# EVALUATION OF TSUNAMI EVACUATION RISK IN PADANG CITY
## -CASE STUDY ON 2009 WEST SUMATERA EARTHQUAKE-

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インドネシア共和国パダン市の沖合で2009年9月30日マグニチュード7.6の地震が発生し多くの被害が出た．幸いにも地震による津波被害はなかったが，パダン市が依然として極めて高い津波被害の危険性に晒されている状況に変わりはない．本研究では筆者らが地震直後に実施した現地被災調査の結果を踏まえ，現時点で一時的に用いられている津波避難施設の配置計画の適用性を評価した．その結果，現状の配置計画では想定される津波浸水域に居住する住民の半数弱が安全に避難できない可能性があることと，避難不可割合は地震による避難経路の被災によりさらに高くなることを示した．また，本研究では地震後に実施した避難施設と避難路の被災状況調査をもとに新たな津波避難施設の配置を提案し，それらを有効活用することで避難可能範囲が大きく拡大することを示した．

***Key Words***: *Tsunami disaster, Evacuation service area, 2009 West Sumatera earthquake, GIS.*

## 1. INTRODUCTION

Padang city, a capital of West Sumatera Province, is one of the most vulnerable cities against tsunami disaster in the world. Padang city spreads on the coastal area, and the city had undergone several strong earthquakes and tsunami disasters. For example, the city had experienced great tsunami events in 1797 and 1833 with their run up height at least 5 m and 4 m respectively[1)].

On September 30, 2009, Padang city had severe damages by the earthquake of magnitude 7.6. It was reported that 1.195 were killed by this earthquake, 1.798 were injured and 2 were missed in West Sumatera province[2)]. Fortunately, no tsunami was occurred due to this earthquake though the epicenter located in the coastal area.

After the catastrophic damages of 2004 Aceh tsunami, the people of Padang realized that they have been living in a very high risk area against tsunami disaster. Since this event, Padang has been making efforts to reduce vulnerabilities against tsunami disaster. For example, KOGAMI, one of the NGO in Indonesia, provides a tsunami hazard map that includes 93 evacuation shelters and evacuation routes. MMAF, the Ministry of Marine Affairs and Fisheries, also provides the map that includes 152 evacuation shelters. Through our field survey right after 2009 West Sumatera earthquake, it was found that many of those shelters were damaged by the earthquake, and were unavailable to be used as temporal shelter.

This study evaluates the validity of tsunami evacuation shelters that were allocated by KOGAMI and MMAF under the damages on 2009 West Sumatera earthquake. Furthermore, this study proposes a new allocation of tsunami shelters based on our field survey, and investigates the effect of those allocated shelters on expanding the service area for safety tsunami evacuation.

## 2. TSUNAMI HAZARD MAP IN PADANG

Several institutions and scientists have developed tsunami hazard map in Padang city. According to consensus at International Workshop on Official Tsunami Hazard Map on August 25, 2008, Padang city accepted the temporal use of an existing hazard map provided by KOGAMI, which is the worst-case scenario set by Borrero et al's model[3]. The MOST model was used to simulate the tsunami generated by the source parameters of historical tsunami of 1797 and 1833. The hazard map is shown in Fig.1.

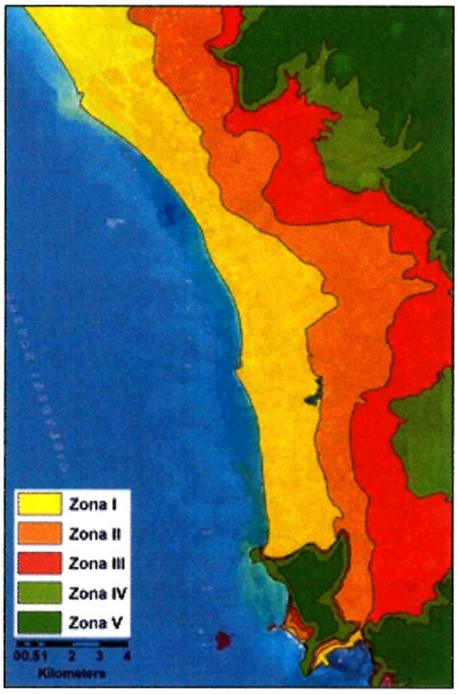


**Fig.1.** Tsunami hazard map of Padang city

This hazard map divided the Padang city into four categories, such as danger zone, alert zone, safe zone, and relocation zone as shown in Table.1[4]. The land use type of danger zone is mostly covered by residential area. This area widely spreads along the coast on Padang city as shown in Fig.1. In 2006, the total population of Padang city is around 819.740[5], and around 269.700 people live in this danger zone. Those are the number of people that have to evacuate firstly when tsunami occurs.

**Table.1.** Hazard categories in Padang city[4]

| Category | Zone | Elevation (m) |
|---|---|---|
| Danger zone | Zone-1 | 0-5 |
| Alert zone | Zone-2 | 5-10 |
| Safe zone | Zone-3 | 10-25 |
| Relocation zone | Zone-4 | 25-100 |
| | Zone-5 | >100 |

## 3. ROAD NETWORK AND SHELTERS DAMAGE ON 2009 WEST SUMATERA EARTHQUAKE

### (1) Existing evacuation planning in Padang city

For evacuation planning, KOGAMI divided Padang city into eight sectors that were bordered by main rivers as seen in Fig. 2, and arranged 93 shelters as shown in Table.2. MMAF divided Padang city into four sectors that were bordered by main rivers and also arranged 152 shelters. All of those existing shelters are used for government office, schools, hotels, mosques, shop-houses and hospitals in common use. The allocation of those shelters in each sector is shown in Fig.2. This study employs the sectors partition arranged by KOGAMI because it is more detail. As shown in Table 2, there are some sectors where no shelters are allocated, because there is no appropriate public building that can be available for temporal shelter in case of tsunami [6].

**Table 2.** The number of existing shelters planed in temporal hazard map in Padang city

| Sector | Existing Shelters | |
|---|---|---|
| | KOGAMI | MMAF |
| Sector -1 | 0 | 1 |
| Sector -2 | 2 | 1 |
| Sector -3 | 16 | 4 |
| Sector -4 | 0 | 0 |
| Sector -5 | 1 | 0 |
| Sector -6 | 37 | 65 |
| Sector -7 | 37 | 81 |
| Sector -8 | 0 | 0 |
| Total | 93 | 152 |

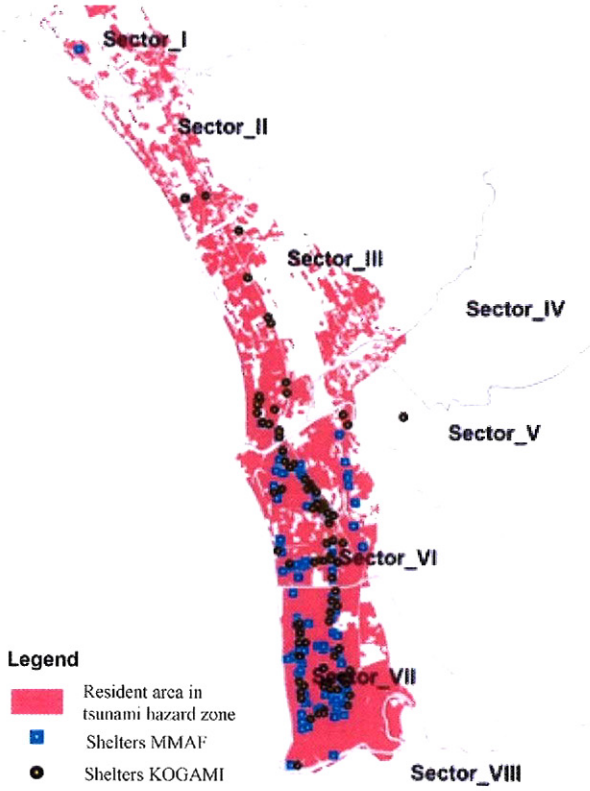


**Fig.2.** The allocation of evacuation shelters arranged by KOGAMI and MMAF in Padang city

(2) **Shelter damages by 2009 earthquake**

Field survey in Padang city was conducted right after the earthquake from October 12 to October 18, 2009. Trough this field investigation, it was observed that the allocated evacuation shelters do not have the special sign as the evacuation place in case of tsunami attacks, and few people use those as the emergency shelter. It was also found that many public buildings that were supposed as evacuation shelter were damaged by the earthquake and were unavailable to use even for temporal shelter. Table 3 shows that 27% of shelters allocated by KOGAMI and 37% of shelters allocated by MMAF were damaged by 2009 West Sumatera earthquake. As shown in Fig.3, the most affected shelters due to this earthquake were located in Sector-VII where was known as the most populated area in Padang city. Photo 1 shows the example of damaged shelter. This shelter was usually used as a shop-house, and had the damage of 'soft storey' phenomenon.

**Photo 1.** Example of shelter had the damage of 'soft storey' phenomenon

**Table 3**. Shelters damage in Padang city

| Existing Shelters arranged by | Before earthquake | After earthquake | |
|---|---|---|---|
| | | Damage | Available |
| KOGAMI | 93 | 25 (27%) | 68 (73%) |
| MMAF | 152 | 57 (37%) | 95 (63%) |

(3) **Road network damage**

After 2009 West Sumatera earthquake, road network damages were most evident in longitudinal cracking and pavement deformation caused by heave or subsidence as shown in Photo 2. In addition, several sections of roadway in highly populated resident area in Padang city were blocked by collapsed buildings as shown in Photo 3. Those conditions caused the block of evacuation networks.

It was found from field investigation that many roads were damage or were blocked by collapsed buildings especially in south part of Padang city as shown in Fig.3. This area is known as an old city where there are many old buildings without reinforced concrete as shown in Photo 4. Collapsed those buildings block the road because the most of those buildings were located close to the road.

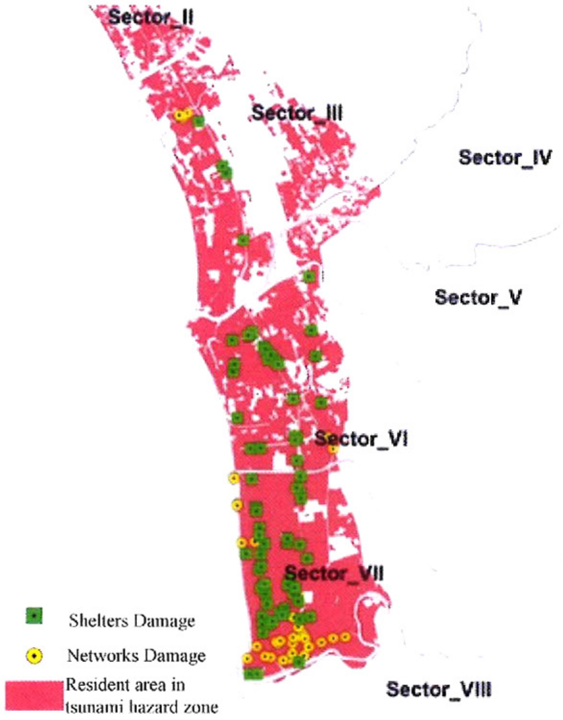


**Fig.3.** The location of Shelters damage arranged by KOGAMI and MMAF and network damage in Padang city


**Photo 2.** Example of damaged road network

**Photo 3.** Example of blocked road network because of the collapsed building


**Photo 4.** Example of old buildings that were built without reinforced concrete for their structures

## 5. EVALUATION OF SHELTER PLANNING AFTER 2009 EARTHQUAKE

### (1) Evaluation of service area

In the evaluation of shelter planning, this study considers on evacuation service area that covers the resident area in tsunami hazard area. This study defines the service area as the minimum area where residents can reach the nearest evacuation shelter from their houses by foot within a clearance time. The clearance time is also defined as the minimum time until the first tsunami wave approach the area after the official warning of tsunami evacuation. The service areas are generated with using both spatial and network analysis on GIS.

It was estimated that the tsunami attacks the Padang city approximately 33 minutes after the earthquake occurs on Sunda megathrust[6]. Judging from the current tsunami warning transmission system, approximately 20 minutes will be consumed after the earthquake. Based on above assumptions, the clearance time to reach evacuation shelter is considered only 13 minutes. By employing the average velocity of normal walking speed on the plain surface is 3.6 km per hour[7], the maximum evacuation route distance within 13 minutes is 780 m. Thus, the service areas were generated based on 780 m along an evacuation route.

Many damaged conditions can be considered when the tsunami attacks the local district after the earthquake. In this study, six scenarios are considered as shown in Table 4 with focusing on the possible network damage and the availability of evacuation shelters under the tsunami disaster with earthquake.

Case-1 and Case-2 evaluate shelter planning arranged by KOGAMI. Case-1 is the scenario before the 2009 earthquake, and all shelters as well as all evacuation networks are available. After 2009 West Sumatera earthquake, 25 shelters arranged by KOGAMI were damaged and became unavailable to be used. Some passes were also damaged or blocked by collapsed building and became unavailable for evacuation. Those conditions are evaluated in Case-2. The same scenarios are employed on shelter planning arranged by MMAF in Case-3 and Case-4.

**Table 4.** Scenarios of network damage and availability of evacuation shelters considered in this study

| Scenario | Availability of Shelters | | Available shelters | Availability of Evacuation Network |
|---|---|---|---|---|
| Case-1 | KOGAMI | All shelters available | 93 | All network available |
| Case-2 | | Non damaged by 2009 earthquake available | 68 | Non damaged by 2009 earthquake available |
| Case-3 | MMAF | All shelters available | 152 | All network available |
| Case-4 | | Non damaged by 2009 earthquake available | 95 | Non damaged by 2009 earthquake available |
| Case-5 | This study | Utilizing non damaged public buildings | 143 | All network available |
| Case-6 | | | | Non damaged by 2009 earthquake available |

Based on the investigations from Case-1 to Case-4, this study proposes a new allocation of evacuation shelters. In this study, the allocation of new shelters is based on our field survey. The effectiveness of this new allocation is evaluated in Case-5. The new shelter allocation in this study is also evaluated in case of network damages under 2009 West Sumatera earthquake in Case-6.

### (2) Result of evaluated service area

In the evaluation of service area in Padang city, this study focuses on the residential area in tsunami hazard zone, where about 269.700 people are living. Fig.4 shows the service area cover on resident area in tsunami hazard zone as well as the resident area in tsunami hazard zone that cannot be covered by service area from Case-1 to Case-4. The non-covered service areas mean that the residents who are living in those areas don't have enough time to evacuate to the nearest evacuation shelters within the clearance time.

In Case-1 and Case-3, the service areas of existing tsunami evacuation shelters allocated by KOGAMI and MMAF only cover partially the inundated resident area as shown in Fig.4. This means that the evacuation shelters both in KOGAMI and MMAF arrangement are not well spread in whole tsunami hazard area. As shown in Fig.2, shelters are centralized in Sector-VI and Sector VII while they are not sufficient in other areas. Table 5 shows the number of residents who cannot reach evacuation shelter within the clearance time in each case. As shown in Table 5, the original evacuation shelter allocated by KOGAMI and MMAF cannot cover 44% and 46% of residents in inundation area, respectively.

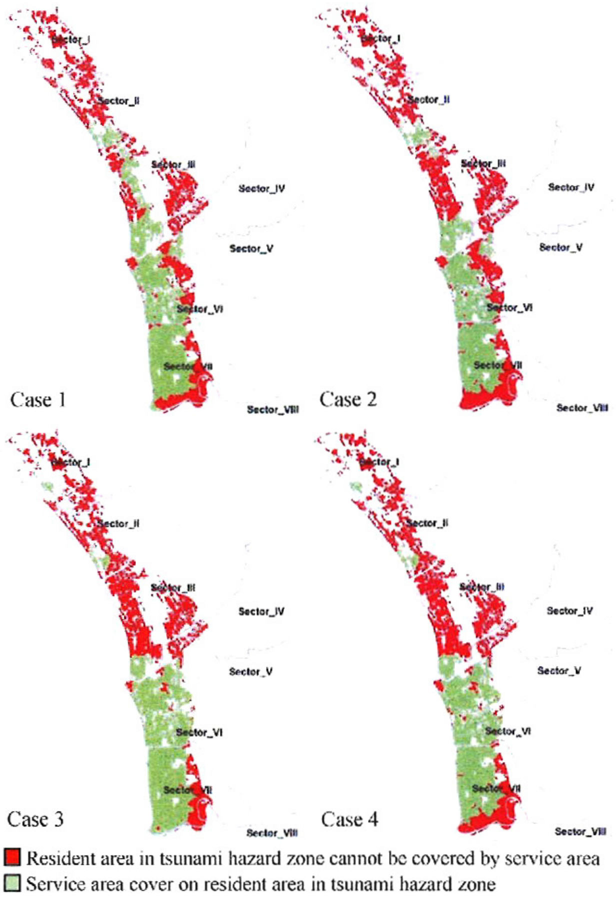


**Fig.4.** Map of service areas cover on resident areas in tsunami hazard zone on shelter planning arranged by KOGAMI and MMAF in Padang city

Some evacuation shelters and road networks were damaged due to the 2009 earthquake. The damages reduced the service areas as shown in Case-2 and Case-4 in Fig.4. The effect of above damages in reducing the service area can be observed mainly in Sector-VII, because this sector had the severest damage under the 2009 West Sumatera earthquake.

In Case-2, 53% of residents are not covered by evacuation shelters as shown in Table 5. Also in Case-4, 51% of residents are not covered. Above results mean that the current allocation of evacuation shelters in tsunami hazard maps provided by KOGAMI and MMAF are insufficient for mitigating tsunami risk on residential area, and new shelter allocation as well as network conservation strategies are strongly desired.

**(3) New shelter allocation**

We checked the damages of shelters allocated by KOGAMI and MMAF one by one through field survey. Also we checked the non-damaged buildings in Padang city after the 2009 earthquake. From above field survey, this study proposes a new shelter allocation to revise the shelter arrangement by KOGAMI and MMAF. In addition to the non-damaged shelters on the map of KOGAMI and MMAF, we utilize the public buildings which were not damaged under 2009 earthquake. Those buildings have more than 2 floors. The total number of evacuation shelter proposed in this study is 143. Those are 47 mosques, 44 government buildings, 35 schools, 6 shopping malls, 6 hotels, 4 hospitals and a hilly open space.

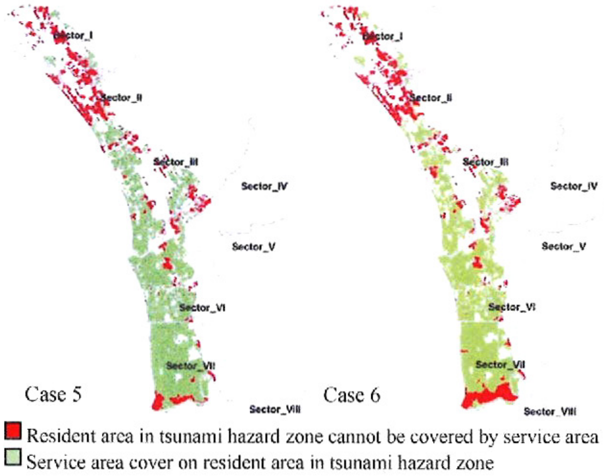


**Fig.5.** Map of service areas cover on resident areas in tsunami hazard zone on proposed shelters allocation in this study

The new shelter allocation in Case-5 increases the service area significantly as shown in Fig.5. The most significant expansion can be seen in Sector-III. Fig. 6 shows the detail illustration of this sector. Trough our field observation, we found many mosques which have more than 2 floors in this area, and they were not damaged even under the 2009 earthquake. Utilizing those buildings as evacuation shelter increases the service area significantly. On the other hand, only a few residential areas in Sector-I and Sector-II can be covered by service area because no other evacuation shelters are available in this sector. This means that some alternative evacuation shelters have to be provided newly in those areas.

In Case-5, the number of residents who cannot be covered by evacuation shelters decrease to 20% as shown in Table-5. On the other hand, the network damages in Case-6 increase non-covered residential area 4%. The networks damage occurred mainly in Sector-VII and this caused the increase of non-covered area.

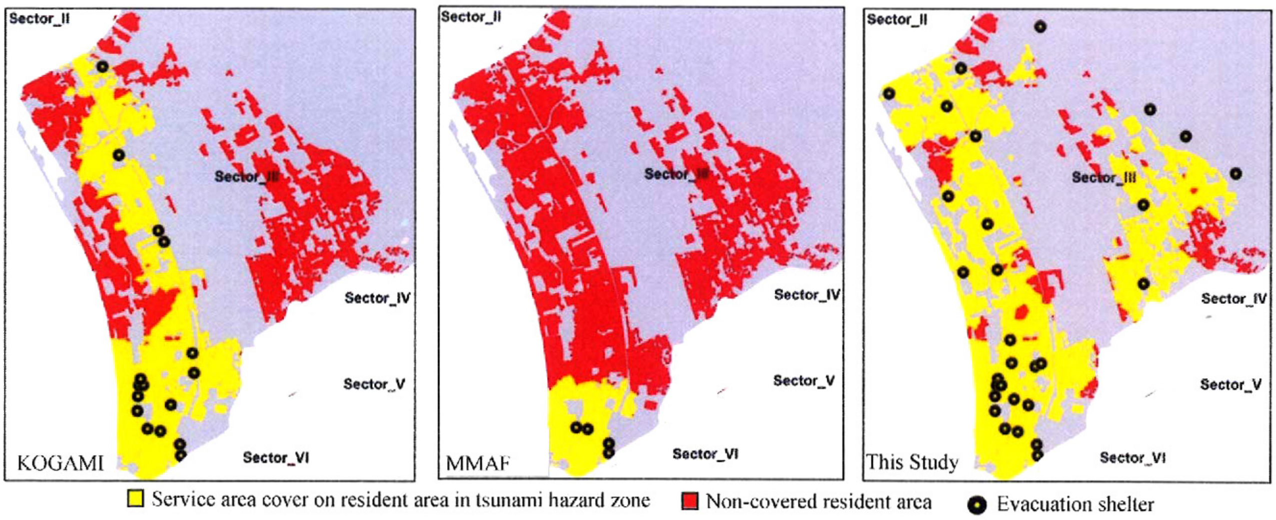


**Fig.6.** The expansion of service areas in Sector-III in this study compared with those of arranged by KOGAMI and MMAF.

**Table 5**. The numbers of residents who cannot reach evacuation shelter within clearance time

| Scenario | Not enough time to evacuate (person) | Percentage (%) |
|---|---|---|
| Case-1 | 119,715 | 44 |
| Case-2 | 142,625 | 53 |
| Case-3 | 122,971 | 46 |
| Case-4 | 136,846 | 51 |
| Case-5 | 52,980 | 20 |
| Case-6 | 64,030 | 24 |

## 6. CONCLUSIONS

This study evaluates the validity of current tsunami shelter allocation proposed by KOGAMI and MMAF in Padang city. The current arrangement of evacuation shelters by KOGAMI covers around a half of residents who live in tsunami hazard zone. Also other existing arrangement by MMAF covers nearly the same.

A new allocation of tsunami evacuation shelters in Padang city was proposed in this study with considering the structural damages by 2009 West Sumatera earthquake. It was cleared that the new allocation of shelters, which makes the most use of current arrangement by KOGAMI and MMAF, expands the service area remarkably.

However, the proposed shelters allocation could not cover whole inundation area. Providing new building for evacuation shelter in Sector-I and Sector-II, reducing building vulnerabilities against earthquake disaster in Sector-VII, and evacuation network conservation in those districts are strongly required in the disaster mitigation planning of Padang city.

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