Demand versus Capacity of Tsunami Shelters in Padang, Indonesia

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Abstract— This paper presents an estimation of demand and its comparison to the capacity of the existing tsunami shelters in Padang. A combination of horizontal and vertical evacuation plans was simulated with giving priority to the horizontal ones. Demand for the existing shelters was estimated with an assumption that the population is spreading uniformly within the administrative area. It was also assumed that the number of people who entered the area is the same as those who went out of the area at the time of the anticipated earthquake occur. The coverage areas of shelters were estimated based on the distance that can be reached by people within an effective available evacuation time. The capacity of the tsunami shelters was obtained from secondary data. The study found that almost half of the existing shelters in Padang will be overloaded if all of the people in the coverage area of a shelter being evacuated to the shelters. Addition of 37 more shelters with a capacity of 2000 is needed.

Keywords— Padang; disaster; tsunami; shelter; demand; capacity.

I. INTRODUCTION

Learning from other countries in preparing for tsunami mitigation, Padang City has put tremendous efforts in developing tsunami early warning systems, increasing the capacity of tsunami evacuation route, building new shelters, evaluating and retrofitting structure of existing many-storey buildings and preparing the rooftop of the buildings as temporary evacuation sites or shelters [1]. As much as 24 buildings are declared as temporary evacuation sites or shelters of the tsunami in 2015 [2]. Many studies have been aimed to learn the use of the shelters such as [3] and [4]. However, the adequacy of the building has not been carefully calculated.

It is a well-known policy in Padang that during the tsunami evacuation, people are suggested to leave their cars and evacuate on foot immediately to the nearest shelters or the safety zones [5]. The use of car has been confirmed to make evacuation more difficult due to traffic jam and bottleneck [6]. A majority of car users preferred to park on street either legally or illegally in Padang, the evacuation routes become more vulnerable to a massive traffic jam during the rush hour and the evacuation.

However, in fact, panic during previous earthquakes in Padang causes congestion in all of the tsunami evacuation routes. Everybody did horizontal evacuation using their cars, but none of them could pass through the traffic and reach the safety zone within the available evacuation time (for example, see [7]. If only the tsunami happened at the time, the impact could not be imagined.

The government has been educating people using religious words, which was used in many countries during the earthquake in Japan to provoke emotions of the people to make it easier for them to understand the situation [8]. However, it seems that the government has hesitant in implementing the policy to save as many people as they could. This might be because they were not confident that the buildings were safe nor the capacity of the shelters was adequate. The adequacy of shelters is an important thing before the government implementing the evacuation plans. Major of Padang is calling experts from universities to help them in the mitigation; plans [9].

This paper aims to immediately answer the call by seeking the ratio of demand and capacity and estimate the adequacy of the existing shelters. Demand for a shelter was estimated based on the population lived within its coverage area, while the capacity was obtained from secondary data published by the government. Based on the evaluations, a recommendation was made whether any addition of shelter was needed or not.

A. A feature of Padang City

Padang is the capital city of West Sumatera Province, Indonesia. Astronomically, Padang is located between 0o44′ and 01o 08′ South Latitude and 100o05′ and 100o34′ East Longitude [10]. The map of Padang is shown in Fig. 1. From the coast, the terrain of Padang has 3-4 km of flat land within zero to a five-meter elevation above sea level and then rising toward hills further inland [1]. The population of
the city in 2014 was 889,646 people \[10\], which about a half of them were living close to the coast.

Fig. 1. Map of Padang City [BPS]

Padang was predicted to hit by a massive earthquake with a possibility to trigger tsunami \[11\]. Many world most massive earthquake have been occurring in the close area of Padang, such as the great M 9.1 earthquake near Aceh on December 26, 2004; M 8.6 near Nias Island in March 28, 2005; M 8.5 and M 7.5 in September 12, 2007 and M 7.8 earthquake on October 25, 2010 which caused a substantial tsunami on the west coast of Mentawai Islands. Although several earthquakes have occurred in the area, a tsunami-generating earthquake is still a threat \[1\]. Muhammad et al. \[12\] predict that Padang may face up to 15 m tsunami inundation.

B. Shelters’ Coverage Area

An attempt to estimate the coverage area of the existing shelters in Padang has been made with an assumption that the coverage area as a circle with radius 1.37 km \[3\]. The radius was estimated from an experiment, which found that the average walking distance within 17.1 minutes was 1.37 km. The duration of 17.1 minutes was estimated as an effective evacuation time, which was calculated, based on the tsunami wave velocity and distance of the epicenter from the shore. Therefore, the effective evacuation time was estimated from the time required for the wave to reach the shore subtracted by the time required for making evacuation preparation.

However, the assumption was considered less accurate. Kemal et al. \[4\] attempted to fix the weakness of \[3\]. Instead of using circles, Kemal et al. \[4\] argued that the hazard also influence the coverage areas during the evacuation such as river, canyon, buildings, and fenced. Furthermore, Kemal et al. \[4\] assumed that when the shelter stands between the people and the shore, less possibility for the people to run back approaching the shore to reach the shelter. Therefore, the coverage area would be shaped like a fan. This approach makes more sense; thus the results were used in this study.

Fig. 2. Steps in drawing the coverage area of shelters (illustrated from \[4\])

The steps in drawing shelter’s coverage area are illustrated in Fig. 2 based on \[4\]. First, using a shelter as the center, a circle with a radius of 1.37 km was drawn. Based on the assumption that people tend to evacuate away from the shoreline, except the shelter is close enough to their position, then the circle was cut into two segments through a line parallel to the shoreline. The position of the line is about one-third of the radius from the center, away from the shoreline. Our focus is on the large part. When the coverage areas of two or more shelters coincide, then the boundary will be drawn through the middle point between the shelters. The coverage area was then modified based on the assumption that the evacuation was winding through the existing street for a maximum total distance of 1.37 km from the shelter.

The demand for each shelter was assumed the density of the population in the coverage area times the area of the shelter coverage.
C. Evacuation Plans

Generally, there are two evacuation plans for tsunami namely horizontal and vertical evacuation plan. The horizontal evacuation plan is the method of evacuation where people in the vulnerable areas are suggested to walk to the nearest hilly ground of at least 15 m above sea level or higher than the highest tsunami wave could reach. The vertical evacuation plan is the method of evacuation were people in the vulnerable areas are suggested to walk to the nearest strong with at least 3-storey building or higher than the highest predicted tsunami wave [5].

Perhaps, the horizontal evacuation plan is cheaper and perceived to be more saver than the vertical ones. However, without careful estimation of the walking speed and the distance of the safety zone, horizontal evacuation could be riskier. Therefore, a combination of vertical and horizontal evacuation should be initiated. Those who expected to reach the safe tsunami zones within the effective evacuation time should navigate to the zone and those who could not navigate to the nearest multi-story building (shelter) [5].

Yosritzal et al. [3] found that the tsunami arrival time at shoreline was 37.1 minutes, slightly slower than [13], which was 35 minutes. Effective evacuation time was 17.1 minutes, which was estimated to be 1.37 km, walking distance. This walking speed is similar to [14] whose found 1.3 m/s for adult and 1.5 m/s for children. Using this walking distance, Yosritzal et al. [3] found the suggested area for horizontal evacuation as shown in the green shaded area in Fig. 3. The area covered by a red border is the coverage area of the shelter. Wood et al. [17] suggested different minimum travel speed to evacuate from hazard zone for each type of walking such as impaired adult (0.89 m/s), slow walk (1.10 m/s), fast walk (1.52 m/s), slow run (1.79 m/s) and fast run (3.85 m/s) depending on the evacuee’s decision to start evacuation, their distance to the safe tsunami region and the minimum available evacuation time. In this context, the decision to start evacuation is playing an important role.

Regarding the start time of evacuation, Sugimoto et al. [18] argue that in general people start evacuation at the different time. Therefore, in their simulation model, Sugimoto et al. [18] divided the population into several groups and assigned a different start time for each group. and Mas et al. [19] threat people individually based on psychological parameters. The delays of resident starting evacuation were caused by psychological factors such as cognitive dissonance and attitudes waiting for a warning. Mas et al. [19] proposed a model based on risk perception.

Another possibility is to estimate the demand based on the origin-destination study-using questionnaire. This approach will use questionnaire and ask respondent where they will go if they have to evacuate. However, the respond of the respondents valid only at the time and might not be valid at another time. Moreover, the study budget hungry and more complicated in prediction.

A more promising study was [16], which use an agent-based simulation to identify demand for tsunami shelters, in La Punta, Peru. However, similar to the origin-destination approach, this model is much more complicated and not easy to be implemented in Padang. Furthermore, given that the vulnerable people in Padang might not be the same as the residents of the same area, the model would not accurately predict how and where people to evacuate. Some of the people are living in the safe tsunami region but working or doing business in the vulnerable areas or vice versa.

Wood et al. [17] estimated minimum walking speed of people in the vulnerable area to reach shelter before the tsunami wave reaches the shoreline, instead of estimating the coverage area of the shelter. Wood et al. [17] suggested different minimum travel speed to evacuate from hazard zone for each type of walking such as impaired adult (0.89 m/s), slow walk (1.10 m/s), fast walk (1.52 m/s), slow run (1.79 m/s) and fast run (3.85 m/s) depending on the evacuees’ decision to start evacuation, their distance to the safety zone and the minimum available evacuation time. In this context, the decision to start evacuation is playing an important role.

D. Estimation of Demand

There were many approaches to estimating the demand for shelter found in literature such as using a geospatial approach based on the satellite image as used in [15]. Building shape, distance, slope elevation, building complexity, etc. are among considered variables. In our opinion, this approach is more realistic for a residential area in the night time. This is because people in a business area are usually not left in the area and people in the residential area would not stay at home in daytime during working hours.

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particular location in a particular group, so that the starting
time of their evacuation would not be accurately predicted.
Psychological parameters are even more difficult to predict
as no such data available for the population in Padang.
Therefore, we decided to stick with our simplified model
and anticipate the worst. We assumed that the evacuation
was conducted on foot with the average speed of 1.33 m/s.
When people evacuated on the higher speed, their
probability to arrive at the shelter before the wave is higher
thus more safety.

E. Demand-Capacity Index (DCI)

To make a plan, a ratio of demand and capacity of the
shelter or Demand-Capacity Index (DCI) was calculated
using Eq. (1).

\[ DCI = \frac{\text{Demand}}{\text{Capacity}} \] (1)

Demand is the estimated population under the coverage
area as discussed in the previous section, while capacity is
the estimated capacity of the shelter. Data for the capacity
of the shelter was obtained from [2].

II MATERIAL AND METHOD

There are three steps followed in this study such as
estimating the demand for each shelter, calculating the ratio
demand and capacity (CDI) of the shelters and then
estimating demand for additional shelters.

A. Estimating Demand

As has been discussed in the previous section, demand for
each shelter was estimated using geospatial application and
base on the population of the area. The fundamental
principle in our estimation in this paper is preparing for the
worst. Some assumption was made such as evacuation was
conducted by walking at 1.33 m/s speed that there is no
different starting time for the evacuation. It was safer to
evacuate immediately after the earthquake, however, some
people tent to wait for evacuation orders from the authority
[1]. Therefore, the evacuation was assumed to start 20
minutes after the earthquake (see [3] for more detailed).

As an earthquake could happen anytime during day or
night-time, there is no specific estimate of the distribution of
people in the vulnerable area at the time when the
earthquake is happening. People tend to move allots
especially during the daytime. However, based on our
experience, in the morning people who leave the coastal area
to the hills are nearly equal to the people who are moving
from the hills to the coastal area during daytime. In this
study, we assumed that the population of an administrative
village (Kelurahan) is spreading uniformly within the
village. The village was used as the smallest cell in this
study because of the data is only available for villages and
not for any area smaller than villages. Demand for each
shelter is estimated as the proportion of the population who
are under the coverage area of the shelter and calculated as
the ratio of the coverage area of the shelter and the area of
the village time’s population of the village. Map from
Google Earth application and AutoCAD software were used
in estimating area size.

B. Estimating the Demand-Capacity Index (DCI)

After estimating the demand for each shelter, the ratio
between demand and capacity was calculated using Eq. (1).
The capacity of the shelters is obtained from the Province
Office of Regional Disaster Management Agency (BPBD)
[2]. The capacity is shown in Table 1.

| ID | Name                                      | Capacity |
|----|------------------------------------------|----------|
| 1  | Masjid Raya Sumatera Barat               | 4000     |
| 2  | Masjid Nurul Iman                        | 2500     |
| 3  | Masjid Al Mahajirin                      | 4000     |
| 4  | Masjid Darussalam                        | 5000     |
| 5  | Masjid Nurul Haq                         | 4000     |
| 6  | Hotel Grand Zuri                         | 3000     |
| 7  | Hotel Ina Muara                          | 4000     |
| 8  | Hotel Mercure                            | 3000     |
| 9  | Hotel Bire                             | 3000     |
| 10 | BPK Sumbar                               | 2000     |
| 11 | Kanwil Ditjien Perbendaharaan Negara     | 2000     |
| 12 | Kantor Gubernur                          | 5000     |
| 13 | Kantor Dinas Prasjalitarkim Sumbar       | 5000     |
| 14 | Kantor Bappeda                          | 2000     |
| 15 | Gedung DPRD                              | 2000     |
| 16 | Gedung Bank Indonesia                    | 1000     |
| 17 | Fak. Olah Raga UNP                      | 2000     |
| 18 | Pascasarjana UBB                         | 2000     |
| 19 | Gedung Kesenian UNP                     | 2000     |
| 20 | SMKN 5                                   | 3000     |
| 21 | TK Al Azhar                              | 3000     |
| 22 | SMPN 25                                  | 3000     |
| 23 | SMAN 1                                   | 3000     |
| 24 | SDN 24                                   | 3000     |

C. Estimating the Additional Shelters

Based on the DCI, predicted level of service of each
shelter is classified into three colours such as red for the
overcapacity ones (DCI > 1.0), yellow for the demand nearly
equal to the capacity (0.7 < DCI < 1.0) and Green for the
lesser demand than capacity (DCI < 0.7).

The additional shelter is needed near to the existing
shelter if the DCI is higher than 1.0. It is recommended to
place an additional shelter when the DCI is higher than 0.7
to anticipate the growing demand in the future. Some other
shelters are needed in the non-covered area depending on the
population in the area.

III RESULTS AND DISCUSSION

Table 2 – 7 show the population of each village in 6
districts, which cover several vulnerable villages. The
yellow shaded rows are the non-tsunami vulnerable villages
because their position is higher than the maximum predicted
high of a tsunami wave. LK is the area of the village, LKRT
is the vulnerable area within the village, LDTS is the area of
the village, which is covered by shelters, P is population,
PRT is the vulnerable population in a village, and JPTS is
some vulnerable people who are under shelter coverage areas.

The data shows that Koto Tangah and Nanggalo District are the most vulnerable district in Padang because they have many villagers who are not covered by any shelter and could not possibly reach the safety zone during the effective evacuation time.

TABLE II
KOTO TANGAH DISTRICT

| Village (Kelurahan) | LK (km²) | LKRT | LDTS | P | PRT | JPTS |
|---------------------|----------|------|------|---|-----|------|
| P Tabing            | 9.41     | 2.77 | 7.77 | 20328 | 20328 | 5994 |
| B Pasang            | 3.32     | 0.35 | 12333 | 9478 | 1286 |
| PN Tigo             | 14.57    | 0.49 | 9427 | 9427 | 319  |
| Gantiang            | 3.32     | 2.48 | 13205 | 9848 | 0.00 |
| DT Hitam            | 11.78    | 7.33 | 0.00 | 18310 | 11397 | 0.00 |
| A Pacah             | 14.72    | 0.12 | 0.00 | 9999  | 80   | 0.00 |
| L Mintr             | 23.29    | 0.00 | 0.00 | 8817  | 0.00 | 0.00 |
| L Buaya             | 3.67     | 3.58 | 0.00 | 22438 | 21888 | 0.00 |
| P Sarai             | 13.24    | 11.85 | 0.00 | 19390 | 17360 | 0.00 |
| I Koto              | 8.18     | 0.00 | 0.00 | 11952 | 0.00 | 0.00 |
| K Pulai             | 5.53     | 0.15 | 0.00 | 2424  | 65   | 0.00 |
| B Gadang            | 106.90   | 0.00 | 0.00 | 15562 | 0.00 | 0.00 |
| B Panjang           | 14.32    | 0.84 | 0.00 | 14226 | 830  | 0.00 |

TABLE III
PADANG UTARA DISTRICT

| Village (Kelurahan) | LK (km²) | LKRT | LDTS | P | PRT | JPTS |
|---------------------|----------|------|------|---|-----|------|
| ATB                 | 1.12     | 1.12 | 0.92 | 15901 | 15901 | 13074 |
| ATT                 | 0.63     | 0.63 | 0.34 | 4239  | 2316  | 1923  |
| UK Utara            | 1.53     | 1.53 | 1.53 | 6845  | 6845  | 0.00  |
| UK Selatan          | 1.39     | 1.39 | 1.15 | 9023  | 7448  | 0.00  |
| Belanti             | 1.62     | 1.62 | 1.62 | 7983  | 7983  | 7983  |
| G Pangilun          | 0.42     | 0.25 | 0.07 | 13438 | 7867  | 2123  |
| AP Kopi             | 1.37     | 0.28 | 0.01 | 12823 | 2588  | 61    |

TABLE IV
PADANG BARAT DISTRICT

| Village (Kelurahan) | LK (km²) | LKRT | LDTS | P | PRT | JPTS |
|---------------------|----------|------|------|---|-----|------|
| Flamboyan           | 0.43     | 0.43 | 0.43 | 4795  | 4795  | 4792  |
| R Kualang           | 0.42     | 0.42 | 0.42 | 3914  | 3914  | 3914  |
| P Pasir             | 0.71     | 0.71 | 0.71 | 4347  | 4347  | 4347  |
| Purus               | 0.68     | 0.68 | 0.68 | 7685  | 7685  | 7685  |
| K Jao               | 1.63     | 1.63 | 1.63 | 3939  | 3939  | 3939  |
| K Pendok            | 0.65     | 0.65 | 0.65 | 3666  | 3666  | 3666  |
| B Nipah             | 0.31     | 0.31 | 0.20 | 5023  | 5023  | 3266  |
| U Gurun             | 0.71     | 0.71 | 0.71 | 4912  | 4912  | 4912  |
| Olo                 | 0.89     | 0.89 | 0.89 | 4777  | 4777  | 4777  |
| B Tangsi            | 0.57     | 0.57 | 0.57 | 2788  | 2788  | 0.00  |

The data shows that Koto Tangah and Nanggalo District are the most vulnerable district in Padang because they have many villagers who are not covered by any shelter and could not possibly reach the safety zone during the effective evacuation time. Therefore, their data are committed to the analysis of the shelters. Table 8 shows more detail of each shelter and their DCI indicators.
As discussed in the previous section, to make it easy to read, the DCI is indicated by colors. Red is used when DCI > 1.0 while yellow is used when the DCI is between 0.7 and 1.0 and green when the DCI less than 0.7. The indicator for the DCI is shown in Fig. 4.

There were 13 out of 24 shelters have DCI higher than 0.7 which is mean that those shelters will not adequate to accommodate the demand in the future, as shown in Table 9. The DCI 0.7 has been chosen as the threshold to anticipate overcapacity of the more preferable shelters.

Based on data in Table 9 and location of shelter in the Fig. 3, it can be seen that some red and yellow shelters are located close to each other. Therefore, the additional shelter could be placed in between. For example, between shelter 16 and 24, some shelters with a total capacity of approximately 2000 are needed. When the additional shelter is prepared to accommodate 1400 evacuees (C 2000 with DCI 0.7), the number of shelters required is shown in Table 10.

Looking back to the Fig. 1 and Fig. 2, there are some areas where people in those areas could not possibly reach the safety zone, and no shelters could be reached within the effective evacuation time. Unfortunately, we could not provide a precise estimation of demand in the areas in this paper. It is predicted that to cover those areas, at least ten new shelters with the capacity of 2000 are needed. Therefore, in total, Padang need 37 more shelters with the capacity of 2000 or higher. When the shelter with the minimum capacity of 2000 is not possible, then the number of shelters would be more than 14.

Please take in mind that those additional shelters are adequate if the government navigate vulnerable people to evacuate to the nearest safety zone, not based on the evacuee preferences. The government should spread many clear and sufficient navigation sign to navigate people to the safety zone. Those who are in the coverage area of a particular shelter are navigated to the shelter except in the case of horizontal evacuation is possible. When the preferences of the evacuee are accommodated, the estimation might not be valid anymore as has been simulated in [19]. Mas et al. [19] found that some shelters are more preferable than others are, therefore in the case of evacuation, the preferred shelters will

| ID | Shelter                  | DCI | 0.7 C | D | Excess |
|----|--------------------------|-----|-------|---|--------|
| 2  | Masjid Nurul Iman        | 0.743| 1750  | 1858| 108    |
| 5  | Masjid Nurul Haq         | 1.453| 2800  | 5818| 3011   |
| 7  | Hotel Inna Muara         | 0.974| 2800  | 3897| 1097   |
| 8  | Hotel Mercure            | 1.514| 2100  | 4541| 2441   |
| 10 | BPK Sumbar               | 1.515| 1400  | 3030| 1630   |
| 15 | DPRD Prov.               | 2.959| 1400  | 5919| 4519   |
| 16 | Bank Indonesia           | 1.375| 700   | 1375| 675    |
| 21 | TK Al Azhar              | 5.401| 1400  | 10801| 9401   |
| 18 | Pascasarjana UBH         | 2.043| 1400  | 4086| 2686   |
| 19 | Gedung Kesenian UNP      | 2.196| 1400  | 4391| 2991   |
| 20 | SMKN 5                   | 1.615| 2100  | 4846| 2746   |
| 21 | TK Al Azhar              | 0.605| 2100  | 2409| 309    |
| 24 | SDN 24                   | 2.187| 2100  | 6561| 4461   |

| ID  | Shelter          | Excess | C 2000 |
|-----|------------------|--------|--------|
| 5   | Masjid Nurul Iman| 3011   | 2      |
| 2   | Masjid Nurul Haq | 108    | 1      |
| 7   | Hotel Inna Muara | 1097   | 4      |
| 8   | Hotel Mercure    | 2441   | 4      |
| 20  | SMKN 5           | 2746   | 5      |
| 15  | DPRD Prov.       | 4519   | 11     |
| 18  | Pascasarjana UBH | 2686   | 4      |
| 19  | Gedung Kesenian UNP| 2991   | 27     |

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be overloaded while the less preferable shelter will be loaded under capacity.

IV CONCLUSIONS

This paper presents the estimation of demand for tsunami shelters in Padang, calculation the ratio of demand and capacity of shelters and estimation of the adequacy of the shelters. The study found that about a half of tsunami shelters in Padang could to overloaded if the vulnerable people to be evacuated to the nearest shelters. Some vulnerable people in some areas could not possibly reach any safety zone either by horizontal neither by vertical evacuation. Those areas are not covered by any shelters and far away from the hilly land. More shelters are needed to increase the possibility to help them from the disaster. In total, this study found that at least 37 more shelters with a capacity of 2000 are needed to ensure entire vulnerable people in Padang getting a help.

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