Analysis of community tsunami evacuation time: An overview

Y Yunarto¹ and A M Sari¹

¹Research Center for Geotechnology, Indonesian Institute of Sciences, Indonesia
E-mail: yunarto@gmail.com

Abstract. Tsunami in Indonesia is defined as local tsunami due to its occurrences which are within a distance of 200 km from the epicenter of the earthquake. A local tsunami can be caused by an earthquake, landslide, or volcanic eruption. Tsunami arrival time in Indonesia is generally between 10-60 minutes. As the estimated time of the tsunami waves to reach the coast is 30 minutes after the earthquake, the community should go to the vertical or horizontal evacuation in less than 30 minutes. In an evacuation, the city frequently does the evacuation after obtaining official directions from the authorities. Otherwise, they perform an independent evacuation without correct instructions from the authorities. Both of these ways have several strengths and limitations. This study analyzes these methods regarding time as well as the number of people expected to be saved.

1. Introduction
Indonesian archipelago along the western part of Sumatra Island, southern Java and Bali Island, Sumbawa to Flores is located in the subduction zone. The subduction zone is an area where the Indian Ocean-Australia plate encounters the highly active Eurasian plate. This region is a source of earthquakes that can cause a tsunami. An earthquake that can trigger a tsunami has these criteria: (1) a tectonic earthquake occurs under the sea; (2) the earthquake (hypocenter) depth is less than 100 km; (3) the earthquake’s strength is 7 on the Richter Scale (SR) or more; (4) the movement of tectonic plates occurs vertically, causing the seabed to rise or fall, and lifting or lowering the above water column [1].

On 26th December 2004, a 9.0 magnitude earthquake shook the province of Aceh and North Sumatra as well as caused tsunami waves in the Indian Ocean. This disaster took more than 250,000 lives. These waves spread in all directions from the tsunami center and swept the region of Aceh and North Sumatra with wave heights of 2 to 48 meters [2].

Tsunami, classified by distance, is defined into [3]:

- Near-field/Local field tsunami
  A Near-field/Local field tsunami is a tsunami occurring at a distance of approximately 200 km from the earthquake epicenter. This tsunami can be caused by an earthquake, landslide, or volcanic eruption.

- Long distance/teletsunami
  A long-distance tsunami is a tsunami occurring in coastal area hundreds of thousands of kilometers from an earthquake source. Originally, it is a close-range tsunami with extensive damage in the area near the earthquake source. The tsunami continues to spread across the entire ocean basin with considerable energy and causes many casualties and damages on the coast more than 1000km from the earthquake source.
2. Tsunami approach the foreshore (ETA)

In Indonesia, tsunami approaches the foreshore generally between 10 - 60 minutes. This time indicates that the tsunami in Indonesia is categorized as a local tsunami [1]. The tsunami waves reached the western coast of West Sumatra 30 minutes after the massive earthquake [4]. According to [5] a study case was conducted to make tsunami modeling based on the historical records of the earthquake in 1797 and 1833. The results obtained that the tsunami waves on the west coast of West Sumatra were estimated in 30 minutes after a major earthquake, with the source of the tsunami located on the west side of the Mentawai Island. According to [6], the tsunami might have arrived at the western coast of Sumatra if it had been triggered by an earthquake in the megathrust region, taking about 32 minutes in Padang city. However, if a tsunami is caused by backthrusts, it will arrive in 20 minutes.

Several methods for assessing the timing of tsunami evacuation are proposed by various researchers, as different regions have different risks depending on the distance to the subduction zone. This paper discusses multiple evacuation time evaluation methods with sufficient contextual information. This review highlights the limitations and advantages of each approach.

3. Evacuation Time

The evacuation time methods are classified as self-evacuation time and evacuation by the correct direction.

3.1. Self-evacuation time

According to [7] in Padang, Sumatra, when the tsunami arrived within 30 minutes, the city’s policy instructed people around the coast to evacuate independently without waiting for the official direction from the authorities. This system had a strong foundation based on the September 2009 earthquake event, when strong earthquakes occurred in Padang, which did not generate a tsunami. The National Tsunami Warning Center in Jakarta took four minutes to determine and announce the source of the earthquakes because its 70 km depth did not have the potential possibility to cause a tsunami. However, the people in Padang did not receive this information for 20-25 minutes afterward. This delay was due to earthquake shocks that shut down the electricity and communication networks (Figure 1). The Center for Disaster Management Operation Control of Padang City received the announcement of Tsunami Warning Center 5 minutes after the earthquake. After September 2009, the Control Center has had the mandate to announce or cancel the evacuation. However, as a precautionary procedure, Padang City preserves its policy that citizens must keep aware on the first shocks before relying on the correct direction that followed.

![Figure 1. Time of tsunami event in Padang 30 September 2009](image)

In the period when tsunami waves hit the west coast of Sumatera Island in less than 30 minutes, people can use the golden time to do vertical evacuation or horizontal evacuation to the higher places.
While waiting for the warning information from BMKG, which is 5 minutes after the earthquake, it has already been wasting 5-minute time to evacuate, especially for archipelago areas in Mentawai and Siberut. By the time the information received, tsunami has striken those areas [8].

BMKG currently has a tsunami early warning system called Indonesia Tsunami Early Warning System (InaTEWS). However, the success of these early warning systems will depend on individual self-awareness of the community to evacuate. When a strong earthquake is felt, people who live in the coastal area perform an independent evacuation automatically, by running away from the seashore looking for a higher ground without waiting for information from the Government or BMKG. Then this awareness could anticipate the number of casualties caused by the tsunami disaster.

Although self-evacuation is effective enough to reduce the number of casualties, it also has the limitation. When an earthquake occurs, the people who evacuate have difficulties to obtain information about where the earthquake source is located; if it is on the seabed or the ground surface. Moreover, these evacuees have lack of information whether there is a potential tsunami or not.

3.2. Evacuation time with official directions

The evacuation time is defined by knowing the time remaining after the warning of tsunami threats until the arrival of tsunami waves [9]. The evacuation time consists of four components, which are [10]: Institutional Decision Time (IDT), Institutional Notification Time (INT), and Reaction Time (RT) of the population. The available response time for evacuation (RT) can be obtained from [10]:

\[
RT = ETA - ToNW - RT.
\]

\[
ToNW = IDT + INT.
\]

\[
RsT = \text{Time required for people to evacuate};
\]

\[
ETA = \text{Estimated Tsunami Arrival};
\]

\[
ToNW = \text{Technical or Natural Warning (8 minutes)};
\]

\[
RT = \text{Reaction Time of Population (10 minutes)};
\]

\[
IDT = \text{Institutional Decision Time (Issuance from Indonesia Tsunami Early Warning System of BMKG - InaTEWS, 5 minutes)};
\]

\[
INT = \text{Institutional Notification Time (Issuance by local government, 3 minutes)}.
\]

According to [9], a study case resulted in only adding the evacuation time to the formula introduced by Post (2009) to increase the time to board the shelter building within 5 minutes (Figure 2). When the tsunami arrived at Cilacap beach, which was estimated within 40 minutes, the evacuation time of the community to the shelter was estimated 22 minutes, then 17 minutes was needed for the journey to the shelter building and 5 minutes to board the shelter building.
According to [12] there is a developed map of horizontal and vertical tsunami evacuation time based on total evacuation time (TET), calculated by adding the initial reaction time (IRT) and evacuation time (ET).

\[ TET = IRT + ET \]
\[ IRT = DT + NT + RT \]

IRT = initial reaction time (IRT)
DT = institutional decision time,
NT = institutional notification time,
RT = reaction time of the community.

Institutional time (DT and NT) is determined by the relevant government agencies that have the authority to issue hazard warnings [13]. Ina-TEWS usually takes 5 minutes to issue a tsunami warning [9,11]. In addition, the time of institutional notice is assumed to be 3 minutes, while community reaction time is 7-10 minutes [10,13]. In this study, the reaction time of society used was 15 minutes by adopting a 7-minute community reaction time.

Based on the arrival time of the Padang tsunami in 1797, the assumption of the estimated time of the earthquake and the arrival of the first wave of tsunami arrived at the seashore of Padang city (ETA) is 30 minutes, which is explained by the decision time (IDT) for 5 minutes, followed by time notification (INT) in 3 minutes, and the preparation time and reaction of the community (RT) in 7 minutes. Then, the time required to reach the evacuation site (30 - 15 minutes) is \( \leq 15 \) minutes, which means that the community has to do vertical evacuation or horizontal evacuation as soon as possible within 15 minutes after receiving early warning information.

BMKG has the authority to decide whether an earthquake can cause a tsunami or not. This information is forwarded to the Center for Operations Control in the regions and also to the social media then to be continued to the community. From this information, people around the coastline will know the location of the earthquake and the next steps to be taking whether to do the evacuation or not.

Another advantage of doing the evacuation from official government directives is that the government can give early information to the public to prepare for the evacuation, based on tsunami waves which are monitored by BMKG.

This method also has disadvantages, including the facts that (1) the area close to the source of a potential tsunami earthquake will be vulnerable to the tsunami disaster (when an early warning was received the tsunami had also hit the area); (2) during a strong earthquake, facilities and infrastructure will be paralyzed (such as damaged buildings, roads, and bridges) so that the early warning system is not functioning and the community does not have initial warning information.

4. Conclusion
The tsunami arrival time in some risk areas may vary, particularly for islands which are very close to the subduction zone (tectonic collision). The tsunami can come in less than five minutes after the earthquake. Therefore, people in this area do not have enough time to wait for a warning from BMKG. After feeling the earthquake striking, the community must immediately act and conduct an independent evacuation. In contrast, in an area 200 km away from the subduction zone, the arrival of the tsunami on the coast is estimated about 30 minutes after the earthquake. People in this area have enough time to wait for warnings from the Government or BMKG, which then react to preparations that are expected to take around 15 minutes after the earthquake so that people can evacuate within 15 – 30 minutes. Based on the experience in the city of Padang, electricity was shut down when a strong earthquake occurred, so communication was cut off, and the public was not well-informed after that within 20-25 minutes. Therefore, tsunami-risk areas need to be equipped with supporting facilities and infrastructure such as adequate communication means and electricity generators, so that when strong
and long earthquakes occur, continuous communication and early warning information from the Government or BMKG can be continuously communicated to the community for immediate evacuation.

The success of these early warning systems will depend on individual self-awareness of the community to evacuate. Therefore, the city needs to form a community group or namely disaster preparedness group – KSB, whose elements consist of local administrators, head of the neighborhood, community leaders, youth, volunteers and religious leaders, who become activators and directors in conducting an evacuation. Moreover, the community needs to get the socialization of preparedness for both independent evacuation and evacuation time to get correct direction from the government. The forms of socialization include having knowledge about the disaster, recognizing the regional environment and disaster, preparing family preparedness from catastrophe, conducting periodic evacuation simulations, and following disaster activities and training.

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