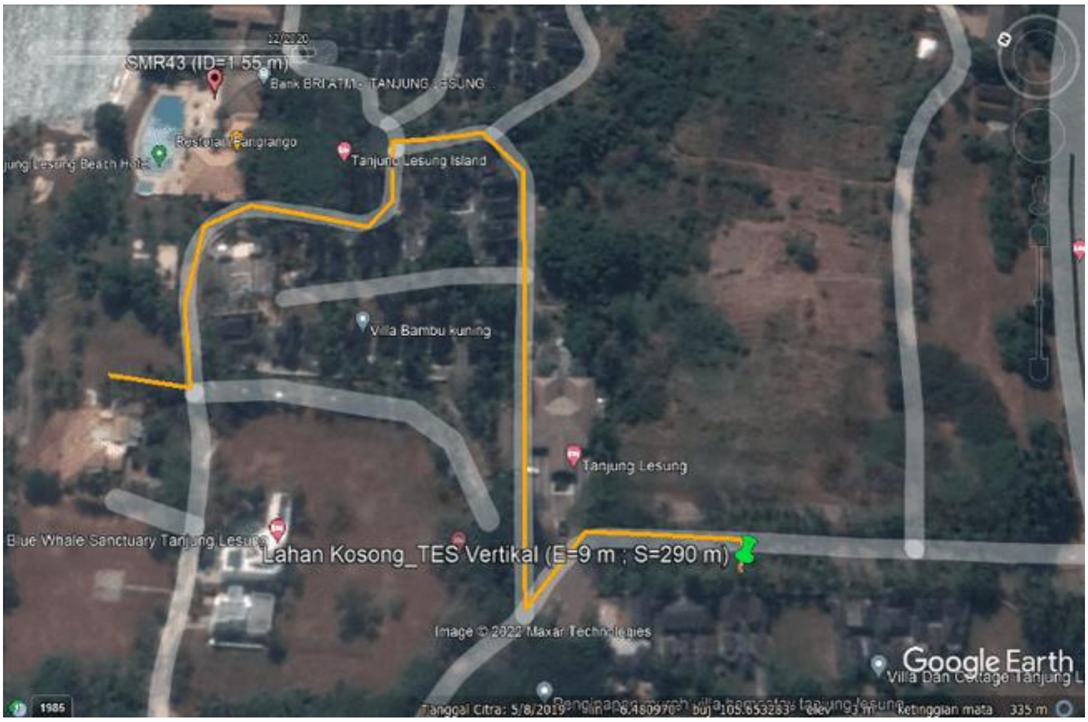

Figure 7. Evacuation Route in Panimbang Subdistrict

The time frame of 30-75 minutes during the night saw an increase in the number of survivors arriving at TES compared to the second 15 minutes, as many as 28% of the last 1,000 refugees. The time frame of 30-90 minutes at night with obstacles experienced an increase in the number of refugees by 30% from the last 1000 refugees. The time frame of 30-91 minutes on a busy touristic night saw an increase in the number of survivors arriving at TES compared to the second 15 minutes, as many as 39% of the last 2,000 refugees. The time frame of 30-100 minutes at night with obstacles experienced a decrease in the number of survivors arriving at TES compared to the second 15 minutes, as many as 10% of the last 2,000 refugees. The percentage reduction is influenced by the factor that TES capacity has reached its maximum limit, refugee density, behavior of refugees towards evacuation situations, limited information, and obstacles so that it takes a longer time for tsunami evacuation. The graph of the difference in the percentage of survivors at TES against the evacuation time in Carita Subdistrict is shown in Figure 8.

The difference in the average speed of evacuees in the tsunami evacuation simulation is due to the topography of the evacuation route, conditions along the evacuation route, and the distance of TES to the coastal area. The road condition factor along the evacuation route is adjusted using the friction value. The average speed of evacuees in Carita Subdistrict is influenced by the topography of the evacuation route at an elevation of 5-38 m from the coastal area, the condition of the road to the evacuation route in the form of a road width of 7-10 m, and the distance of TES from the shoreline as far as 838-1660 m. The reduction in the average speed of evacuees walking in Labuan Subdistrict is influenced by the topography of the evacuation route towards the coastal area, namely the evacuation route is at an elevation of 2 m from the coastal area, and the condition of the evacuation route is in the form of a local road with a road width of 4-7 m, and the distance of TES from the shoreline as far as 553-829 m.

The reduction in the average speed of evacuees walking in Panimbang Subdistrict is influenced by the topography of the evacuation route towards the coastal area, namely the evacuation route is at an elevation of 5 m from the coastal area, the condition of the evacuation route is in the form of a local road with a road width of 4-8 m, and the distance of TES from the shoreline as far as 279 m. A comparison of the average speed of refugees walking from the results of the tsunami evacuation simulation is shown in Figure 9.

The results of the evacuation simulation are the average speed of evacuees walking compared to the average speed of evacuees walking from the simulation results in the field at night in the Carita Subdistrict. The average speed of evacuees walking on the results of a night evacuation simulation in Carita Subdistrict with Evacuware Software is 0.55 m/s, where this speed is the same as one of the average speeds of evacuees walking from direct simulation results in the field in Carita Subdistrict, namely male runners -male 1. The equation for the average walking speed of refugees shows the suitability of the friction value to illustrate the actual conditions in the field.

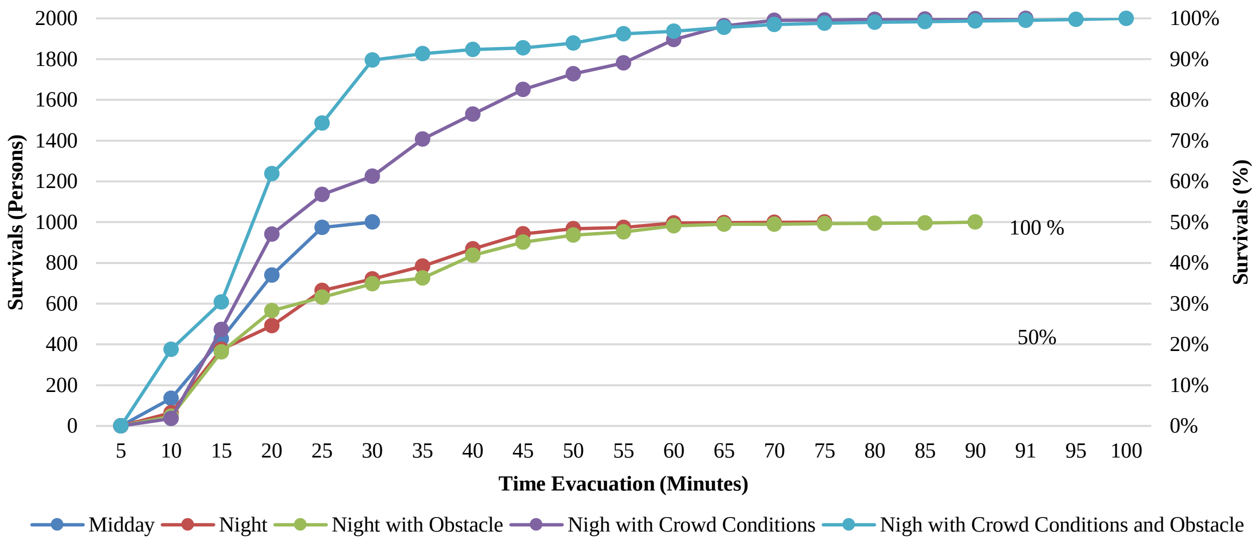

Figure 8. Graph of the Difference in the Percentage of Survivors at TES Against the Time of Evacuation in Panimbang Subdistrict

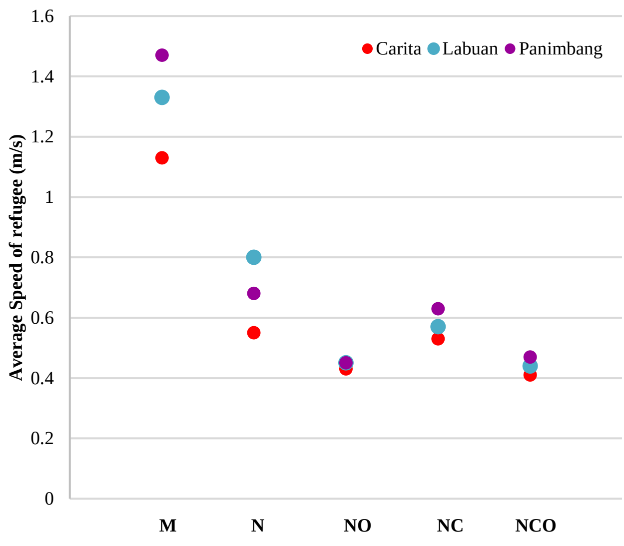

Figure 9. Comparison of The Average Speed of Refugees Walking Based on The Results of The Tsunami Evacuation Simulation in Each Subdistrict

The tsunami evacuation time is influenced by the number of evacuees and the tsunami evacuation scenario. Evacuation scenarios in the tsunami evacuation simulation are daytime tsunamis, night tsunamis, night tsunamis with obstacles, night tsunamis when it's busy tourism, and night tsunamis when it's busy tourism with obstacles in the evacuation route. The results of the tsunami evacuation simulation show the effect of the number of evacuees and evacuation scenarios on evacuation time, where the number of evacuees of 2,000 people requires a longer evacuation time than the number of evacuees of 1,000 people. The daytime tsunami evacuation scenario with 1,000 evacuees shows an evacuation time of 25 minutes in the Carita Subdistrict and an evacuation time of 30 minutes in the Labuan Subdistrict and Panimbang Subdistrict. The tsunami evacuation scenario at night without obstacles or with obstacles with a total of 1000 evacuees shows an evacuation time frame of 50-56 minutes in Carita Subdistrict, an evacuation time frame of 75-85 minutes in Labuan Subdistrict and Panimbang Subdistrict. The tsunami evacuation scenario at night with dense tours free of obstacles or accompanied by obstacles with 1,000 evacuees shows an evacuation time frame of 60-65 minutes in Carita Subdistrict, an evacuation time frame of 90-100 minutes in Labuan Subdistrict and an evacuation time frame of 90- 100 in Panimbang Subdistrict. Differences in evacuation time based on the results of the evacuation simulation. The evacuation time frame of 75-85 minutes in the Labuan Subdistrict and Panimbang Subdistrict. The tsunami evacuation scenario at night with dense tours free of obstacles or accompanied by obstacles with 1,000 evacuees shows an evacuation time frame of 60-65 minutes in Carita Subdistrict, an evacuation time frame of 90-100 minutes in Labuan Subdistrict and an evacuation time frame of 90-100 in Panimbang Subdistrict. Differences in evacuation time based on the results of the evacuation simulation. The evacuation time frame of 75-85 minutes in the Labuan Subdistrict and Panimbang Subdistrict. The tsunami evacuation scenario at night with dense tours free of obstacles or accompanied by obstacles with 1,000 evacuees shows an evacuation time frame of 60-65 minutes in Carita Subdistrict, an evacuation time frame of 90-100 minutes in Labuan Subdistrict and an evacuation time frame of 90-100 in Panimbang Subdistrict. Differences in evacuation time based on the results of the evacuation simulation and the evacuation time frame is 90-100 in Panimbang Subdistrict. Differences in evacuation time based on the results of the evacuation simulation and the evacuation time frame is 90-100 in Panimbang Subdistrict.

Table 8. Evacuation Time Based on The Calculation Results

Subdistict	L	V	ETA (s)	ETA (minutes)
Carita	1,492	0.71	2,101.408	35.0
Labuan	1,356	0.71	1,909.859	31.8
Panimbang	873	0.71	1,229.577	20.5

Evacuation time based on the results of evacuation simulations (Table 8) in the three subdistricts can be used as a parameter for community preparedness in dealing with a tsunami disaster. Evacuation time is compared to the wave propagation time from around the Mount What complex to reach the Banten region for 35-45 minutes [25]. The comparison results show that the average evacuees in the Districts of Carita, Labuan, and Panimbang are classified as 25% ready for a tsunami disaster. The probability of preparedness is 25%, indicating that the evacuees will survive the evacuation during the day under normal conditions because daylight is only ¼ day (6 hours out of 24 hours) and presented. Factors causing refugee preparedness are lighting along evacuation routes, obstacles assumed by the number of refugees, and road conditions.

4. Conclusions

The run-up height is the basis for assessing potential damage to buildings due to the tsunami, where moderate building damage was in Carita Subdistrict and Labuan Subdistrict, and damage to tall buildings in Panimbang Subdistrict. Based on the damage to the building, a review of existing land use can be carried out, where existing land can be used as TES, namely Carita Vacant Land and Carita 1 Middle School in Carita Subdistrict, LDII Labuan Mosque and Labuan Shelter Building in Labuan Subdistrict, and Vacant Land in Panimbang Subdistrict. Planning an evacuation route to TES simulates the tsunami evacuation process using Evacuware Software. The results of the tsunami evacuation simulation show that the evacuation time is 25-65 minutes with average evacuees walking speed of 0.41-1.13 m/s, in Carita Subdistrict, the evacuation time is 30-100 minutes with average evacuees walking speed of 0.44-1.33 m/s in Labuan Subdistrict, and evacuation time of 30-100 minutes with average evacuees walking speed of 0.45-1.47 m/s in Panimbang Subdistrict. Based on the evaluation time, community preparedness in the three sub-Subdistricts was included in the 25% ready category to face a tsunami disaster. Evacuation time from the calculation of the estimated evacuation time (ETA) is 20-35 minutes, with the average speed of evacuees walking at 0.71 m/s. Therefore, community preparedness is included in the 25% ready category to face a tsunami disaster.

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