

4.1.2 Overview of Tsunami Disaster in Indonesia

Table 4.1.1 shows the tsunami incidents in Indonesia during 1960 -2006.

Serious tsunami disasters in recent years include Flores (1992) with more than 1,950 dead, East Java (1994) with 240 dead, Biak (1996) with 107 dead, the Sumatra Earthquake and tsunami (2004) with about 300,000 dead, West Java (2006) with more than 668 dead. Coastal Areas of Indonesia have been attacked by tsunami at the frequency of once every year, and the potential of the tsunami hazards could be highest in the world.

Table 4.1.1 Tsunami Cases in Indonesia During 1960-2006

No.	YEAR	EPICENTER	MAX RUN-UP HEIGHT(m)	VICTIM (DIED/INJURED)	AREA
1	1961	8,2 Lat. S; 122 Long.E	NA	2/6	NTT, Central Flores
2	1964	5,8 Lat. N; 95,6 Long.E	NA	110/479	Sumatra
3	1965	2,4 Lat. S; 126 Long.E	NA	71 died	Maluku, Seram, Sanana
4	1967	3,7 Lat. S; 119,3 Long.E	NA	58/100	Tinambung South Sulawesi
5	1968	0,7 Lat. N; 119,7 Long.E	8/10	392 died	Tambo Central Sulawesi
6	1969	3,1 Lat. S; 118,8 Long.E	10	64/97	MajeneSouth Sulawesi
7	1977	11,1 Lat. S; 118,5 Long.E	5-8	316 died	NTB, Sumbawa Island
8	1977	8 Lat. S; 125,3 Long.E	NA	2/25	NTT, Flores, Atauro Island
9	1979	8,4 Lat. S; 115,9 Long.E	NA	27/200	NTB,Sumbawa,Bali,Lombok
10	1982	8,4 Lat. S; 123 Long.E	NA	13/400	NTT,Larantuka
11	1987	8,4 Lat. S; 124,3 Long.E	NA	83/108	NTT, East Flores, P.Pantar
12	1989	8,1 Lat. S; 125,1 Long.E	NA	7 died	NTT, P. Alor
13	1992	8,5 Lat. S; 121,9 Long.E	11,2-26,2	1952/2126	NTT,Flores, P. Babi
14	1994	10,7 Lat. S; 113,1 Long.E	19,1	38/400	Jember, Banyuwangi Jatim
15	1996	1,1 Lat. S; 118,8 Long.E	NA	3/63	Palu. Central Jaya
16	1996	0,5 Lat. S; 136 Long.E	13,7	107 died	P. Biak, Irian Jaya
17	1998	2,02 Lat. S; 124,87 Long.E	2,75	34 died	Tabuna Maliabu Maluku
18	2000	0,6 Lat. N; 119,92 Long.E	3,0	2	Banggai, Central Sulawesi
19	2004	3,298 Lat. N; 95,6 Long.E	34.5	>300.000	NAD, North Sumatra
20	2005	2,065 Lat. N; 97,01 Long.E	3.5	NA	Nias North Sumatra
21	2006	9,4 Lat. S; 107,2	7,6	>668	Jabar, Jateng, DIY

Source: S.Diposaptono, NOAA Tsunami Database, K. Kato et al. (1995)

4.2 Disaster Characteristics of Tsunami Disaster and Countermeasures in Kabupaten Jember

4.2.1 Disaster Characteristics of Tsunami Disaster in Kabupaten Jember

1) Tsunami Disaster in the past

(1) Past Tsunami Disaster in Java Island

The list of the huge Earthquake and tsunami in recent years generated in Java trench (Sunda trench) in Southern offshore of Java island which seems to affect the coast of Kabupaten Jember is shown in Table 4.2.1.

The huge tsunamis occurred after 1960 is three on 1977, 1994 and 2006. The tsunamis in 1977 and 2006 caused serious damages along the coasts near each sources of tsunami, but didn't cause them along the coast of Kabupaten Jember where is very far from them. East Java tsunami (June 3, 1994) whose epicenter located at 240 km offshore from the coast affected all of southern coast of East Java province. Therefore, The East Java Tsunami is fixed as a Target of investigation of past tsunami disaster in Kabupaten Jember in this study.

Table 4.2.1 Tsunami Event offshore Java Island (1960-2006)

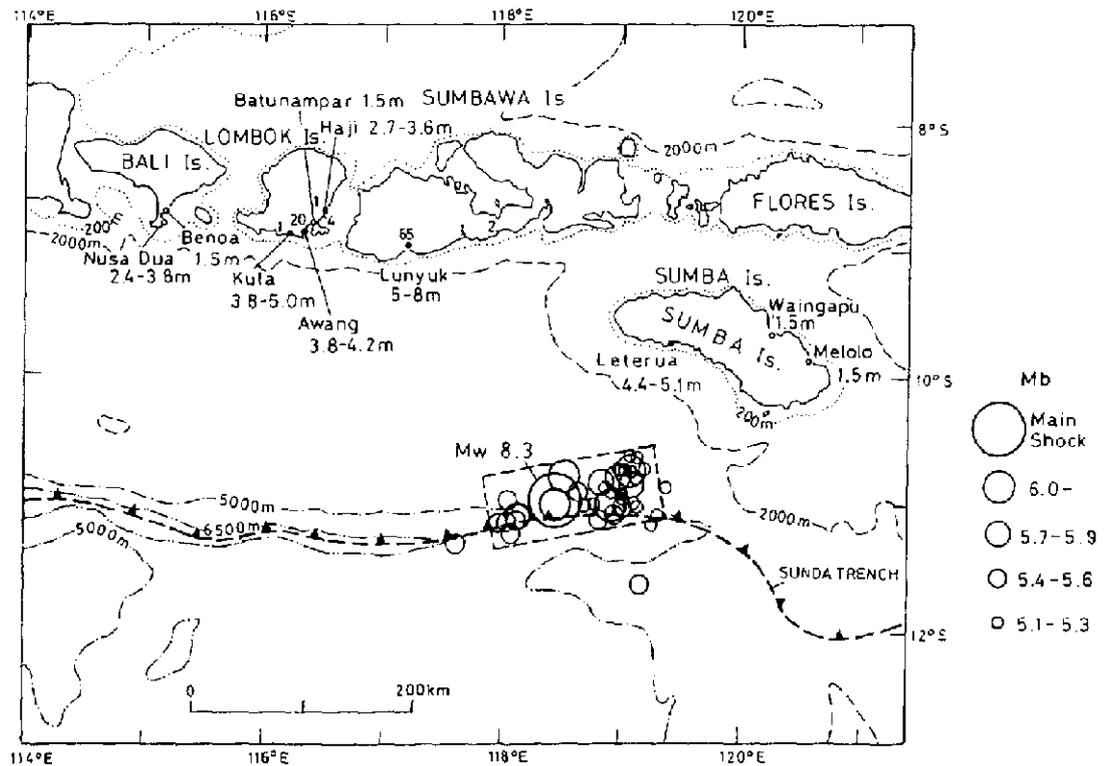
Date	EPICENTER	MAX RUN-UP HEIGHT(m)	VICTIM (DIED/INJURED)	AREA
August 19,1977	11,1 Lat. S; 118,5 Long.E	5-8	316 died	NTB, Sumbawa Island
June 3, 1994	10,7 Lat. S; 113,1 Long.E	19,1	38/400	Jember, Banyuwangi Jatim
July 17, 2006	9,4 Lat. S; 107,2	7,6	>668	Jabar, Jateng, DIY

Source: S.Diposaptono, NOAA Tsunami Database, K.Kato et al. (1995)

A. Tsunami of the Sumba Earthquake (August 19, 1977)

A large earthquake with magnitude Mw 8.3 occurred at the offshore of the southeast coast of Sumba Island, Indonesia at 6h 08m GMT (14h 08m local time) on August 19, 1977 (Given and Kanamori, 1980). This earthquake generated a big tsunami that hit the coasts of Bali, Lombok, Sumbawa and Sumba Islands, whose run-up height were reported 5-8m on Lunyuk, Sumbawa Island, 5.0m on the south coast of Sumba Islands, and 2.4-3.8m on the coast of Bali Island. And also the damages of this tsunami were recorded to cause a few hundreds dead, more than 400 damaged houses, and more than 400 damaged ships. It seemed that this tsunami, even though it might be small, reached the coast of Kabupaten Jember because this tsunami was reported to hit Bali Island.

The positions of the epicenters and coastal tsunami height are shown in Figure 4.2.1.



Source: K.Kato et al. (1995)

Figure 4.2.1 Location of the Main shock and Aftershock of Sumba Earthquake (Mw=8.3) of August 19, 1977 and Tsunami Height

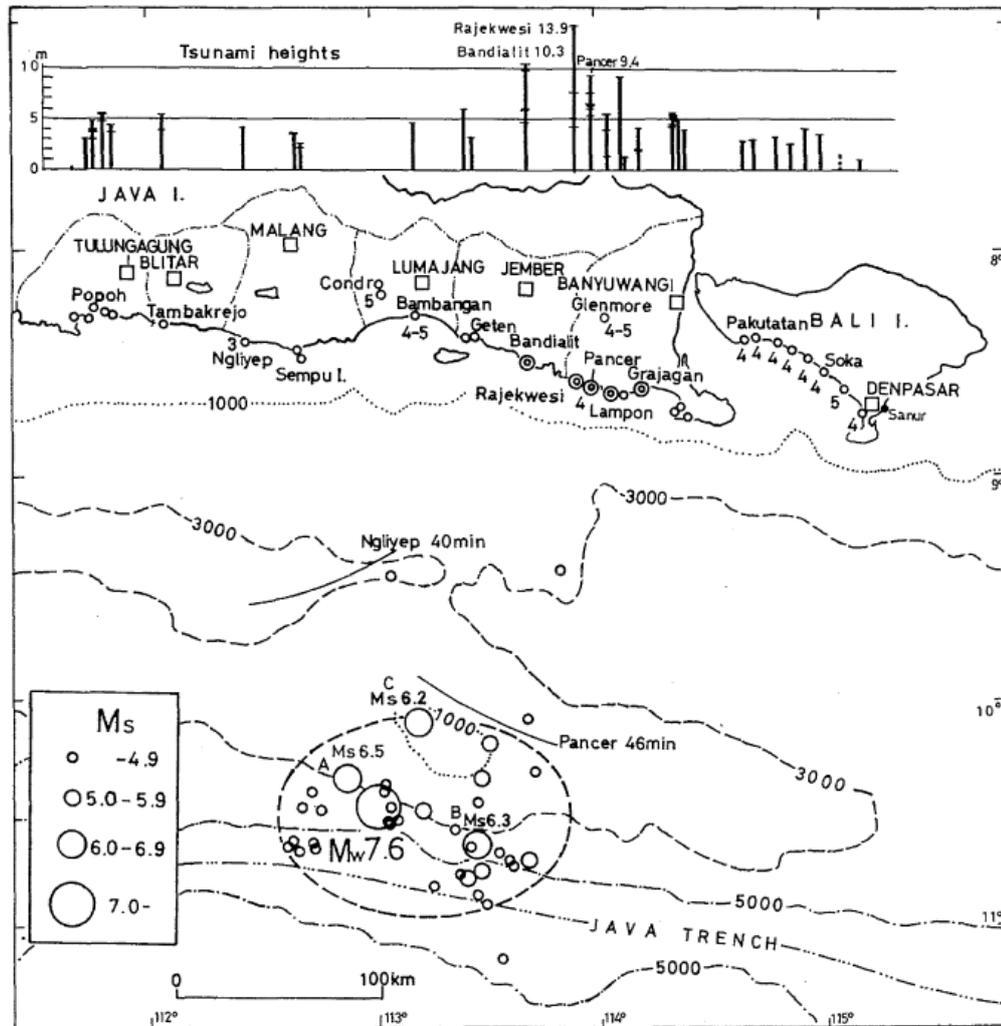
B. East Java Earthquake and Tsunami (June 3, 1994)

A large earthquake with magnitude Mw 7.6 occurred off the southeast coast of Java Island, Indonesia at 18h 17m GMT on June 2 (01h 17m local time on June 3) 1977 (Y. Tsuji et al., 1995). The ground shaking due to this earthquake was small, and the direct damage by the seismic shaking was not reported. Thus only 10-20% of the inhabitants of the villages on the nearest coasts were awakened by the ground shaking. In contrast, about 40-50 minutes after the main shock, a sizable tsunami hit the coast, inflicting heavy damage on several coastal villages in Kabupaten Banyuwangi and Kabupaten Jember regencies of East Java Province.

The location of the epicenters and the distribution of the tsunami height on the coast are shown in Figure 4.2.2. And also Tide-gauge records from Kabupaten Banyuwangi are shown in Figure 4.2.3.

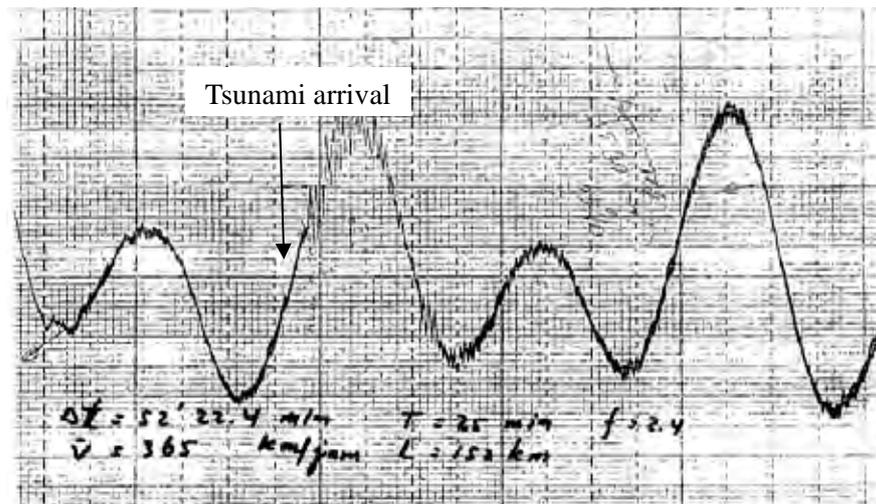
Regarding the tsunami run-up height of the coast, the records of Rajekwesi in Kabupaten Banyuwangi is the highest and 13.9m. The second record is 11.2m on the coast of Bandialit in Kabupaten Jember, and the third one is 9.4m on the coast of Pancer in Kabupaten Banyuwangi.

However, these tsunami run-up heights are local heights, and the average run-up height of the Kabupaten Jember and Kabupaten Banyuwangi where the run-up height were comparatively large is about 5-7m.



Source: Y. Tsuji et al. (1995)

Figure 4.2.2 Distributions of Tsunami Heights, Seismic Intensity, and Aftershocks of the 1994 East Java Earthquake



Source: A.Maramai et al. (1997)

Figure 4.2.3 Tide-gauge Records from Kabupaten Banyuwangi

The arrival time of tsunami was 30-40 minutes from the main shocks (at 2h local time) according to the interview carried out in 1994. According to tide-gauge records observed in Kabupaten Banyuwangi (Figure 4.2.3), the arrival time is at about 2 o'clock that agree the result of Healing. Investigation that Matsutomi et al. (1995) executed at that time indicates that cyclic time of the tsunami is about 10-15 minutes and the tsunamis hit the coast 3-4 times, and the second wave was biggest.

The damage due to tsunami of East Java province is shown in Table 4.2.2. In East Java Province, the damage of Kabupaten Banyuwangi was extremely large, but the damage of Kabupaten Jember is much smaller than that though it was second. Because it seemed that the coast of Kabupaten Banyuwangi was attacked by the tsunami as large as the tsunami that hit the coast of Kabupaten Jember, the difference of the characteristic of coastal topography and land use brought out the difference of size of the damages. The domiciles in Pancer, Kabupaten Banyuwangi that damaged most severely (121 dead and 704 damaged houses) were the flat place near the sea and whose elevation was about 5m.

Table 4.2.2 Statistics of human and house damage by Regencies in East Java Province

Regency	Human Damage				House Collapsed			Damaged Ships
	Killed	Missing	Injury		Totally	Partially	Slightly	
			Heavy	Slight				
Tulungagung	2	-	20	-	62	59	-	84
Blitar	2	-	-	-	-	3	-	153
Malang	1	-	-	2	31	7	4	168
Jember	12	-	4	7	36	33	11	119
Banyuwangi	206	15	21	-	591	66	235	380
Total	223	15	45	9	720	168	250	904

Source: Y. Tsuji et al. (1995)

The following factors are pointed out that expanded the damage due to East Java Tsunami (1994) and as the features of the tsunami.

- There were a lot of residents who were in bed because the East Java Earthquake and Tsunami occurred at midnight.
- The earthquake size was not so big ($M_w=7.5$) and ground shaking was small. So there was hardly anyone who noticed the earthquake as the sign of the tsunami. However the tsunami scale ($m_H=3$)¹ was bigger than that was estimated from the scale of the earthquake. Such a kind of the earthquake and tsunami is called “Tsunami Earthquake”.
- The arrival time of tsunami was 30-40 minutes from main shock and the residents lived in coastal area could have evacuated to safe place if the action of the administration and the residents had been fast. But because of lack of knowledge about the earthquake and tsunami, and lack of evacuation information, the people could not do so.

¹ Tsunami Magnitude (Hatori, 1986): Tsunami Magnitude is calculated from the tsunami height generated by earthquake. This function is used for expressing the scale of “Tsunami Earthquake”

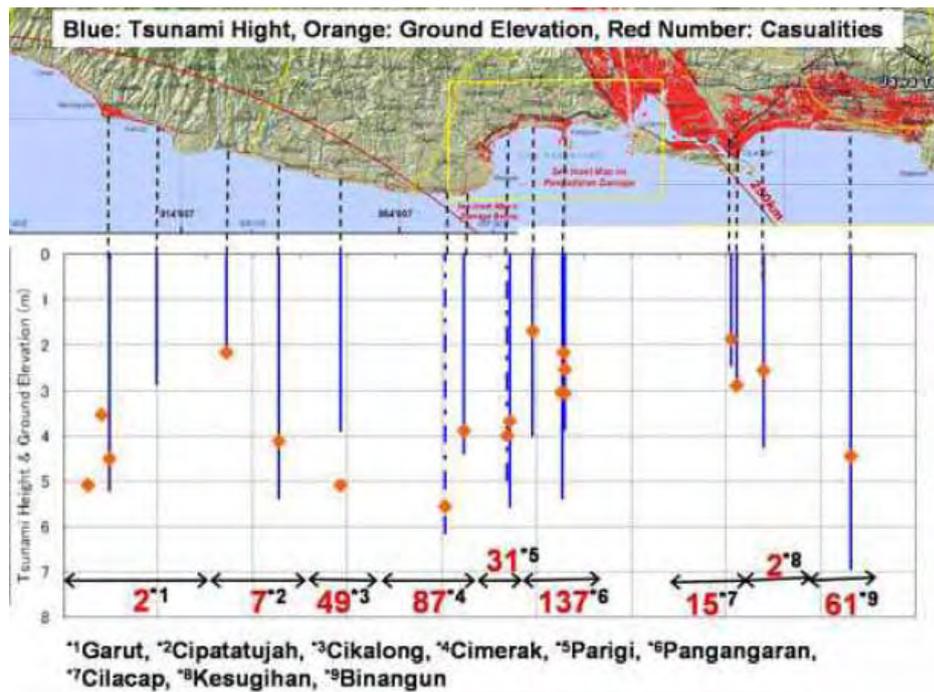
C. West Java Earthquake and Tsunami (July 17, 2006)

A large earthquake with magnitude M_w 7.7 (USGS) occurred off southwest coast of Java Island, Indonesia at 08h 24m UTC on July 17 (15h 24m local time on July 17) 2006. The tsunami generated by the earthquake hit the southwest coast of Java island and the tsunami run-up heights were 3-5m.

This earthquake generated a big tsunami that hit the southwest coast of Java island, whose run-up heights were reported 6m on Cilacap, 3-5m on Pangangaran, Chiamis, and 5.0m on Tasikmalaya. Most of the coastal areas protected by the sand dune that has about 4m elevation were not damaged. On the other hand, the area that the tsunami invaded from the low sand dune and the river mouth, at Pangangaran whose ground elevation is low, were seriously affected by tsunami. The dead increased to more than 600 people.

Serious damage was not reported in Kabupaten Jember because that the coast of Kabupaten Jember is 600km far away from the epicenter. But according to interviews in this field survey, Bandialit was attacked by the tsunami which was more than 2m. The phenomenon that the tsunami was bigger than that was estimated by the scale of earthquake is similar to the feature of the East Java Tsunami (1994). Therefore this tsunami disaster is useful case for considering the tsunami disaster of Kabupaten Jember.

The location of the epicenters and the distribution of the tsunami height on the coast are shown in Figure 4.2.4. Also, the damages that occurred in each kabupaten are shown in Figure 4.2.5.



Source: Debrief session for Field Survey of West Java Earthquake and Tsunami, Abstract, JSCE (2006)

Figure 4.2.4 Tsunami Height and Ground Elevation



Source: OCHA Situation Report No.5 (2006)

Figure 4.2.5 Damage due to 2006 West Java Earthquake and Tsunami

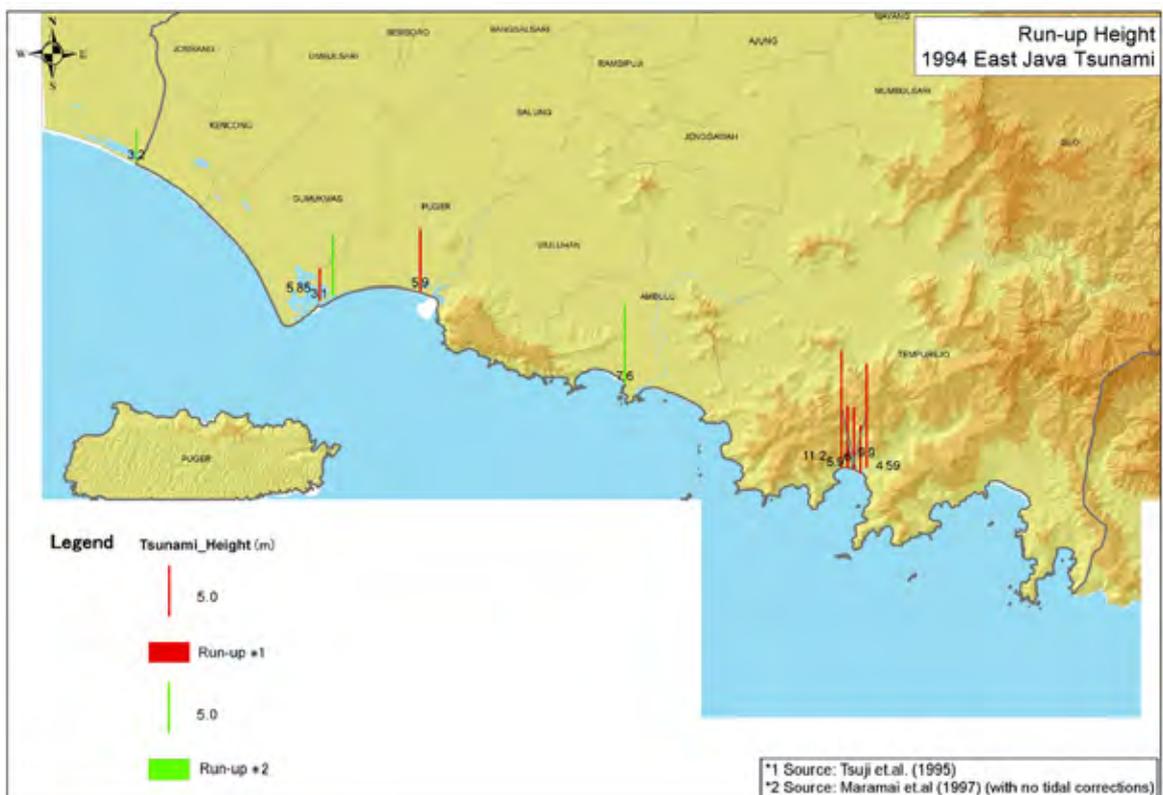
(2) 1994 East Java Tsunami Disaster in Kabupaten Jember

The field survey to investigate the tsunami height, the inundated area, and the damages due to the East Java Tsunami which are target disasters in this study was carried out in order to formulate the Hazard map.

A. Distribution of Tsunami Height

The distribution of tsunami height on the coast of Kabupaten Jember is shown in Figure 4.2.6. The values of tsunami heights are integrated to GIS Map (Figure 4.2.6) from the reports which mentioned the result of field survey at that time by Study Team. Although the information of tsunami height was collected in this investigation, the data was not used to make the map because the accuracy of the data which is composed of the interviews about the disaster which occurred more than 10 years ago seems to be low.

The maximum tsunami run-up height was 11.2m of Bandialit. The reason why it was extremely high compared with other records is assumed to be due to geological features, which are the shape of the bay and the cliff behind the coast. The tsunami run-up heights on the coast that has vast low-lying land behind it are 5.9m on Puger, 7.6 on Watuulo. The average tsunami run-up height on the coast of Kabupaten Jember was 6-7m



Source: Study Team

Figure 4.2.6 Distribution of Tsunami Height due to 1994 East Java Tsunami

B. Inundated Area

The inundated area of East Java Tsunami estimated in this study is shown Figure 4.2.7. Because there are no reports which indicate the inundated area, the inundated area was estimated by considering both the maximum distance of water ingression obtained from the interviews and the coastal topography. The characteristic coastal topography is the long beach occupying the 1/3 of the coastal line of Kabupaten Jember. There are grown sand dunes, whose elevations are 3-6m, behind the beach, and on the lines of that in the flat land the several villages are located (Figure 4.2.8). It seems that these sand dunes defended the low flat land behind the coast, whose elevation is 1-3m, from the East Java Tsunami (1994). Such a phenomenon also had been seen in West Java Tsunami in 2006.

According to the interviews, the distance that the tsunami ran up in a river which flow in the flat land is 3km from the river mouth and flooded from both riversides to inland about 100m. Therefore the distance tsunami run-up in the similar rivers is set as 3km from the river mouth, and the inundated area along the rivers is 100m width from the both riversides.



Source: Study Team

Figure 4.2.7 Inundated Area due to 1994 East Java Tsunami

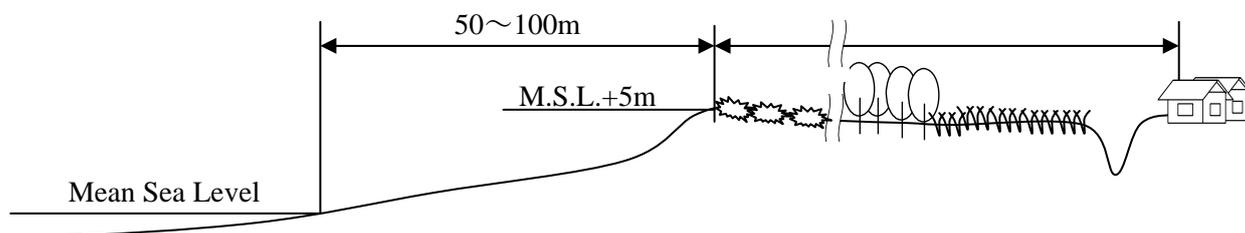


Figure 4.2.8 Cross section of the Coast in Desa Kepanjen

C. Damage due to Tsunami

The total damage obtained from the resident interview on the field survey is shown in Table 4.2.3 and the positional chart is shown in Figure 4.2.9.

In Bandialit where the maximum tsunami run-up height was recorded, the tsunami washed away the fishing village which is located in 100m from the coast and 5 people sleeping in their houses died. In Payagan, the tsunami also washed away the houses near the coast (refer to Figure 4.2.10), and 4 fisherman preparing to ship out to sea died. In Getem, the tsunami penetrated about 1km in land and damaged many houses that were located in low land around the river mouth. Also, in the Kalimalang Kulon 2km above the river mouth, the tsunami which ran-up in the river, overflowed its bank and caused the inundation disaster. In the other area protected by the sand dunes, there was hardly any damage.

Therefore, the most inundation disaster due to the tsunami occurred in the low and flatland which didn't have the sand dune, excluding peculiar geographical features such as Bandialit. Also, it is understood that the risk in such a region is very high.

It seems that the reason why the total damage (Total*1 in Table 4.2.3) obtained in this investigation is different from the past records (Total*2 in Table 4.2.3) is difficult to identify the damages due to the tsunami that occurred in midnight since the memory of interviewees about that tsunami that occurred more than 10 years ago are obscure.

There were some damage to ships and crops due flooding by seawater, and to the bridge excluding human and house damage. These damages should not be neglected because they affected post-disaster living and rehabilitation.

The beaches hit by the tsunami were eroded although it didn't cause any damage directly. However the sediment discharge at the beach should be noted since it is used as mooring facilities of fishing boats.

Table 4.2.3 Statistics of Human and House Damage in Kabupaten Jember

Regency	Human Damage				House Collapsed			Damaged Ships
	Killed	Missing	Injury		Totally	Partially	Slightly	
			Heavy	Slight				
Bandialit *1	5	-	-	-	24	-	-	20
Payagan *1	4	-	-	-	30	>30		4
Puger *1	1	-	-	-	-	-	-	1
Getem *1	30	-	-	-	50	-	-	-
Kalimalang Kulon *1	-	-	4	-	-	5	-	100
Total *1	40	-	4	-	104	>35		125
Total *2	12	-	4	7	36	33	11	119

*1 Data Source: Interview to Resident on this study *2 Data Source Y. Tsuji et al. (1995)

Source: Study Team, Y. Tsuji et al. (1995)



Source: Study Team

Figure 4.2.9 Location-map of the Areas Damaged by 1994 East Java Tsunami

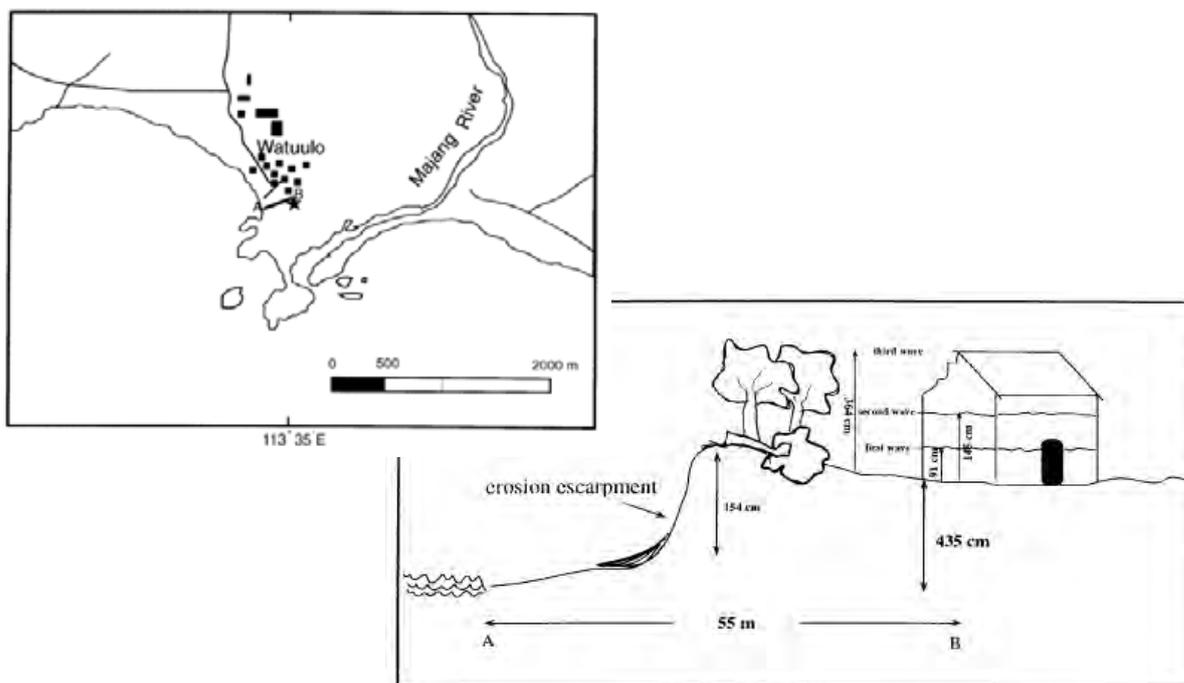


Figure 6. Detail of the A-B section in Figure 5 at Watuulo.



Figure 7. Watuulo: damaged house where marks of three different waves were observed. The third wave caused the roof collapse.

Source: A.Maramai et al. (1997)

Figure 4.2.10 Damaged Houses in Watuulo (Payagan)

2) Factors for Damages due to Tsunami

Past tsunami damage mentioned above in Kabupaten Jember can be classified as follows.

- Human damage such as drowning death
- House damage such as destruction due to flow
- Structure damage such as destruction of roads and bridge
- Fishery industry damage such as outflow of fishery boats
- Agriculture damage caused by seawater and sediment inflowing to farmland
- Landform change of beach

Thus the external force to cause these damages was that seawater intruded inland due to tsunami. These tsunami damage records indicate that the level of damage varies in depth and flood velocity.

Moreover, from the inundation area due to East Java Tsunami in 1994 shown in Figure 4.2.7, the inundation area was concentrated in the low-lying area near the mouth. Therefore, the low ground and the distance from the coastline can be said to be a geological damage factor due to tsunami. Additionally, the V-shape bay such as Bandialit where the tsunami energy concentrated in the head of V-shape bay and the maximum run-up height due to 1994 East Java Tsunami was recorded in Kabupaten Jember could be a geological damage factor.

1994 East Java Tsunami attacked the coastal area suddenly and didn't give the time to the residents near the coast to evacuate because that the earthquake occurred at midnight and the ground shaking was small. Also, the inadequate knowledge of Tsunami of the residents at that time could be a damage factor from the viewpoint of disaster mitigation. Compared with the present situation and the situation at that time regarding disaster mitigation, the situations are similar in terms of structural countermeasure because structural countermeasures such as sea wall have not been installed in Kabupaten Jember. However, the situation about non-structural countermeasures could be said better because related government agencies like BMG have preceded the maintenance of early warning network, the designation of evacuation sites, and tsunami drill. Moreover, the knowledge and public awareness of tsunami have grown compared with the 1994 situation.

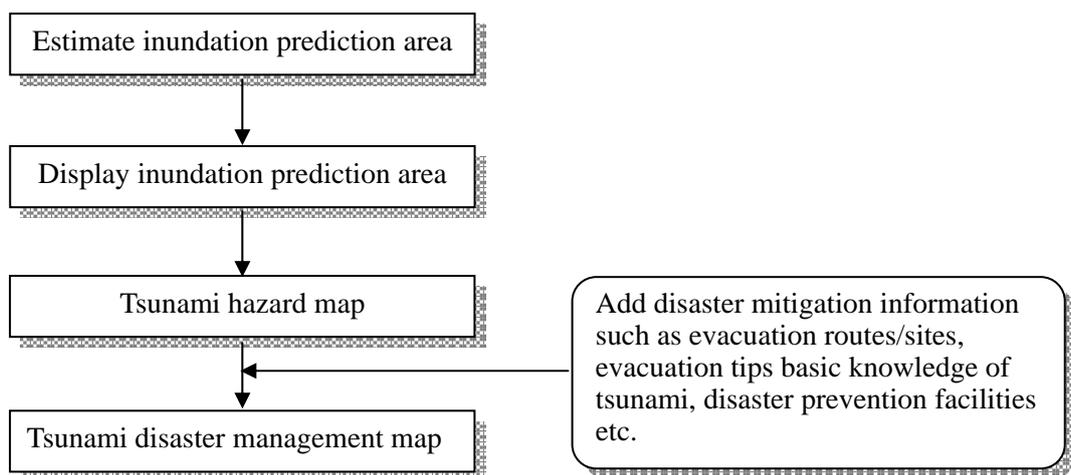
4.2.2 Tsunami Hazard Map in Kabupaten Jember

1) Overview of formulation of Tsunami Hazard Map

Tsunami damage is caused by seawater intruding into land due to tsunami. Therefore, Tsunami hazard could be expressed by inundation depth and flow velocity of the flood. Hence, we shall express that Tsunami Hazard by inundation depth of flood because the macro estimation method considering the synergy effect among the inundation depth and the flow velocity of flood has not been established yet.

According to Guideline for Development and Utilization of Tsunami Disaster Management Map (Port Technology Group, ASEAN-Japan Transport Partnership, 2008), Tsunami hazard map is defined as the map which shows the predicted inundation areas. Also, the map which has disaster information such as evacuation routes and sites, evacuation tips and basic knowledge of tsunami to the hazard map is called Tsunami disaster management map. The purpose of preparing a tsunami hazard map / tsunami disaster management map is to provide residents with necessary information for evacuation and to assist administrative bodies in carrying out their duties such as devising and taking disaster prevention measures.

Figure 4.2.1 shows the Flow of preparing tsunami hazard map and tsunami disaster management map. The main part of tsunami hazard map is the predicted inundation areas. The predicted inundation area is prepared based on the result of inundation prediction in case of a possible tsunami attack. There are mainly four kinds of inundation prediction method as shown in Table 4.2.4.



Source: Guideline for Development and Utilization of Tsunami Disaster Management Map, Port Technology Group, ASEAN-Japan Transport Partnership, 2008

Figure 4.2.11 Flow of Preparing Tsunami Hazard Map and Tsunami Disaster Management Map

Table 4.2.4 Characteristics of Each Inundation Prediction Method

Method	Outline of the method	Prediction image for tsunami hazards
a. Numerical simulation method	Numerical simulation method is the method which predicts inundation areas based on numerical simulations using a numerical model of tsunami propagating through the ocean and flooding coastal areas.	
b. Level filling method	Level filling method provides estimation of inundation areas in which inundation depth on the ground is calculated based on water volume intruding from coasts by a tsunami. The tsunami is calculated using a numerical model of tsunami propagating through the ocean.	
c. Method based on historical inundation records	Method based on historical inundation records is to indicate inundation areas of historical tsunamis.	
d. Estimation based on ground elevation	Estimation based on ground elevation determines inundation areas under the tsunami height which is predicted from a tsunami numerical simulation.	

*Dotted red line: Inundation areas predicted by the numerical simulation

Source: Guideline for Development and Utilization of Tsunami Disaster Management Map, Port Technology Group, ASEAN-Japan Transport Partnership, 2008

Basically, prediction should be based on a numerical simulation method (a), because it precisely estimates the data necessary for preparing a tsunami hazard map and it can reflect the effects of protection facilities. However, it requires many data items such as bathymetric and topographic data and tsunami scenarios including where the tsunami occurs and the magnitude of the tsunami to conduct a numerical simulation of tsunami. Also, such data is not widely available in many districts. When a numerical simulation method is difficult to conduct, simpler alternatives are available for inundation prediction. For example, inundation area could be estimated by using historical tsunami inundation records (c. Method is based on historical inundation records). Therefore, according to technology, available data and necessity, tsunami hazard shall be developed step-by step.

2) Applicability evaluation of inundation in Kabupaten Jember

Table 4.2.5 shows the applicability of each inundation prediction method in Kabupaten Jember. Although there is some data for carrying out each method, it is not enough to get the correct results for each method.

Basically, tsunami hazard map shall be developed by Estimation based on ground elevation because it is comparatively simple method to determine the hazard area and the level from only relation between possible tsunami height given by numerical simulation and the ground elevation.

Table 4.2.5 Applicability of Each Inundation Prediction Method in Kabupaten Jember

Method	Data for conducting each method	Applicability	Remarks
a. Numerical simulation method	Not enough	Not practicable (for ocean area)	Some previous results exists for ocean area.
b. Level filling method	Not enough	Partly Practicable	There are no accurate data of the height levee/sand dune along the coast.
c. Method based on historical inudation records	Not enough	Partly Practicable	East Java Tsunami in 1994
d. Estimation based on ground elevation	Enough	Practicable	

3) **Indices of Hazard Map for Tsunami Disaster**

(1) **Inundation area and depth estimated by level filling method (H_1)**

Level filling method provides estimation of inundation areas in which inundation depth by a tsunami on the ground is calculated based on water volume intruding from coasts. The tsunami is calculated using a numerical model of tsunami propagating through the ocean.

A. Calculation of water volume intruding from the coast

The water volume intruding from the coast was calculated for 1994 East Java Tsunami. The basic data of tsunami was settled based on the records and previous study of numerical simulation of tsunami. They are shown in Table 4.2.6 and Figure 4.2.12. In addition, the temporal alteration of tsunami was modeled as shown in Figure 4.2.13 in order to calculate the water volume overtopping the coast. In this model, the wave pattern was approximated by linear regression and the duration time was divided 5 in order to water volume. The calculated amount of the overflow is shown in Table 4.2.7.

Table 4.2.6 Tsunami Data for Calculating Water Discharge Intruding Inland

Item	Value	Source
Tsunami Height	8.0 (m) above mean sea level	Records of 1994 East Java Tsunami
Period	900 (sec)	ditto
Length of coast line intruded by tsunami	40.1 (km)	Coast line except dominant cliff along coast line
Height of sand dune	4.0 (m) above mean sea level	Topographical data and Field survey
Number of the waves overtopping the top of sand dune	3 waves	Records of 1994 East Java Tsunami

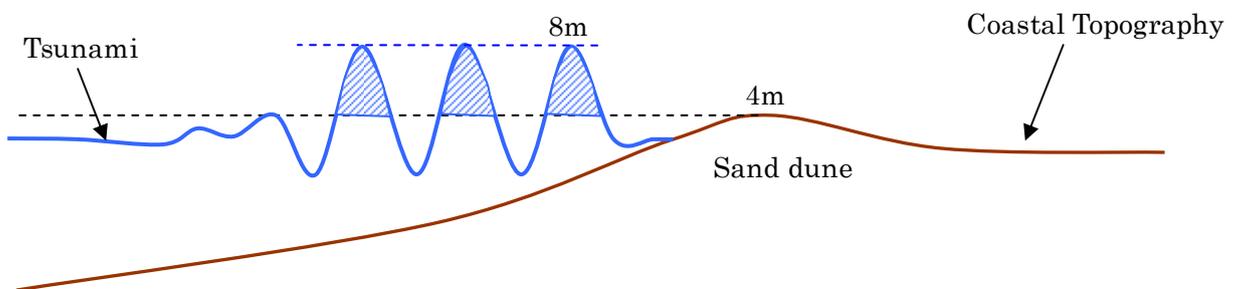


Figure 4.2.12 Cross Section of Model

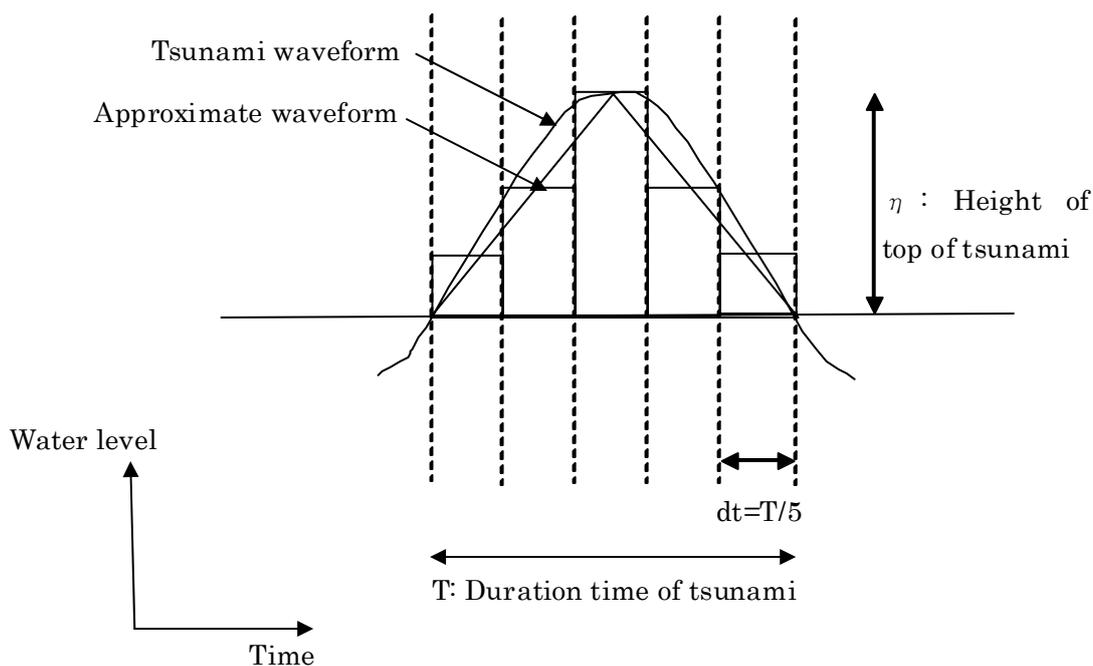


Figure 4.2.13 Modeling of Time Waveform

Table 4.2.7 Water Volume Intruding by Tsunami

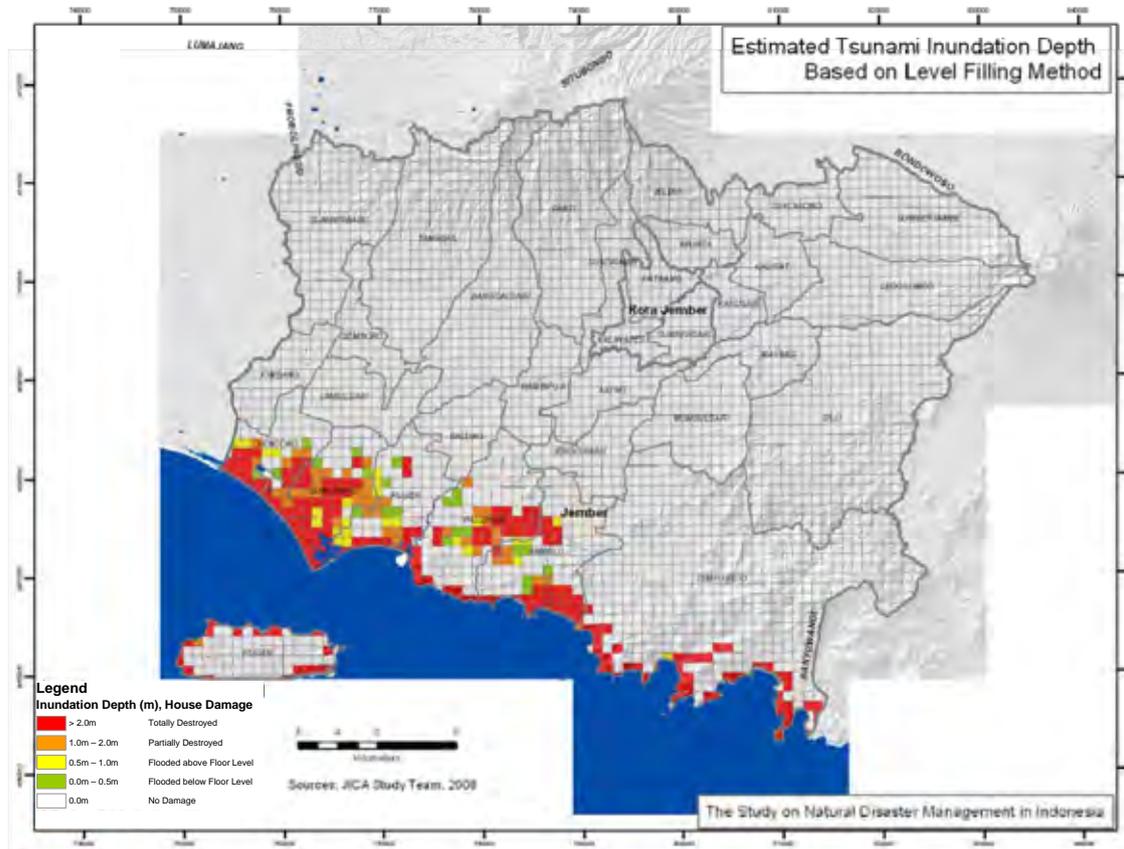
No.	(A) Tsunami Height	(B) Sand dune Height	(A)-(B)	(D) Q1 (m ² /sec)	(E) Δt (sec)	(D)*(E) Q2 (m ²)
1	1.6	4	-2.4	0.00	90	0.00
2	4.8	4	0.8	1.11	90	99.79
3	8.0	4	4.0	12.40	90	1115.65
4	4.8	4	0.8	1.11	90	99.79
5	1.6	4	-2.4	0.00	90	0.00
Summation				(per 1 wave and 1m)		1315.23
				(per 3 wave and 1m)		3945.68

B. Inundation area and depth

The expected inundation map based on water volume overtopping the coast shown in Table 4.2.7 is presented in Figure 4.2.14. The grade and the corresponding scores are as follows:

- i) 2.0m< (Totally destroyed) Score 4
- ii) 1.0m<H≤2.0m (Partially destroyed) Score 3
- iii) 0.5m<H≤1.0m (Flooded above floor level) Score 2
- iv) 0.0m<H≤0.5m (Flooded below floor level) Score 1
- v) H=0.0m (No damage) Score 0

Level filling method requires a structure or landform that prevents the waves from overtopping it along the coast. However, there are no structures along the coast and the landform such as sand dune doesn't cover all of the coast in Kabupaten Jember. Therefore, the expected inundation area might be underestimated at the river mouth where the sand bar is lower than the height (=4m) given by the above-mentioned model.



Source: Study Team

Figure 4.2.14 Inundation Area and Depth Estimated by Level Filling Method (H_1)

(2) Inundation area based on historical inundation records (H₂)

The coastal region of Kabupaten Jember seriously suffered from the East Java tsunami disaster in 1994. The disaster area is indicated in Figure 4.2.15. The grade and the corresponding scores are as follows:

- i) Damaged area due to past tsunami Score 5
- ii) No damaged area Score 0

The following hazard area is based on the result of interview with residents and the records of tsunami run-up height. It is not easy to say that the inundation area is accurate because there are no records indicating the past inundated area and it is based on interviews about events which occurred more than 10 years ago. In addition, the inundation map is based on historical inundation records that could not evaluate the inundated depth.

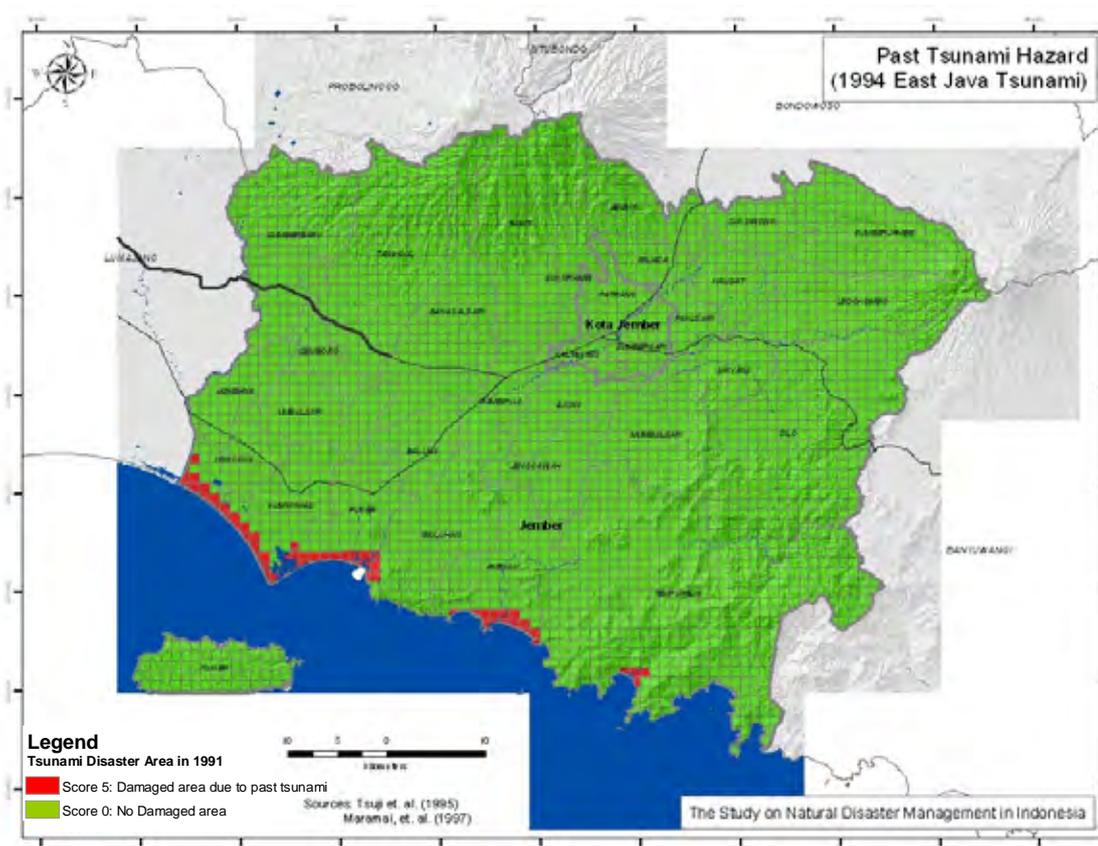


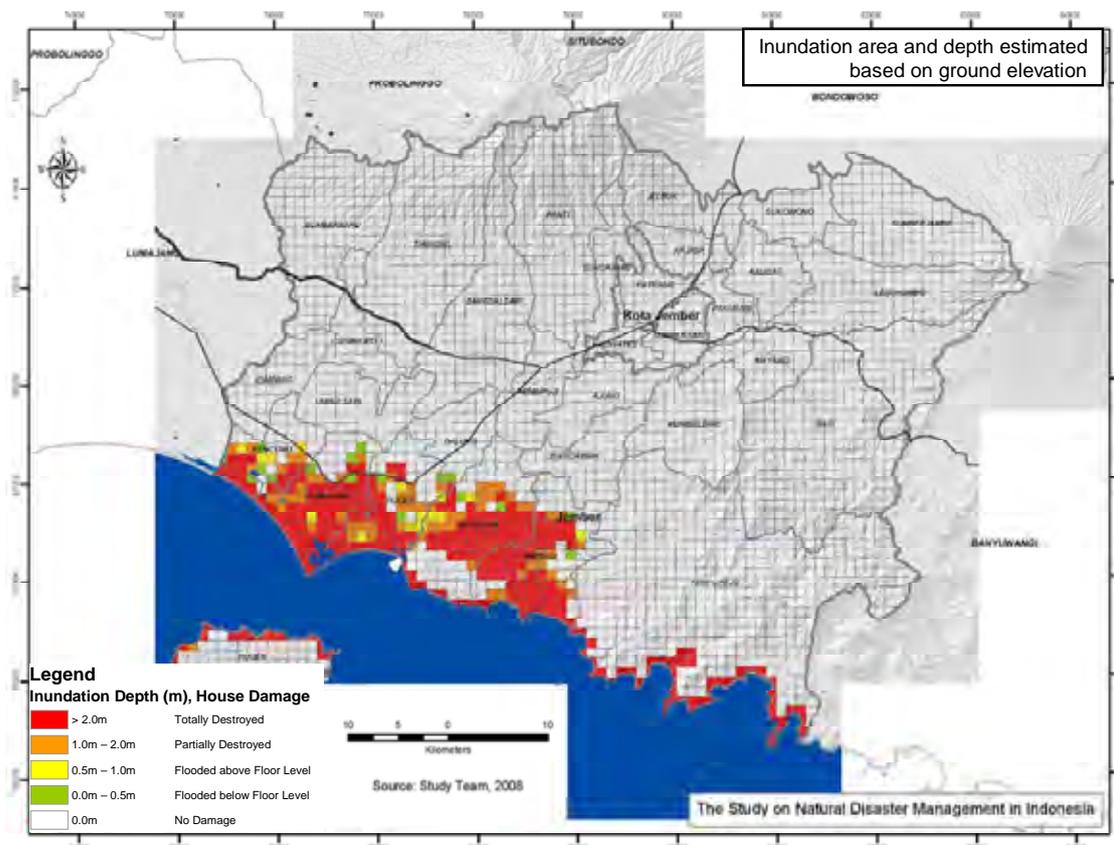
Figure 4.2.15 Tsunami Disaster Area in 1994 (H₂)

(3) Inundation area and depth estimated based on ground elevation (H₃)

Estimation based on ground elevation is a comparatively simple method to determine the hazard area and the level from only the relation between possible tsunami height given by numerical simulation and the ground elevation. The maximum run-up height of the East Java tsunami (1994) was 8m or less. Therefore, 8m above sea level was set to standard height of the expected tsunami run-up. The grade and the corresponding scores are as follows:

- i) 2.0m < (Totally destroyed) Score 4
- ii) 1.0m < H ≤ 2.0m (Partially destroyed) Score 3
- iii) 0.5m < H ≤ 1.0m (Flooded above floor level) Score 2
- iv) 0.0m < H ≤ 0.5m (Flooded below floor level) Score 1
- v) H = 0.0m (No damage) Score 0

Compared with the result of flood area due to East Java Tsunami in 1994, the expected tsunami hazard area is larger than it. Thus the expected tsunami flood area based on ground elevation is judged a little overstated, which is the dangerous side of estimation.



Source: Study Team

Figure 4.2.16 Inundation Area and Depth Estimated Based on Ground Elevation (H₃)

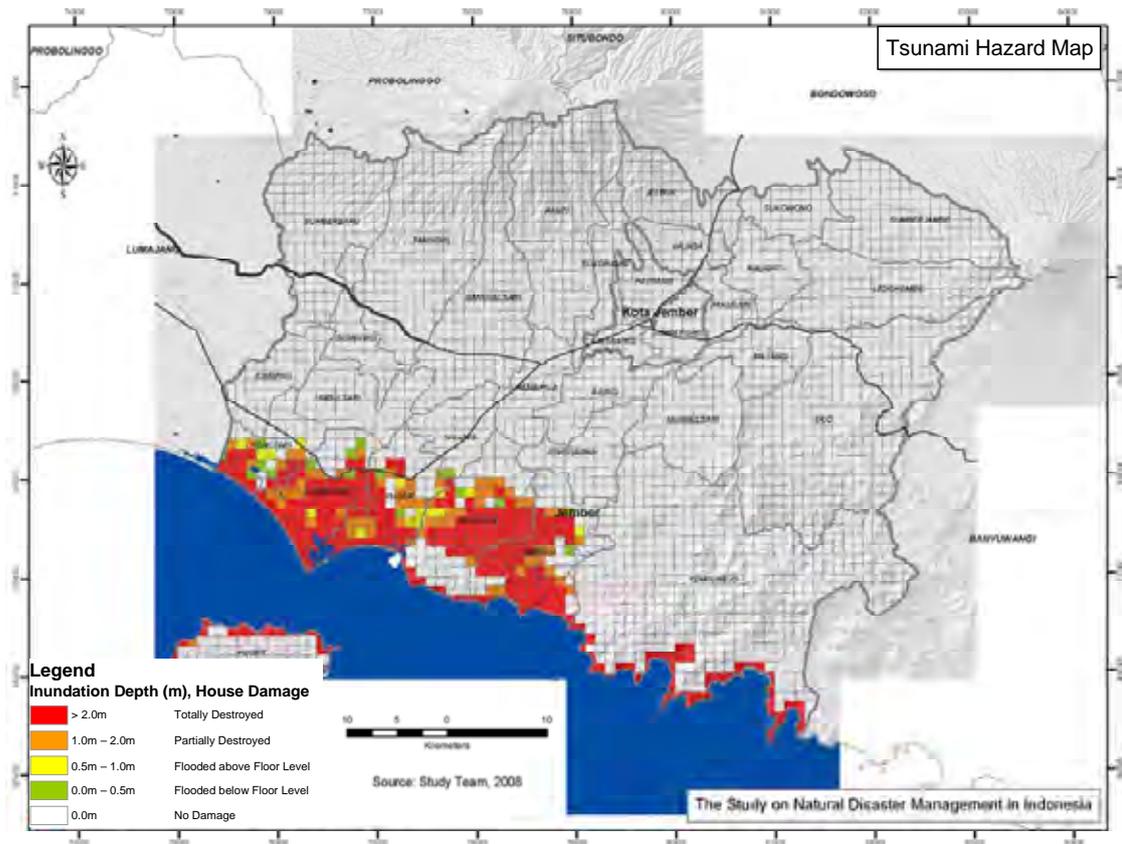
4) Tsunami Hazard Map in Kabupaten Jember

When the above-mentioned three indices are compared, the result on the dangerous side is given in the order of the inundation area based on ground elevation (H_3), the inundation area estimated by level filling method (H_1), and the inundation area based on historical inundation records. Essentially, it is better to adopt the prediction method with the highest accuracy. In this study, the inundation area, based on ground elevation (H_3), which gives the result on the most dangerous side and is comparatively easy to formulate, shall be adopted because all prediction methods have a problem with accuracy which depends on available data and its accuracy. An inundation map with higher accuracy can be formulated after the various data are maintained and available.

The hazard map for tsunami disaster, which was created based on Expected Inundation Depth (H_3), is shown in Figure 4.2.17. In this figure, the values of tsunami hazard were divided into 4 classes as shown below.

- | | | | | |
|------|------------------------------------|-----------------------------|---------|---------------------------|
| i) | $2.0\text{m} <$ | (Totally destroyed) | • • • • | Score 4 (Highest hazard) |
| ii) | $1.0\text{m} < H \leq 2.0\text{m}$ | (Partially destroyed) | • • • • | Score 3 (Higher hazard) |
| iii) | $0.5\text{m} < H \leq 1.0\text{m}$ | (Flooded above floor level) | • • • • | Score 2 (Moderate hazard) |
| iv) | $0.0\text{m} < H \leq 0.5\text{m}$ | (Flooded below floor level) | • • • • | Score 1 (Lower hazard) |
| v) | $H = 0.0\text{m}$ | (No damage) | • • • • | Score 0 (No damage) |

Figure 4.2.17 indicates that the tsunami hazard is concentrated in the low-lying area near the coast. Also, the expected tsunami flood area is widely extended from the coast to inland in accordance with the vast low-lying area, which is one of the geographical features of Kabupaten Jember.



Source: Study Team

Figure 4.2.17 Tsunami Hazard Map

4.2.3 Tsunami Risk Map in Kabupaten Jember

1) Basis of Risk Map Creation for Tsunami Disaster

The damages due to tsunami hazard are of great variety. The main damages are as follows.

Human damage such as drowning death / House damage such as destruction due to flow / Civil structure damage such as destruction of roads, railways, and bridges / Lifeline damage such as outage of electricity and water service / Fishery damage such as outflow of fishery boats / Commerce and industry damage such as destruction of factories near the coast / Agriculture damage caused by seawater and sediment inflowing to farm land / Forest damage / Fire damage / Landform change of beach / Destruction of power plant / etc.

In this study, the risk caused by tsunami hazard shall be estimated focusing on house and human damage which are the main damages. Therefore, the risk is given by the expressions shown below. The damage rate based on inundation depth is neglected because the score of inundation depth includes it. But the damage rate based on the distance from the coast is considered because it is thought that the houses are not destroyed inland where the flow velocity of flood becomes smaller. In fact, the completely-destroyed and partially-destroyed houses could be assumed to be found within 1km from the coastline. In addition, the area where the house damage could occur is within the range of 3km from the coastline which was the actual damaged area of East Java Tsunami in 1994.

When the death toll due to tsunami is calculated, the death rate corresponding to the tsunami height is multiplied by the population staying around the coast. Human damage was also estimated by same method as that of house damage.

$$[\text{Tsunami Risk}] = [\text{Tsunami Hazard}] \times [\text{Damage rate}] \times [\text{Population Density} + \text{Built up Area}]$$

1) **Vulnerability indices**

Vulnerability is defined as “The conditions determined by physical, social, economic, and environmental factors or processes, which increase the susceptibility of a community to the impact of hazards.” according to “Living with Risk” (UN/ISDR, 2004). The vulnerability indices used for making tsunami risk map are: Population density (V_1), Built-up area (V_2), Distance from coastline (V_3), which were calculated from the available data source.

(1) **Population density (V_1)**

The population density was calculated based on the population in living area (residential area). The population density was divided into five ranks and the scores were set up as follows:

- i) 50 (pop./ha) < Score 5
- ii) 25~50 (pop./ha) Score 4
- iii) 10~25 (pop./ha) Score 3
- iv) 5~10 (pop./ha) Score 2
- v) ≤ 5 (pop./ha) Score 1

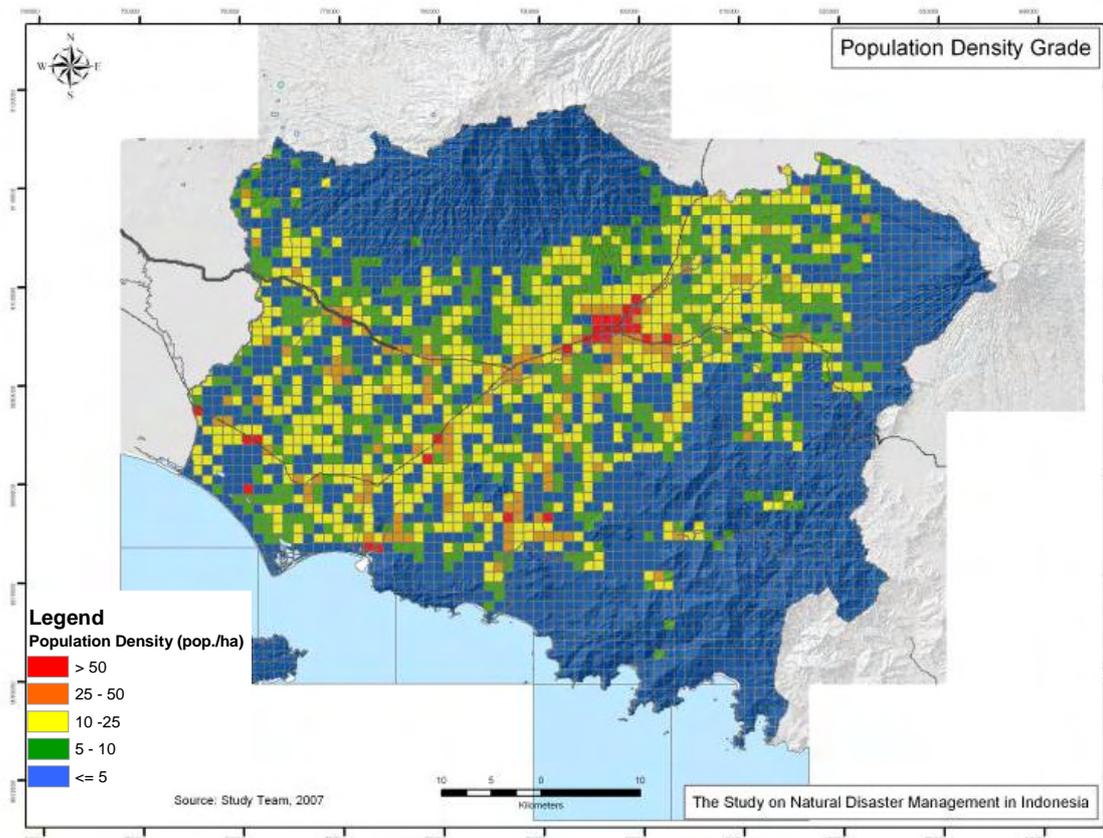


Figure 4.2.18 Population Density (V_1)

(2) Built-up area (V_2)

Built-up area can be regarded as disaster vulnerable area which was created based on the existing land use map of Kabupaten Jember (BAKOSURTANAL, 1999). The classification was ranked by the area of built-up area per a unit (1 km^2).

- i) $0 \sim 5 \text{ (ha/km}^2\text{)}$ Score 1
- ii) $5 \sim 20 \text{ (ha/km}^2\text{)}$ Score 2
- iii) $20 \sim 30 \text{ (ha/km}^2\text{)}$ Score 3
- iv) $30 \sim 50 \text{ (ha/km}^2\text{)}$ Score 4
- v) $50 \text{ (ha/km}^2\text{)} <$ Score 5

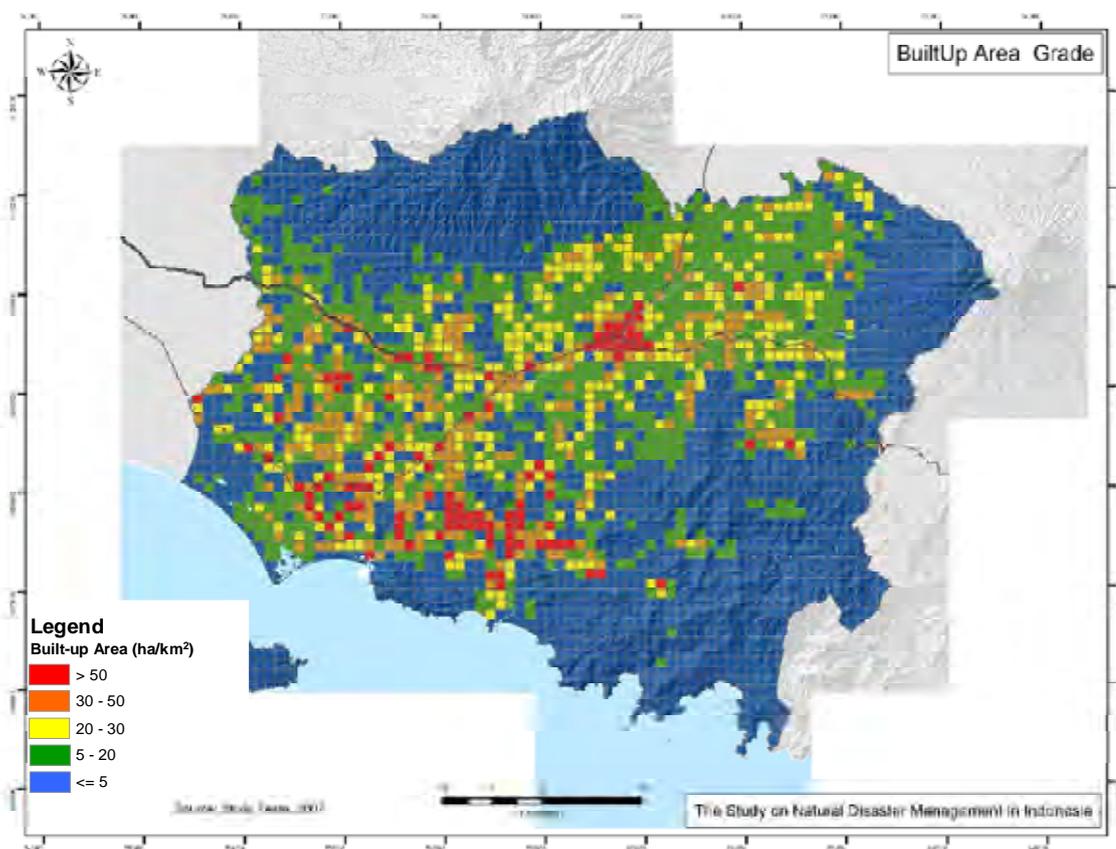


Figure 4.2.19 Built-up Area (V_2)

(3) Distance from coastline (V_3)

“Distance from coastline” was selected as one of the indices of tsunami Vulnerability. The grade and the corresponding scores are as follows:

- i) $0\text{km} \leq L < 1.0\text{km}$ (Serious Damage) . . . Score 5
- ii) $1.0\text{km} < L < 3.0\text{km}$ (Partially Damage) . . . Score 3
- iii) $3.0\text{km} \leq L$ (No Damage) . . . Score 0

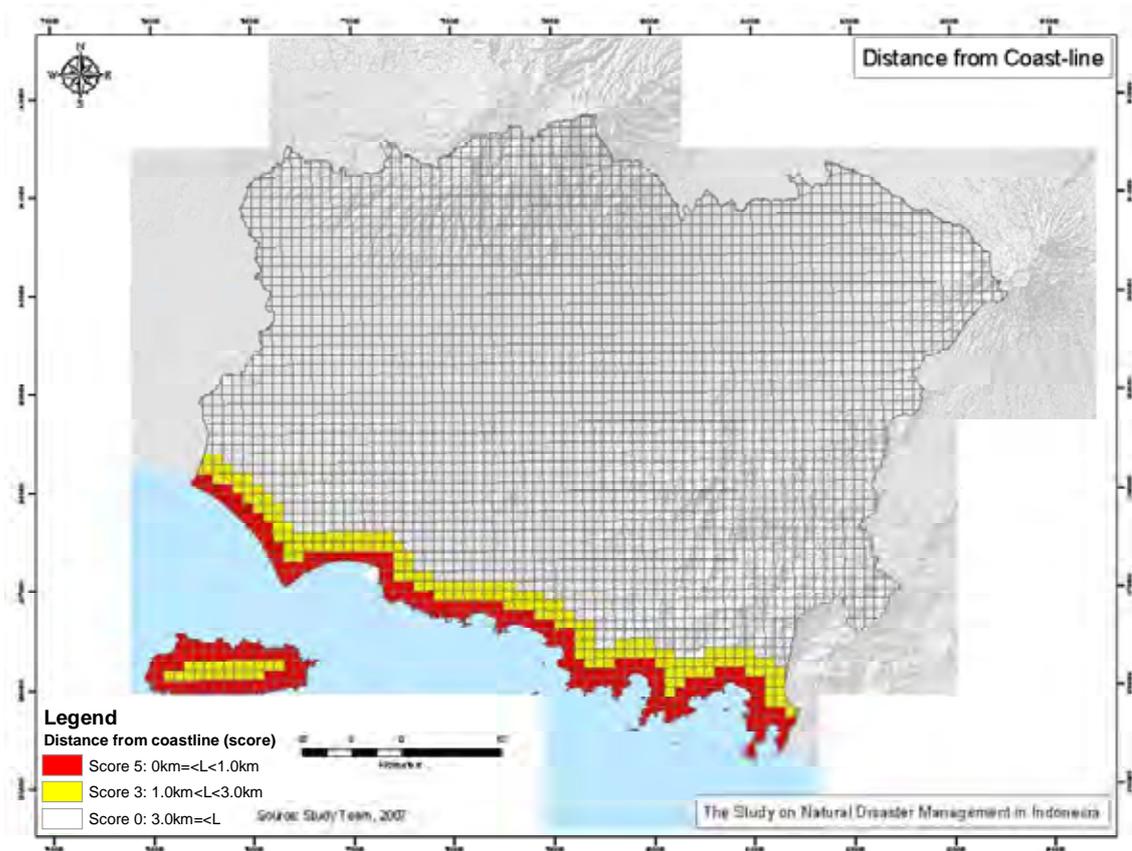


Figure 4.2.20 Distance from the Coastline (V_3)

2) Tsunami Risk Map in Kabupaten Jember

Figure 4.2.21 shows the Tsunami Risk map calculated from the formula mentioned above. As indicated in Figure 4.2.21, the values of tsunami hazard were divided into 5 classes indicating relative hazardous classification. “Red” means the highest hazard and “Orange” indicates high hazard. Moderate hazard is shown in “Yellow” while “Green” means low hazard. Further, “Blue” shows the lowest hazard. Figure 4.2.21 indicates that the tsunami risk is concentrated on the villages in the low-lying area near the coast and river mouth such as Puger, Getem, and Watuulo of the west-center coast. In the east area, the village which has risk for tsunami hazard is only Bandialit, located at teh head of the bay. These villages in low-lying areas near river mouth have usual fishery port or slipways for fishing boats. Thus the risk of fishery damage is very high in addition to the risk of house damage and human damage.

The risks regarding Tsunami disaster were calculated based on Eq.4.2.1.

$$(H_3) \times (V_3) \times (V_1+V_2) \quad \cdot \cdot \cdot \text{Eq. 4.2.1}$$

where, H_3 : Inundation area and depth estimated based on ground elevation, V_1 : Population density. V_2 : Built-up area and V_3 : Distance from the coastline.

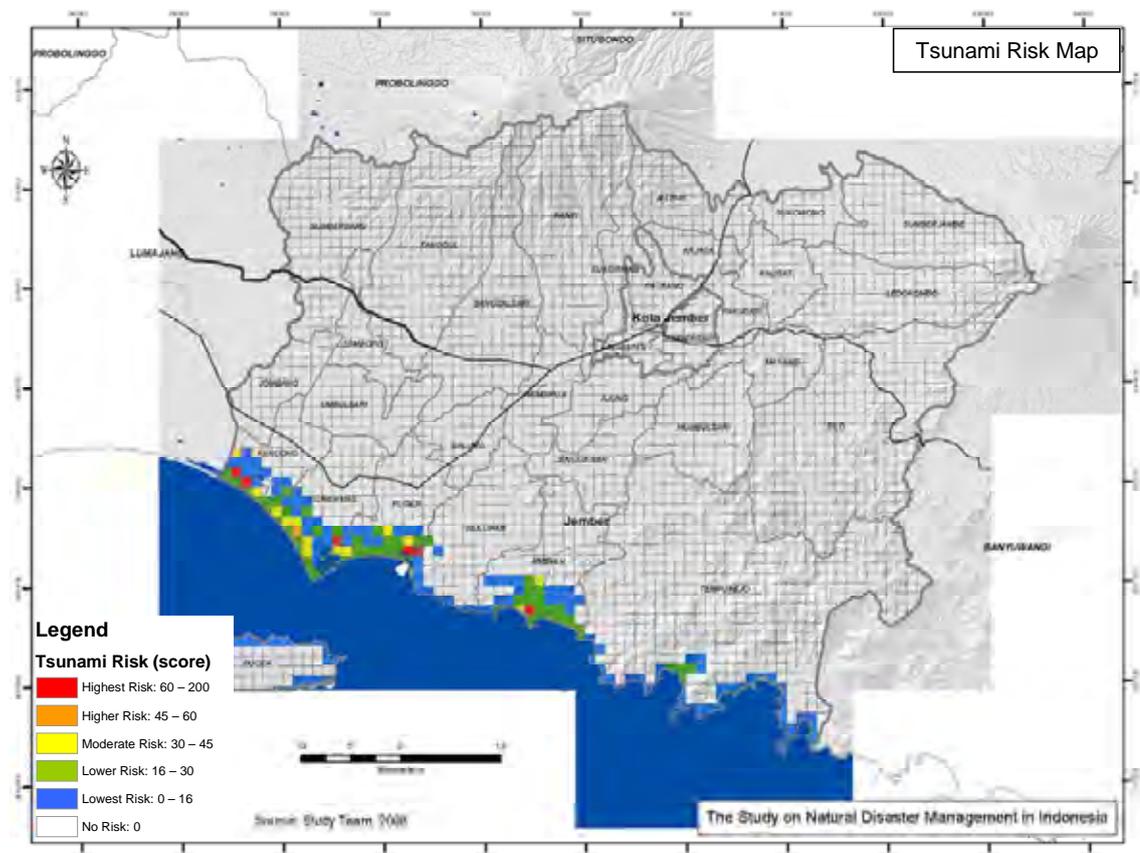


Figure 4.2.21 Tsunami Risk Map

4.2.4 Possible Countermeasures against Tsunami Disaster in Kabupaten Jember

1) Recent Tsunami Disaster and the Feature

There are some tsunamis that reached the coast of Kabupaten Jember in recent years such as West Java Tsunami in 2006, the most recent one. However, only the East Java Tsunami in 1994 caused serious human damage and property damage to Jember coast.

The following points are given as the topographic features focusing on the places damaged by East Java Tsunami in 1994 in Kabupaten Jember. Almost all of them are low-lying areas in the coastal area, and the damage centered on the geographical weak points such as river mouth where the height of the sand dune is rather low. Moreover, the serious damage occurred in topographic features such as indented bay where the tsunami is amplified. In Bandialit located at the head of the bay, the wave height of 11.2m was recorded, and it took a heavy toll of lives.

Areas of high Tsunami disaster risk are as follows:

- Beach and Low-lying area(*e.g.* Payagan, Getem)
- River mouth and the part where the height of sand dune is lower than that of other coast.(*e.g.* Payagan, Getem, Bandialit)
- Low-lying area along river (*e.g.* Mayangan)
- Indented coastline and bay (*e.g.* Bandialit)

2) Countermeasures against Tsunami

The basis to evade tsunami disaster is to go away from the districts mentioned above, since they have high disaster risks. Relocation to higher place, which is one of the most effective means has been recommended for a long time. However, it is often difficult to obtain consent of the residents such as fishermen because a tsunami disaster doesn't occur frequently. Therefore, it is necessary to consider comprehensive measures including the reinforcement of houses against the waves and evacuation, etc. in order to reduce the tsunami hazard. Possible countermeasures against tsunami and its applicability to Kabupaten Jember are discussed below.

(1) Structural Countermeasures

A. Tide embankment, Tsunami breakwater, Tsunami floodgate, and River embankment

As structural countermeasures, there are a few measures which are mentioned below.

Tide embankment, Tsunami breakwater, River embankment installed at river mouth, and River embankment to limit the inundation to shore and river run-up physically. But they are not realistic measures for Kabupaten Jember because all of them require tremendous amount of investment and time. If a structural countermeasure may be implemented, it is proposed that the road designed on the sand dune along the coast shall be raised as tide embankment when it is constructed.

B. Coastal Forest

There are large and long sand dunes along the coast of Kabupaten Jember and they serve as natural tide embankment. Thus, planting of coastal forest is recommended as a countermeasure against tsunami and blown sand, which will also enhance the protection function of sand dune on a long term basis. (Refer to Figure 4.2.22)



Source: Left photo: Study team, Right photo: Ministry of Marine Affairs and Fisheries

Figure 4.2.22 Sand Dune in Watuulo (left) and Forestation (right)

C. Wave-proof buildings

In a fishing village, it is difficult to obtain the agreement for the relocation to higher place. Thus, other measures such as improving the wave resistance of the present houses is necessary. Present fishing village and improved house are shown in Figure 4.2.23.



Source: Left photo: Study team, Right photo: Ministry of Marine Affairs and Fisheries

Figure 4.2.23 Present Village of Payagan (left) and High-floored House Reinforced against Wave (right)

(2) City planning for tsunami disaster prevention

A. Relocation

As described above, the basis of tsunami countermeasures is to go away from the place where tsunami can hit. The most effective method is to move residences to the place where the tsunami doesn't reach. When relocation is difficult, the ground of the dwelling might be raised. Actually, in Kabupaten Jember, the destroyed village of Bandialit has been reconstructed from the place attacked by tsunami in 1994 to about 200m inland. In general, it is not easy to gain consensus for the reasons of economic efficiency and convenience to relocate the residents to a higher place. In fact, they may return to the original location as years go by for similar reasons. However, it is expected to set up important public facilities such as town office, police station, and fire station, and the facilities for vulnerable people such as hospitals and schools on high ground where the effect of the tsunami doesn't reach.

B. Regulation of land-use

Effective regulatory measures are needed to enforce reconstruction of wave-proof buildings which are stronger in addition to limit the activity and development in tsunami hazard area by regulation of land-use.

(3) Tsunami hazard map

The hazard map is a very useful tool to offer the information for evacuation and education of tsunami disaster to the residents. Also, it can be used to study the location of evacuation site and development of disaster-prevention facilities. The tsunami hazard map is often made from past tsunami flood results and the results of numerical simulation of tsunami to complement it. In this study, it was made from past flood results of 1994 East Java Tsunami. Although East Java Tsunami in 1994 was the biggest tsunami for the coast of Kabupaten Jember on record, the number of records is not enough to say that a bigger tsunami will not occur. Therefore, there is a possibility that the inundated area could get larger than the area shown in hazard map, and it is necessary to make an ingenious hazard map that prevents the residents from having a fixed image for tsunami disaster risk area.

(4) Maintenance of evacuation site and route

Evacuation when a tsunami hits is necessary and it is very important not to go away from tsunami horizontally but to go up to the places which are higher than the tsunami. As will be appreciated from the formulated tsunami hazard map, there is a possibility of deep flooding to the inland when the tsunami overtopping the sand dune in the coast occurs because the area behind the sand dune is a vast low-lying area. Therefore, it is necessary to decide the evacuation site with enough height and space and to move the evacuation route in the low-lying area near the coast to a higher area. In addition, the residents would rather decide their own evacuation site and route than let the administration decide it. An example of the evacuation route set up in Bandialit is shown in Figure 4.2.24.

There is a vast low-lying area behind the coast of Kabupaten Jember and that area may not have high places that can be used to serve as shelter. In that case, it is necessary to construct a shelter building, etc. with enough strength and height against tsunami.



Source: Study Team

Figure 4.2.24 Evacuation Route in Bandialit

(5) Tsunami Drill

The tsunami arrival time to the coast of Kabupaten Jember was about 30 minutes during the 1994 East Java Tsunami. Since the arrival time is not long enough to evacuate without preparation, Tsunami drills are necessary to establish procedures for evacuation of residents near the coast to higher places promptly without any confusion. In Kabupaten Jember, a tsunami drill has already been executed, and it is necessary in the future to improve the evacuation plan while using the regional disaster prevention plan and the tsunami hazard map, and tsunami risk map formulated by this study.

(6) Education

More than 10 years have passed from the East Java Tsunami in 1994, and there is concern that the residents will lose the memory of the tsunami hazard. It is necessary to maintain the opportunity for the education about tsunami disaster and hand down the lessons learned from past tsunami disasters.

4.2.5 Activities for Capacity Development

The work to formulate the hazard maps is helpful for developing the capacity of Community Participation (C/P) and the staff of the organizations related disaster prevention. Therefore, the hazard maps were basically formulated with C/P, and the techniques involved were transferred. The activities for capacity development are as follows:

- Joint field survey
- Workshop

The activities for capacity development in Kabupaten Jember are shown in holding situation of the combination locale survey and the workshop is shown in Table 4.2.8.

Table 4.2.8 Joint Field Survey and Workshop

Date	Time	Location	Participants (CP)	Participants (Study Team)	Agenda
June 26, 2007	10:00-16:00	Desa Sumberejo (Payangan)	PU Officer	Nagasawa, Watanabe	• Joint Survey with C/P
June 27, 2007	10:00-16:00	Desa Andongerejo (Bandi alit)	PU Officer	Nagasawa, Watanabe	• Joint Survey with C/P
July 9, 2007	10:00-16:00	Desa Mayangan Desa Majomulyo (Getem)	PU Officer Officer and staff of Kantor Kecamatan Gumukmas	Nagasawa	• Joint Survey with C/P
July 18, 2007	10:00-12:00	JICA Study Office in Kab. Jember	PU Officer Officer and staff of Kantor Kecamatan Gumukmas	Tsukamoto, Nagasawa, Watanabe	• Workshop about Tsunami HM

4.3 Disaster Characteristics of Tsunami Disaster and Countermeasures in Kabupaten Padang Pariaman

4.3.1 Disaster Characteristics of Tsunami Disaster in Kabupaten Padang Pariaman

1) Tsunami Disaster in the past

(1) Past Tsunami Disaster in Sumatra Island

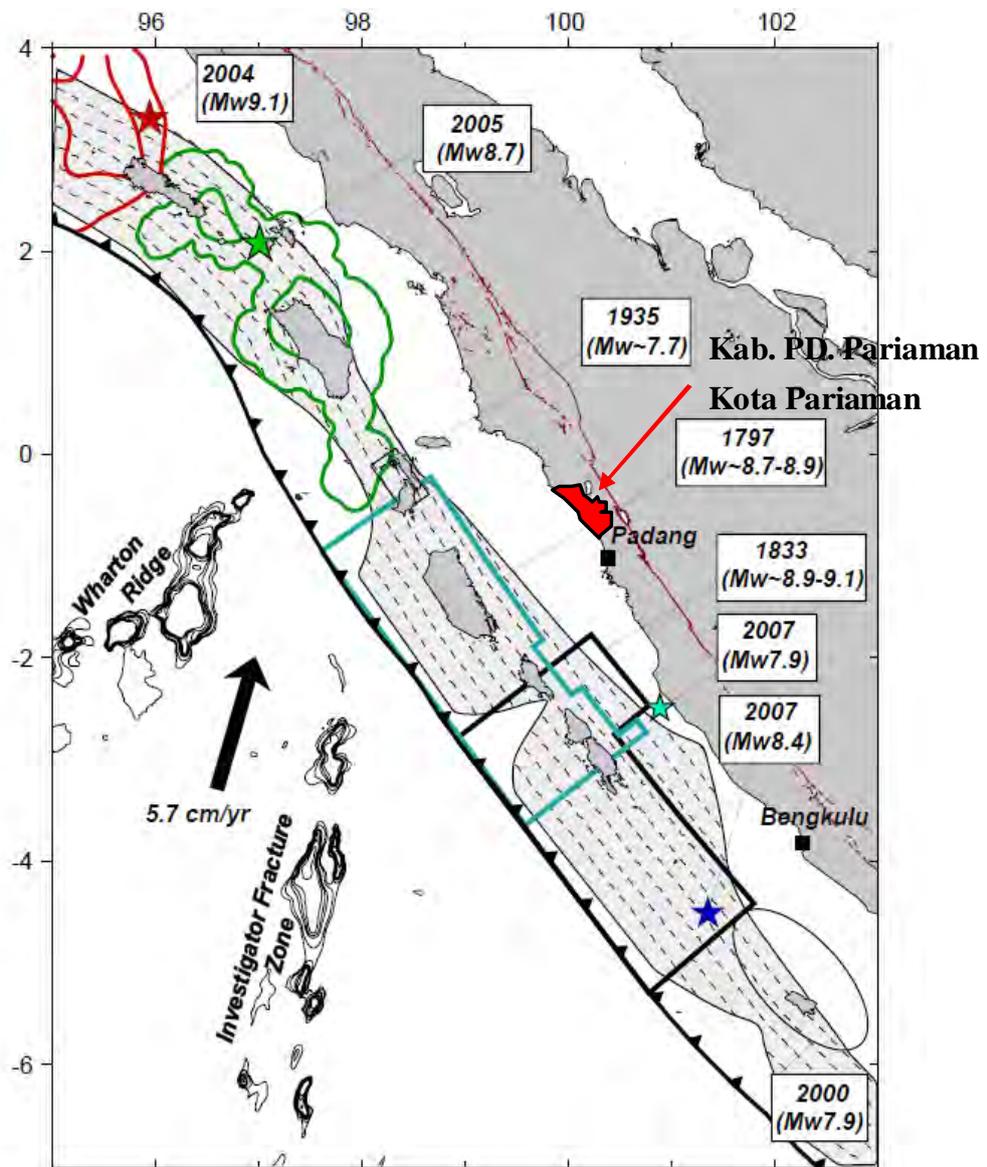
The list of the huge historical Earthquakes and tsunamis generated in Sunda trench in Western offshore of Sumatra which seems to affect the coast of Kabupaten Padang Pariaman and Kota Pariaman are shown in Table 4.3.1, and the locations of historical tsunami sources are shown in Figure 4.3.1.

The tsunamis which most heavily affected the coast of Kabupaten Padang Pariaman and Kota Pariaman are the tsunamis in 1797 and 1833 whose sources were located offshore of Kabupaten Padang Pariaman and Kota Pariaman. Although there are no records that the flood damage occurred in Kabupaten Padang Pariaman and Kota Pariaman, there are damage records in Kota Padang. Those records are useful for considering the future tsunami disaster in Kabupaten Padang Pariaman and Kota Pariaman.

Table 4.3.1 Tsunami Events Offshore from Sumatra Island

No.	YEAR	EPICENTER	MAX RUN-UP HEIGHT(m)	VICTIM (DIED/INJURED)	AREA
1	1797	-	>5	NA	Offshore Padang, Sumatra
2	1833	-	3-4	NA	Offshore Padang, Sumatra
3	1843	-	2	NA	SW Sumatra
4	1861	-	7	1105	Nias Island, NW Sumatra
5	1907	-	2	400	NW Sumatra
6	1935	-	-	NA	Batu Island, NW Sumatra
7	2004	3,298 Lat. N; 95,6 Long.E	34.5	>300.000	NAD, NW Sumatra
8	2005	2,065 Lat. N; 97,01 Long.E	3.5	NA	Nias Island, NW Sumatra
9	2005	2,065 Lat. N; 97,01 Long.E	3.5	NA	Offshore Bengkulu, Sumatra

Source: S.Diposaptono, NOAA Tsunami Database, Solov'iev and Go (1975) Tsunami Catalogue:



Source: Natawidjaja et al. (2006), Comparison of interseismic coupling along the megathrust with the rupture areas of the great 1799, 1833, 2005 and 2007

Figure 4.3.1 Location of Historical Tsunami Source

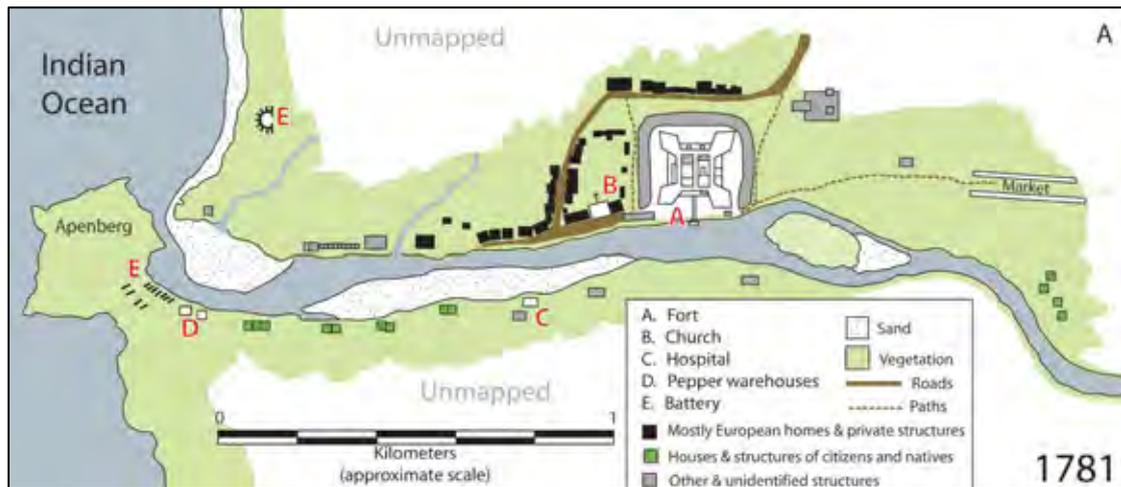
A. 1797 Earthquake and Tsunami (February 10, 1797)

A large earthquake with magnitude $M_w=8.7-8.9$ occurred offshore of the west coast of Sumatra Island at 22h (LT) on February 10, 1797. This earthquake generated a big tsunami that hit the west coast of Sumatra Island and caused serious damage to Padang according to some reports. Although the whole town was flooded and several houses washed away, only 2 deaths were recorded in Air Manis because several people climbed trees to escape the tsunami. There were three or four ebbs and surges in the river harbor, and one report indicates that the surge rose one third the height of the Apenberg (refer to Figure 4.3.2), the 104-m-high peninsula that juts out from the south bank of the river (i.e., about 34 m). All the boats in the river ended up on dry land. A 150- to 200-ton English sailing ship that was tied to a tree near the mouth of the harbor rode the surge 0.75 English miles up river (to behind either the fort or the bird market, depending on the account), destroying three homes while in transit. The surges carried several smaller boats up the river as well and deposited them behind the market, about 1.8 km from the river mouth. All seaside homes were reported flooded as well.

These descriptions about the area near the river are limited because Padang harbor and houses were located near the river at that time. From the above-mentioned records, tsunami run-up height was estimated at least 5m, and inundated depth was estimated about 5-10m (Natawidjaja et al., 2006).

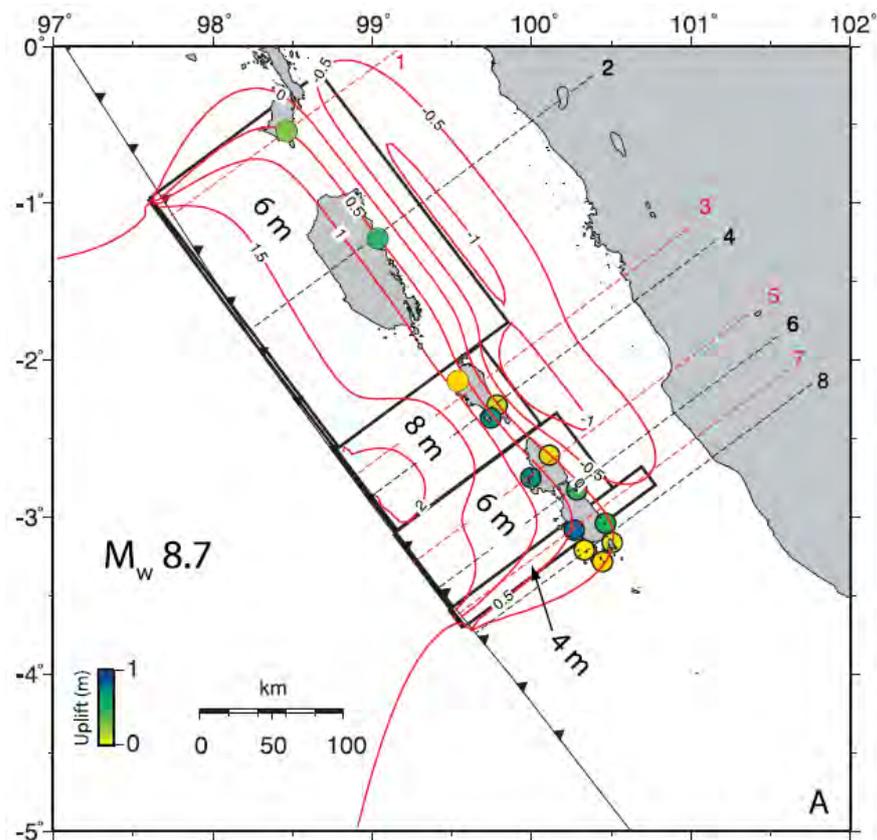
Although the descriptions imagine that the tsunami had reached the coast Kabupaten Padang Pariaman and Kota Pariaman, there are no records about Tsunami height and damage in Kabupaten Padang Pariaman and Kota Pariaman.

Fault model estimated by the investigation of coral reef is shown in Figure 4.3.3



Source: Natawidjaja et al. (2006), Source parameters of the great Sumatran megathrust earthquakes of 1797 and 1833 inferred from coral microatolls, Journal of Geophysical research, vol.111, B06403, doi:10.1029/2005JB004025,2006

Figure 4.3.2 Location Map of Padang City in 1781



Source: Natawidjaja et al. (2006), Source parameters of the great Sumatran megathrust earthquakes of 1797 and 1833 inferred from coral microatolls, Journal of Geophysical research, vol.111, B06403, doi:10.1029/2005JB004025,2006

Figure 4.3.3 Composite Forward Model for the 1797 Rupture Beneath the Mentawai Islands

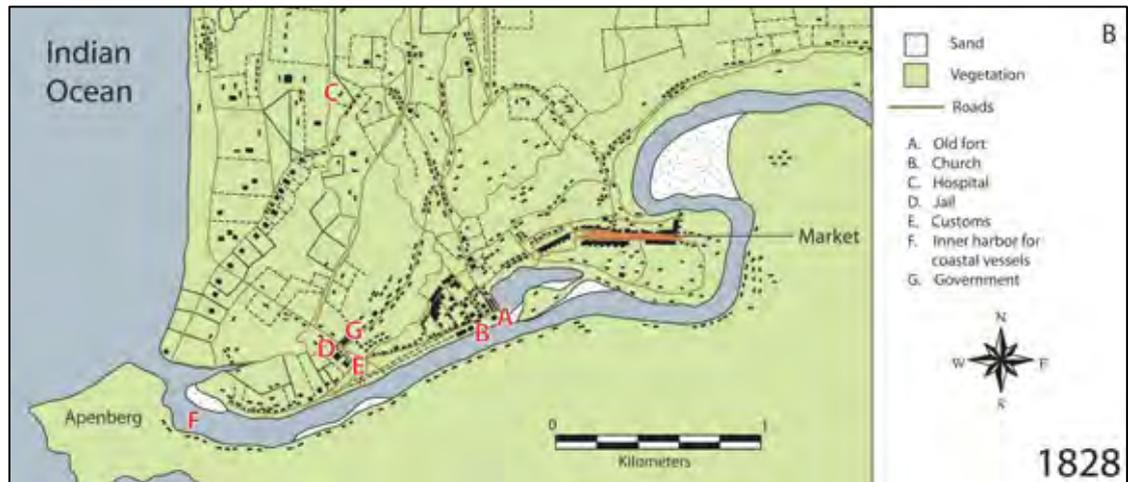
B. 1833 Earthquake and Tsunami (November 24, 1833)

A large earthquake with magnitude $M_w = 8.9-9.1$ occurred off the west coast of Sumatra Island at 20:00 (LT) on November 24, 1977. Ground shaking was severe along the coast from Bengkulu to Pariaman and continued for 5 minutes in Bengkulu and 3 minutes in Padang. In Pariaman the shaking was so strong that no one could stand. According to some reports, damage due to this tsunami was substantial in both Padang and Bengkulu, but was greater in Bengkulu, where all structures were damaged and the fort and tower had to be torn down. In Padang, wooden houses fared well, but many stone structures lost walls and roofs.

The tsunami generated by this earthquake reached to Bengkulu, Pulau Cinco, Indrapura, Padang and Pariaman, and the sea ran up 3-4m at the beach. This tsunami caused 1 death in Padang and washed away the boats. The map (Figure 4.3.4) shows sparse settlement along the beach and the center of town still along the northern bank of the river, a kilometer or more inland. In Pariaman, the tsunami started with the withdrawal of the sea. The surge tore all boats from their anchors. At Pulau Cinco (100 km southeast of Padang, near the mainland coast) the sea rushed in and carried away several houses and people. At Indrapura, "terrible waves" rolled in over the low countryside and one village was completely washed away. One woman and her child were swept away, but many people survived by climbing trees and waiting there until morning. In the Seychelles, 5000 km west of Sumatra in the Indian Ocean, the 1833 tsunami was similar to that which followed the giant Aceh-Andaman earthquake of 2004.

The long duration of the earthquake and its severity certainly suggest a very large source rupture. Tsunami damage appears to have been greater at Indrapura and Bengkulu than at Padang. Boats were torn from their moorings in Pariaman and Padang, and the descriptions imply (but do not expressly state) that the water did not surge over the riverbanks as it had in 1797. Nonetheless, the surge rose 3-4 m at the beach in Padang, which would have been high enough to flood at least a few hundred meters inland, given that the earthquake occurred during a spring tide and that elevations are under 5 m up to at least one kilometer inland. This might not have inundated many structures, given the sparse settlement near the beach shown on Figure 4.3.4

Figure 4.3.5 shows the situation of 1833 tsunami, and fault model estimated by the investigation of coral reefs is shown in Figure 4.3.6



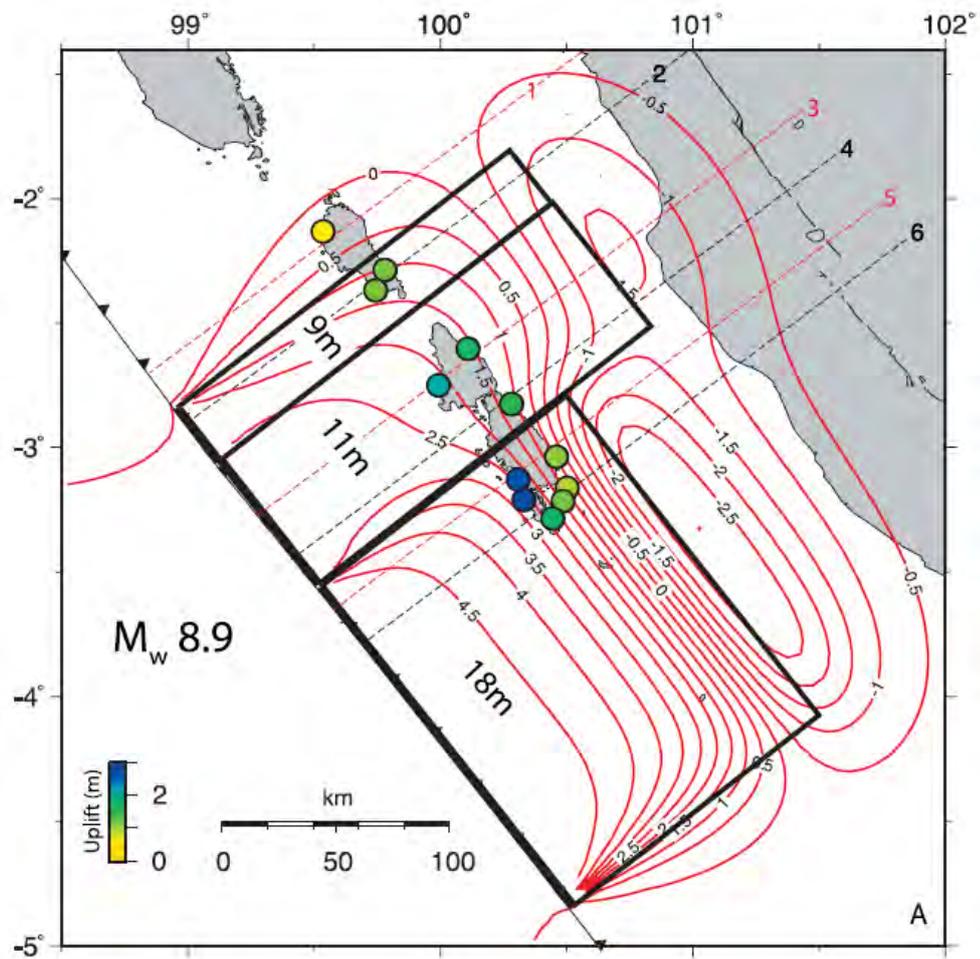
Source: Natawidjaja et al. (2006), Source parameters of the great Sumatran megathrust earthquakes of 1797 and 1833 inferred from coral microatolls, *Journal of Geophysical research*, vol.111, B06403, doi:10.1029/2005JB004025,2006

Figure 4.3.4 Location Map of Padang City in 1781



Source: Engraving of the 1833 Tsunami (by Edward Riou, 1833-1900; National Information Service for Earthquake Engineering, University of California, Berkeley).

Figure 4.3.5 Engraving of the 1833 Tsunami



Source: Natawidjaja et al.. (2006), Source parameters of the great Sumatran megathrust earthquakes of 1797 and 1833 inferred from coral microatolls, Journal of Geophysical research, vol.111, B06403, doi:10.1029/2005JB004025

Figure 4.3.6 Composite Forward Models for the 1833 Rupture Beneath the Mentawai Islands

C. 2004 Indian Ocean Tsunami (December 25, 2004)

A huge earthquake with magnitude $M_w = 9.1$ occurred off the north coast of Sumatra Island at 07:00 (LT) on December 25, 2004. The major tsunami generated by the Off-Sumatra Earthquake propagated over Andaman Sea and Indian Ocean and hit the coastal regions of Thailand, Malaysia, Sumatra (Indonesia), India, Sri Lanka, Maldives and the east coast countries of the African continent. It caused the serious damage to the coast around the Indian Ocean. The deaths worldwide due to this tsunami have reached about 300,000. The tsunami was named Indian Ocean Tsunami 2004.

Overview of the Off-Sumatra Earthquake is described below according to USGS (United States Geological Survey).

- Outbreak Date: 26th December 2004, 00:58:49 (UTC), 07:58:49 (Local Time)
- Epicenter: Off the West Coast of North Sumatra (3.244°N, 95.825°E)
- Depth of Epicenter: 10 km
- Magnitude of Earthquake: 9.1 (M_w^1)

The location of the epicenter of the Main Shock and the Aftershock Area ($M \geq 4$) are presented in Figure 4.3.7.

¹ Moment Magnitude (M_w) is the magnitude of earthquake defined by the common logarithm of the energy of the Fault Movement accompanied by the earthquake.



Source: USGS Earthquake Hazards Program; U. S. Geological Survey

Figure 4.3.7 Epicenter of Off-Sumatra Earthquake and Aftershock Area

D. Generation and Propagation of Tsunami

Indian Ocean Tsunami 2004 took place at the plate boundary where the Indo-Australian Plate is subducted under the Eurasia Plate. Figure 4.3.8 presents the propagation diagram of Indian Ocean Tsunami by the numerical model simulation (after Satake, 2005). According to Figure 4.3.8, the tsunami was estimated to reach the coast of Kabupaten Padang Pariaman and Kota Pariaman in 2-3 hours after earthquake. Tide-gauge records of Sibolga which is located in north of Kabupaten Padang Pariaman and Kota Pariaman is shown in Figure 4.3.9. This figure indicates that the tsunami which is about 1.25m reached Shibolga in 2 hours 36 minutes after the earthquake. This figure suggests that the similar tsunami could reach the coast of Kabupaten Padang Pariaman and Pariaman. However, there are no records of damage from 2004 Indian Ocean Tsunami.

E. 2007 Bengkulu Earthquake and Tsunami (September 12-13, 2007)

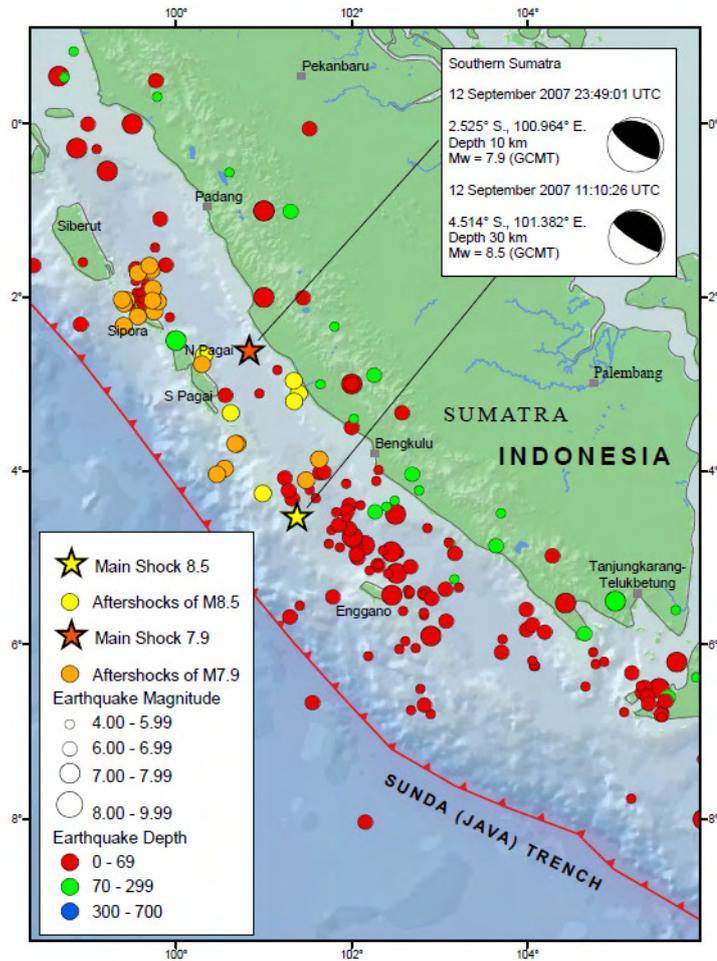
A tsunami caused by a great earthquake of $M=8.2$ occurred offshore Banglahulu, where a seismic gap is located after the 2004 Sumatra earthquake in Indian Ocean, on 12 September and hit the coastal area in the western Sumatra, which resulted in a death toll of nearly 25 people and great damage in the area. Several aftershocks were generated including the earthquake of $M7.9$ on 13 September, which also generated the tsunami. The tsunami was a water wave train generated by impulsive disturbances of water surface due to the fault motion from the offshore of the southwestern Sumatra where the Indian-Australia plate is subducting under the Eurasia one, and several earthquakes with $M=8-8.5$ have happened followed by tsunamis in the past (Aydan et al., 2007).

Figure 4.3.10 shows the main shock and aftershocks in September 2007. Figure 4.3.11 shows tidal records to measure the sea level change the tsunamis attack at Padang city; the station was renovated recently with the addition of realtime data transmission. The tsunamis were generated not only by the main –shock and but $M=7.9$ aftershock on 13 September. This figure shows where the tsunami reached in 1 hour after earthquake and started with the withdrawal of the sea.

Tsunami run-up height surveyed by ITST (International tsunami Survey Team) is shown in Figure 4.3.12. The tsunami height of Padang Port which is located in the south of Kabupaten Padang Pariaman and Kota Pariaman is about 2m and inundation occurred. Although the fact suggests that the tsunami with 1-2m reached the coast of Kabupaten Padang Pariaman and Kota Pariaman, there are no records of damage due to tsunami.

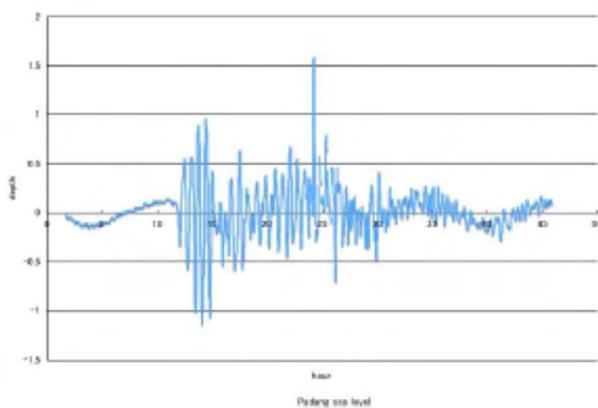
The overview and the damages of this tsunami are presented in Table 4.3.2. 21 deaths were not caused by tsunami but the earthquake. From the interview of earthquake and tsunami residents, evacuation was decided promptly and performed comparatively smoothly. The lesson of 2004 Indian Ocean tsunami and information system exert the effects.

The tsunami damage was small except for the specific area such as Serangai which is located in the front of the tsunami source. Field observations in the past tsunamis indicate that mangroves also prevented people being washed into the sea, which is major cause of death. In addition, mangroves trapped driftwood thus preventing its damage to property and injury to people Green belts of other trees, coastal dunes, and intact coral reefs perform similar functions. In this event, at Serangai there is green belt composed of Mangrove along the coast, which could stop the floating material of timbers moved by the tsunami from coast. However, the houses behind the green could not survive and were completely destroyed. This suggests the limitation of the green belt to reduce the entire tsunami impact force (Aydan et al., 2007).



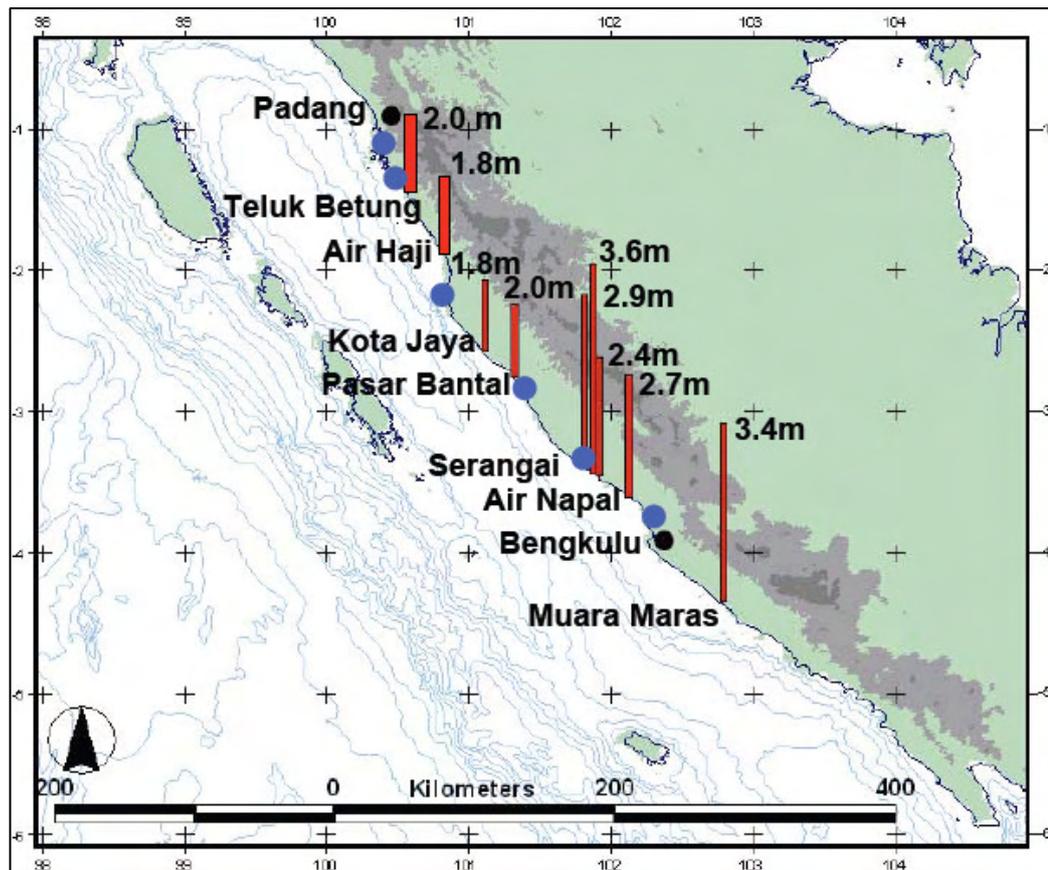
Source: USGS (2007)

Figure 4.3.10 The Main Shock and Aftershock in September 2007



Source: Aydan et al..., Bengkulu Earthquake, Indonesia, September 12, 2007

Figure 4.3.11 Tidal Records in Padang on 12 September



Source: Aydan et al..., Bengkulu Earthquake, Indonesia, September 12, 2007

Figure 4.3.12 Tsunami Run-up Height due to 2007 Bengkulu Tsunami

Table 4.3.2 Damage of 2007 South Sumatra

ITEM	2007 South Sumatra Earthquake and Tsunami
Earthquake Magnitude and Max. Mercari Modified Intensity scale	M8.4, MMI=7-8
Tsunami Run-up height	2-4m
Dead	21 No due to the tsunami
Missing	0
Heavily injured	18
Heavily damaged houses	>13,000

(2) Target Tsunamis in Kabupaten Padang Pariaman

In recent years, the huge tsunamis which caused serious damage in coastal area of Sumatra have come in groups in 2004, 2005, and 2007. These waves reached the coast of Kabupaten Padang Pariaman but didn't damage anything, and a large tsunami has not occurred offshore of Kabupaten Padang Pariaman after the tsunami in 1797 and 1833. Accordingly, the area offshore of Kabupaten Padang Pariaman has attracted attention as the area which has the high possibility that the huge earthquake and tsunami will occur in the future. Therefore, the recurrent earthquake and tsunami in 1797 and 1833 is fixed as a Target of tsunami disaster in Kabupaten Padang Pariaman on this plan.

Figure 4.3.13 shows the shape of fault model which generate the tsunami, and Table 4.3.3 shows the fault Parameter. In this fault model, the earthquake of one fault is composed of 1797 fault and one of the 1833 fault excluding the area destroyed at 12 September, 2007 that will be destroyed all together. As for the detail of this fault model, refer to Chapter2 Topography and Geology in Pilot Region.

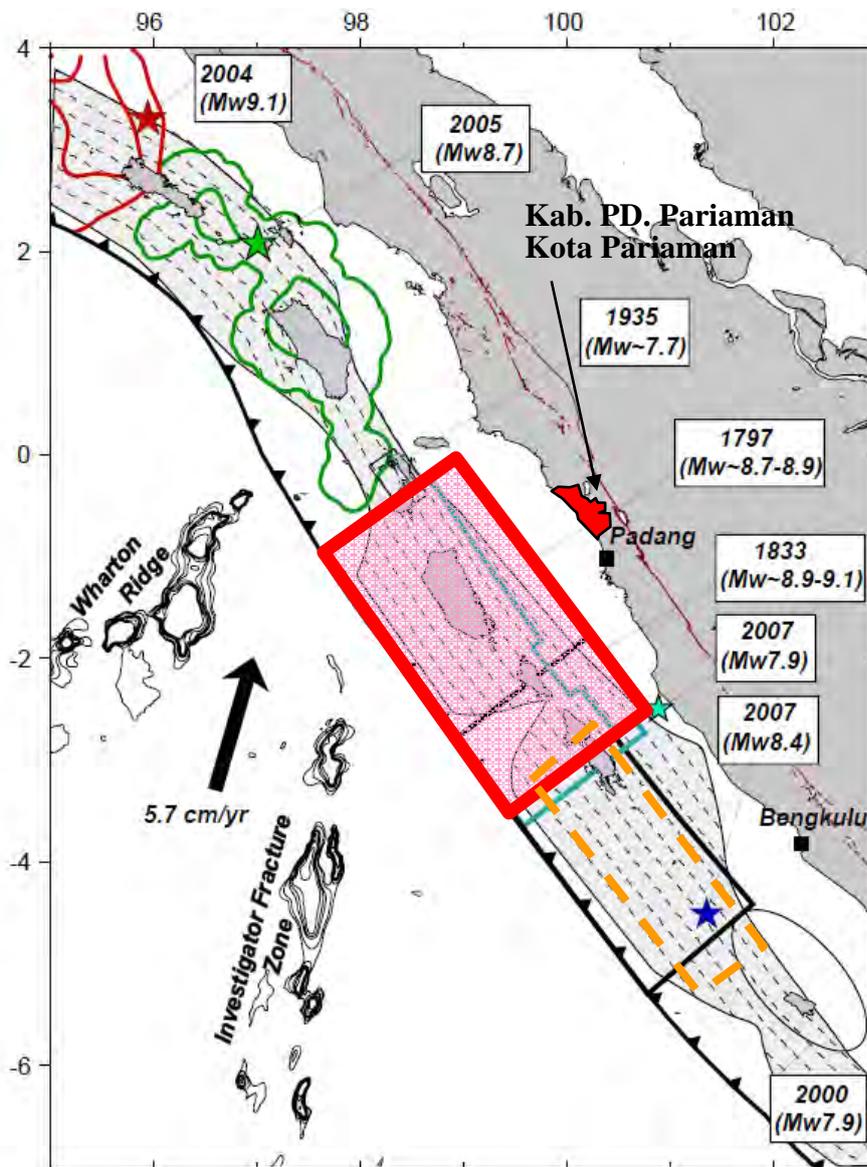


Figure 4.3.13 Fault Model of Target Earthquake

Table 4.3.3 Fault Parameters of Target Earthquake

Latitude (degree)	Longitude (degree)	Depth (km)	Length (km)	Width (km)
-3.6	99.5	0	360	190

A. Distribution of Tsunami Height

The distribution of the target tsunami height along the coast in Kabupaten Padang Pariaman is shown in Figure 4.3.14. Kabupaten Padang Pariaman doesn't have historical past tsunami records. As for the flood damage there is only one record that the boats were washed away which was the tsunami in 1833, which is not enough to estimate the tsunami height or inundated depth. Therefore, we referred to the records of Kota Padang which is adjacent to the south of Kabupaten Padang Pariaman in order to fix the expected tsunami height of target tsunami. According to the tsunami records of 1797 and 1833 in Kota Padang, the height of 1797 tsunami is 5-10m and the height of 1833 tsunami is 5m or less. In view of these records and other previous study of numerical simulation of target tsunami, the height of target tsunami is fixed 5m above mean sea level in this study. Hence, when the evacuation sites are installed, it is preferable to develop them at the elevation over 10m considering the maximum tsunami height and the uncertainty of assumptions.

Comparison between the historical tsunami heights and target tsunami height is shown in Figure 4.3.14. Also, cross section of coast in Pasir baru Kecamatan Sungai Limau with target tsunami height is shown in Figure 4.3.16. The Figure indicates that a tsunami can completely overflow the top of sand dune along the coast.

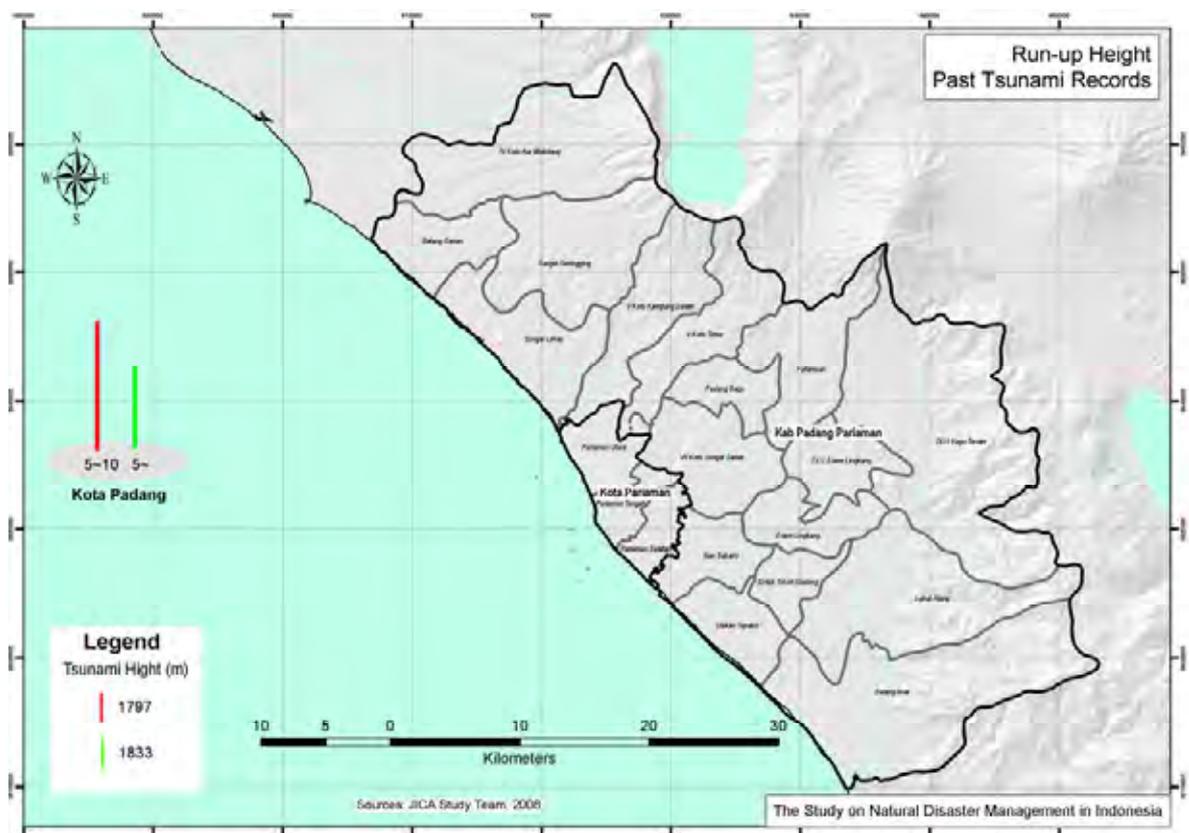


Figure 4.3.14 Distribution of Tsunami Height due to 1797 and 1833 Tsunamis

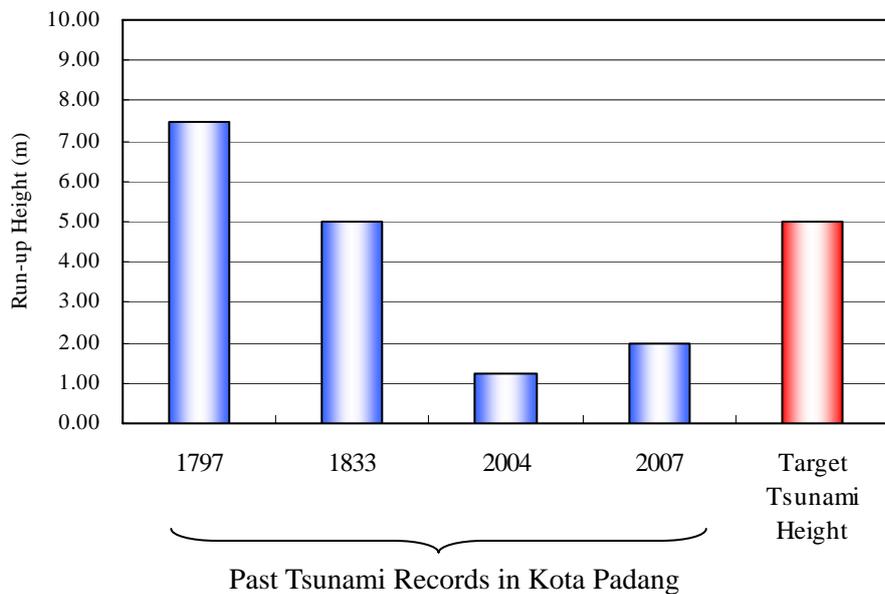


Figure 4.3.15 Comparison between the Historical Tsunami Heights and Target Tsunami Height

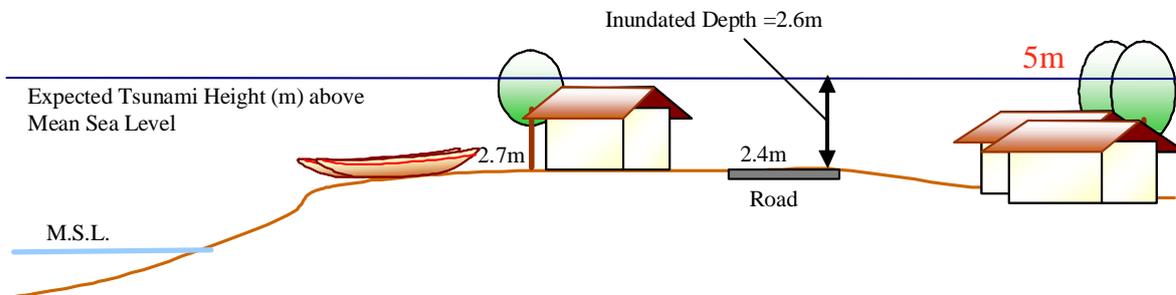


Figure 4.3.16 Cross section of Coast in Pasir baru Kecamatan Sungai Limau

B. Inundated Area

Although there are no records of inundation area of a target tsunami in Kabupaten Padang Pariaman, there are some records in Kota Padang. According to these records, 1797 tsunami intruded about 2km inland from the coast and also 1833 tsunami intruded about 1km inland from the coast. Comparing the elevation of low-lying area of Kota Padang and that of Kabupaten Padang Pariaman, both elevations are considered similar at that time. Thus, it is guessed that there were no big differences in the flood situation and the inundation distance between both regions.

C. Damage due to Tsunami

The historical damage records of target tsunamis are shown in Table 4.3.4. The human and house damage due to tsunamis are small considering the flood situation. The reason was guessed that the center of Padang city with old records was one kilometer more inland from the coast. Additionally, there are no clear records about the number of heavily damaged house and boats.

Currently, there are many houses near the coast and the land-use of coastal areas have changed from that of 1797 and 1833. Therefore, it is necessary to consider the damages in terms of present land-use, etc.

Table 4.3.4 Damage Records of Target Tsunami in 1797 and 1833

ITEM	1797 Tsunami	1833 Tsunami
Earthquake Magnitude and Max. Mercari Modified Intensity scale	Mw8.7-8.9	Mw8.9-9.1
Tsunami Run-up height	5-10 m	< 5 m
Deaths* ¹	2 (Padang)	1(Padang) 2(Indrapura)
Missing	No records	No records
Heavily injured	Ditto	Ditto
Heavily damaged houses	Some houses	Some houses

Source: Natawidjaja et al. (2006), Source parameters of the great Sumatran megathrust earthquakes of 1797 and 1833 inferred from coral microatolls, Journal of Geophysical research, vol.111, B06403, doi:10.1029/2005JB004025

2) Factors for Damages due to Tsunami

Past tsunami damage above-mentioned in Kabupaten Padang Pariaman can be classified as follows:

- Human damage such as drowning deaths
- House damage such as destruction due to flow
- Fishery industry damage such as outflow of fishery boats
- Landform change of beach

Thus the external force to cause these damages was that seawater intruded inland due to tsunami. These tsunami damage records indicate that the level of damage varied in depth and flood velocity.

According to the records in Kota Padang, tsunami could intrude inland in the low-lying area near the river mouth, etc. The shape of coastline in Kabupaten Padang Pariaman is almost straight and there are no characteristic land forms which the tsunami might concentrate in. The elevation of top of sand dune along the coast is low and especially the vast low-lying area spread inland in south coastal area. Therefore, the low ground and the distance from the coastline could be said to be the geological tsunami damage factor.

Comparing the present situation and the past situation regarding disaster mitigation, the situations are similar about structural countermeasures because structural countermeasures such as sea wall are not installed in Kabupaten Padang Pariaman. However, the situation about non-structural countermeasures can be said better now because related government agencies like BMG have preceded with the maintenance of early warning network, the designation of evacuation site and tsunami drills. Moreover, the knowledge and public awareness of tsunami have improved compared with 1797 and 1833 situation. Additionally, tree planting on the beach as tsunami disaster mitigation has already been practiced before in other regions.

4.3.2 Tsunami Hazard Map in Kabupaten Padang Pariaman

1) Overview of formulation of Tsunami Hazard Map

Refer to 4.2.2 Tsunami Hazard Map in Kabupaten Jember, 1) Overview of formulation of Tsunami Hazard Map.

2) Applicability evaluation of inundation in Kabupaten Padang Pariaman

Table 4.3.5 shows the applicability of each inundation prediction method in Kabupaten Padang Pariaman. Although there is some data for carrying out each method, it is not enough to get the correct results for each method.

Basically, tsunami hazard map shall be developed by Estimation based on ground elevation because it is comparatively simple method to determine the hazard area and the level from only relation between possible tsunami height given by numerical simulation and the ground elevation.

Table 4.3.5 Applicability of Each Inundation Prediction Method in Kabupaten Padang Pariaman

Method	Data for conducting each method	Applicability	Remarks
a. Numerical simulation method	Not enough	Not practicable (for ocean area)	Some previous results exists for ocean area.
b. Level filling method	Not enough	Partly Practicable	There are no accurate data of the height levee/sand dune along the coast.
c. Method based on historical inundation records	Not enough	Not practicable	1797, 1833 Tsunami
d. Estimation based on ground elevation	Enough	Practicable	

3) **Indices of Hazard Map for Tsunami Disaster**

(1) **Inundation area and depth estimated by level filling method (H_1)**

Refer to 4.2.2 Tsunami Hazard Map in Kabupaten Jember, 3)Indices of HazardMap for Tsuanmi Disaster, (1) Inundation area and depth estimated by level filling method (H_1)

A. Calculation of water volume intruding from the coast

The water volume intruding form the coast was calculated for 1797 and 1833 tsunamis. The basic data of tsunami was settled based on the records and previous study of numerical simulation of tsunami. They are shown in Table 4.3.6 and Figure 4.3.17. In addition, the temporal alteration of tsunami was modeled as shown in Figure 4.2.13 in order to calculate the water volume overtopping the coast. In this model the wave pattern was approximated by linear regression and the duration time was divided 5 in order to water volume. The calculated amount of the overflow is shown in Table 4.3.7.

Table 4.3.6 Tsunami Data for Calculating Water Discharge Intruding Inland

Item	Value	Source
Tsunami Height	5.0 (m) above mean sea level	Records of 1797 and 1833 Tsunami in Kota Padang
Period	1,260 (sec)	Some previous results of reconstruction of 1797 and 1833 Tsunami by the numerical simulation
Length of coast line intruded by tsunami	41.8 (km)	Topographical data
Height of sand dune	2.5 (m) above mean sea level	Topographical data and Field survey
Number of the waves overtopping the top of sand dune	3 waves	

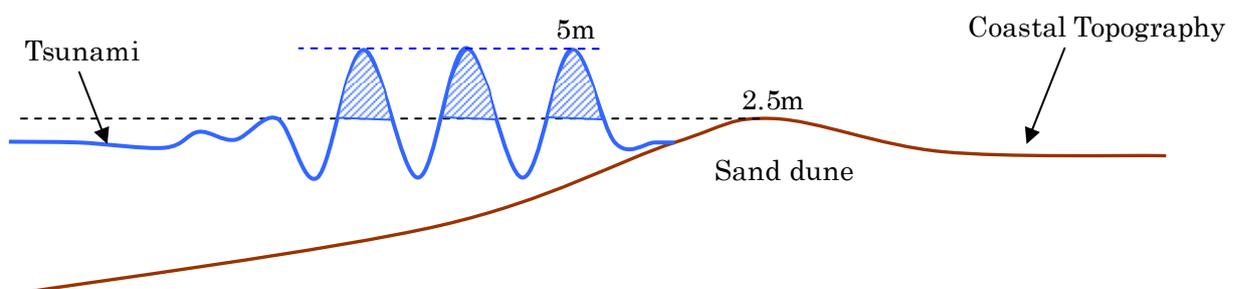


Figure 4.3.17 Cross section of Model

Table 4.3.7 Water volume intruding by tsunami

	(A)	(B)	(A)-(B)	(D)	(E)	(D)*(E)
No.	Tsunami Height	Sand dune Height	-	Q1 (m ² /sec)	Δt (sec)	Q2 (m ²)
1	1.0	2.5	-1.5	0.00	126	0.00
2	3.0	2.5	0.5	0.55	126	69.03
3	5.0	2.5	2.5	6.13	126	771.75
4	3.0	2.5	0.5	0.55	126	69.03
5	1.0	2.5	-1.5	0.00	126	0.00
Summation				(per 1 wave and 1m)		909.80
				(per 3 wave and 1m)		2729.41

B. Inundation area and depth

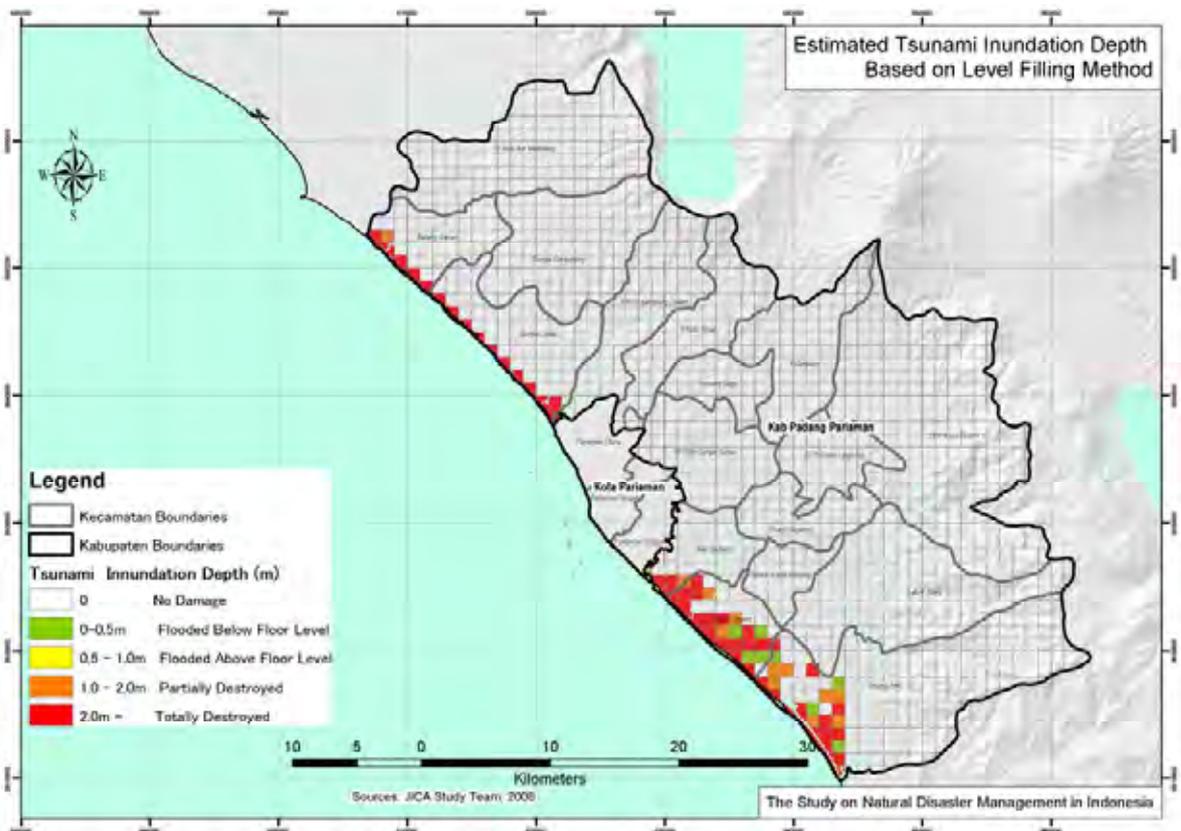
The expected inundation map based on water volume overtopping the coast shown in Table 4.3.7 is presented in Figure 4.3.18. The grade and the corresponding scores are as follows:

- i) 2.0m < (Totally destroyed) Score 4
- ii) 1.0m < H ≤ 2.0m (Partially destroyed) Score 3
- iii) 0.5m < H ≤ 1.0m (Flooded above floor level) Score 2
- iv) 0.0m < H ≤ 0.5m (Flooded below floor level) Score 1
- v) H = 0.0m (No damage) Score 0

Level filling method requires a structure or landform that prevents the waves from overtopping it along the coast. However, there are no structures along the coast and the landform such as sand dune doesn't cover all of the coast in Kabupten Padang Pariaman. Therefore, the expected inundation area might be underestimated at the river mouth where the sand bar is lower than the height (=2.5m) given by the above-mentioned model.

(2) Inundation area based on historical inundation records (H₂)

There were no historical record found for the past Tsunami disaster in Kabupaten Padang Pariaman.



Source: Study Team

Figure 4.3.18 Inundation Area and Depth Estimated by Level Filling Method (H₁)

(3) Inundation area and depth estimated based on ground elevation (H_3)

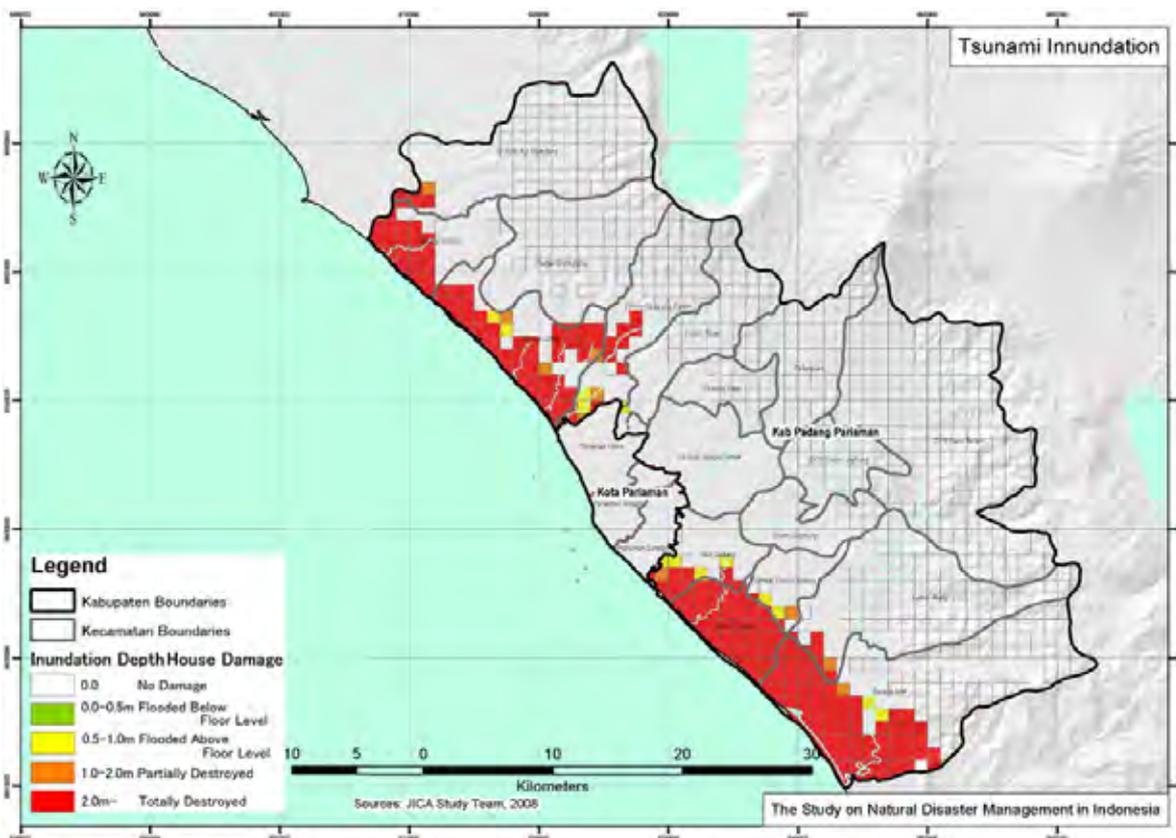
Estimation based on ground elevation is comparatively simple method to determine the hazard area and the level based only on the relation between possible tsunami height given by numerical simulation and the ground elevation². The maximum run-up height of the recurrent earthquake and tsunami in 1797 and 1833 was 5m or less. Therefore, 5m above sea level was set to standard height of the expected tsunami run-up. The grade and the corresponding scores are as follows:

i)	$2.0\text{m} <$	(Totally destroyed)	• • • • Score 4
ii)	$1.0\text{m} < H \leq 2.0\text{m}$	(Partially destroyed)	• • • • Score 3
iii)	$0.5\text{m} < H \leq 1.0\text{m}$	(Flooded above floor level)	• • • • Score 2
iv)	$0.0\text{m} < H \leq 0.5\text{m}$	(Flooded below floor level)	• • • • Score 1
v)	$H = 0.0\text{m}$	(No damage)	• • • • Score 0

Compared with the historical tsunami records of Padang in 1833 which describe that the tsunami intruded at least 1km from the coast, the expected tsunami hazard area has extended more than this. Thus the expected tsunami flood area based on ground elevation is judged to be a little overestimated, which is the dangerous side of the estimation.

² The ground elevation data are made from the calibrated SPOT DEM. It is calibrated using the several actual elevations obtained by the leveling which was conducted by Study Team.

A SPOT DEM is a digital elevation model produced by automatic correlation of stereopairs acquired by the [HRS](#) instrument on SPOT 5, which is the fifth satellite in the SPOT series, placed into orbit by an Ariane launcher.



Source: Study Team

Figure 4.3.19 Inundation Area and Depth Estimated Based on Ground Elevation (H₃)

4) Tsunami Hazard Map in Kabupaten Padang Pariaman

When the above-mentioned three indices are compared, the result on the dangerous side is given in the order of the inundation area based on ground elevation (H₃) and the inundation area estimated by level filling method (H₁). Essentially, it is better to adopt the prediction method with the highest accuracy. In this study, the inundation area based on ground elevation (H₃), which gives the result on the most dangerous side and is comparatively easy to formulate, shall be adopted because all prediction methods have a problem with accuracy which depends on available data and its accuracy. An inundation map with higher accuracy can be formulated after the various data are maintained and available.

The hazard map for tsunami disaster was created based on Expected Inundation Depth (H₃). As indicated in Figure 4.3.20, the values of tsunami hazard were divided into 4 classes as shown below.

- i) 2.0m < (Totally destroyed) Score 4 (Highest hazard)
- ii) 1.0m < H ≤ 2.0m (Partially destroyed) Score 3 (High hazard)

- iii) $0.5m < H \leq 1.0m$ (Flooded above floor level) Score 2 (Moderate hazard)
- iv) $0.0m < H \leq 0.5m$ (Flooded below floor level) Score 1 (Low hazard)
- v) $H = 0.0m$ (No damage) Score 0 (No damage)

Figure 4.3.20 indicates that the tsunami hazard is concentrated on the low-lying area near the coast. The low-lying area of the northwest of Kabupaten Padang Pariaman is comparatively narrow and 1-3km in width because the plateau is close to the coast as a geomorphic characteristic. In contrast, the southern part near the coast is a vast low-lying area which extends 5-7km from the coast to inland. Accordingly, the tsunami hazard area has extended deeply to inland.

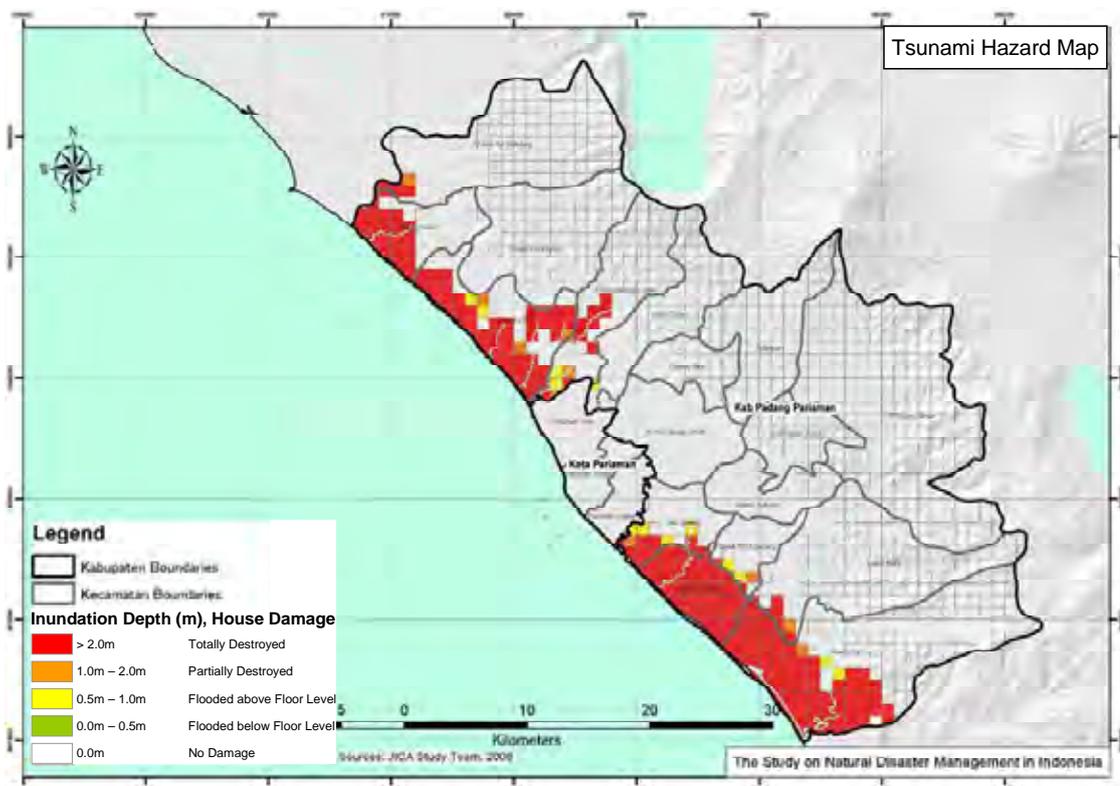


Figure 4.3.20 Tsunami Hazard Map

4.3.3 Tsunami Risk Map in Kabupaten Padang Pariaman

1) Basis of Risk Map Creation for Tsunami Disaster

The damages due to tsunami hazard are of great variety. The main damages are as follows.

Human damage such as drowning death / House damage such as destruction due to flow / Civil structure damage such as destruction of roads, railways, and bridges / Lifeline damage such as outage of electricity and water service / Fishery damage such as outflow of fishery boats / Commerce and industry damage such as destruction of factories near the coast / Agriculture damage caused by seawater and sediment inflowing to farm land / Forest damage / Fire damage / Landform change of beach / Destruction of power plant / etc.

In this study, the risk caused by tsunami hazard shall be estimated focusing on house and human damage which are the main damages. Therefore, the risk is given by the expressions shown below. The damage rate based on inundation depth is neglected because the score of inundation depth includes it. But the damage rate based on the distance from the coast is considered because it is thought that the houses are not destroyed inland where the flow velocity of flood becomes smaller. In fact, the completely-destroyed and partially-destroyed houses could be assumed to be found within 1km from the coastline. In addition, the area where the house damage could occur is within the range of 3km from the coastline.

When the death toll due to tsunami is calculated, the death rate corresponding to the tsunami height is multiplied by the population staying around the coast. Human damage was also estimated by same method as that of house damage.

$$[\text{Tsunami Risk}] = [\text{Tsunami Hazard}] \times [\text{Damage rate}] \times [\text{Population Density} + \text{Built up Area}]$$

2) **Vulnerability indices**

Vulnerability is defined as “The conditions determined by physical, social, economic, and environmental factors or processes, which increase the susceptibility of a community to the impact of hazards.” according to “Living with Risk” (UN/ISDR, 2004). The vulnerability indices used for making tsunami risk map are Population density (V_1), Built-up area (V_2), Distance from coastline (V_3), which were calculated from the available data source.

(1) **Population density (V_1)**

The population density was calculated based on the population in living area (residential area). The population density was divided into five ranks and the scores were set up as follows:

- i) $50 \text{ (pop./km}^2\text{)} <$ Score 5
- ii) $30 \sim 50 \text{ (pop./km}^2\text{)}$ Score 4
- iii) $20 \sim 30 \text{ (pop./km}^2\text{)}$ Score 3
- iv) $5 \sim 20 \text{ (pop./km}^2\text{)}$ Score 2
- v) $0 \sim 5 \text{ (pop./km}^2\text{)}$ Score 1

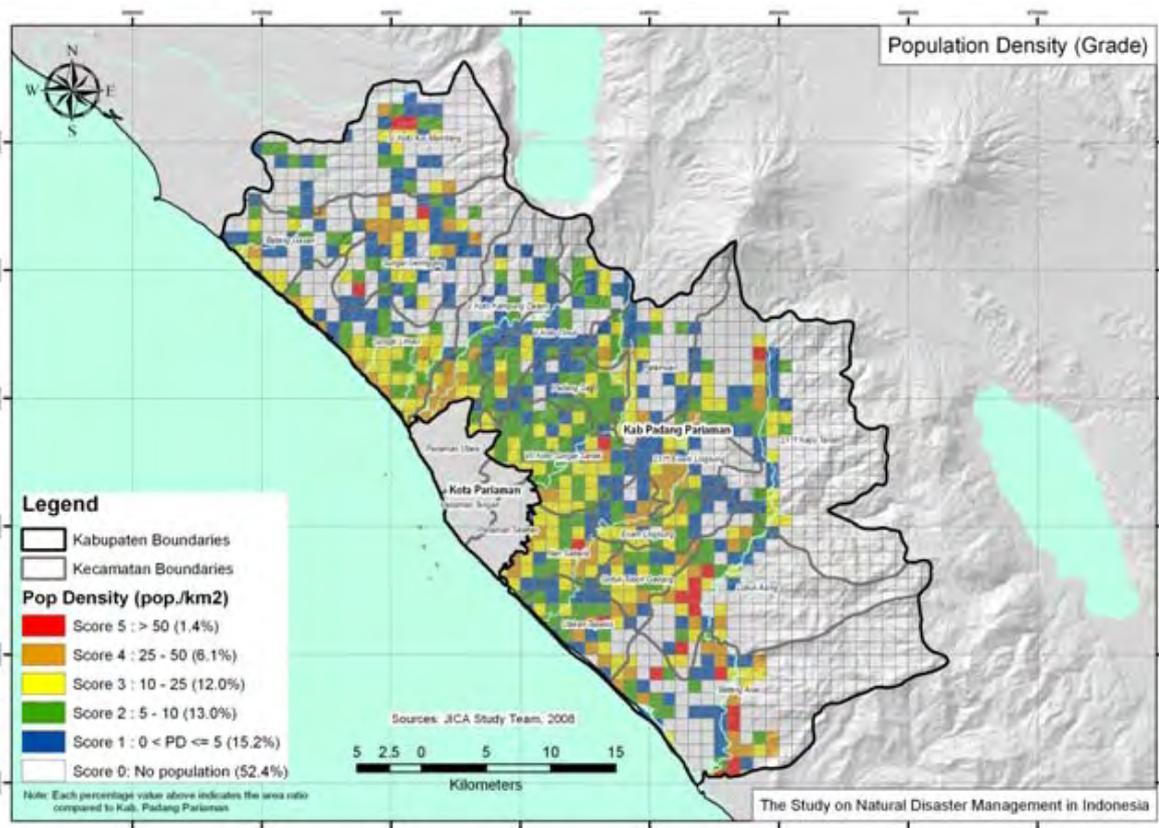


Figure 4.3.21 Population Density (V_1)

(2) **Built-up area (V_2)**

Built-up area can be regarded as disaster vulnerable area which was created based on the existing land use map of Kabupaten Padang Pariaman. The classification was ranked by the area of built-up area per a unit (1 km^2).

- i) $0 \sim 5 \text{ (km}^2/\text{km}^2)$ Score 1
- ii) $5 \sim 20 \text{ (km}^2/\text{km}^2)$ Score 2
- iii) $20 \sim 30 \text{ (km}^2/\text{km}^2)$ Score 3
- iv) $30 \sim 50 \text{ (km}^2/\text{km}^2)$ Score 4
- v) $50 \text{ (km}^2/\text{km}^2) \leq$ Score 5

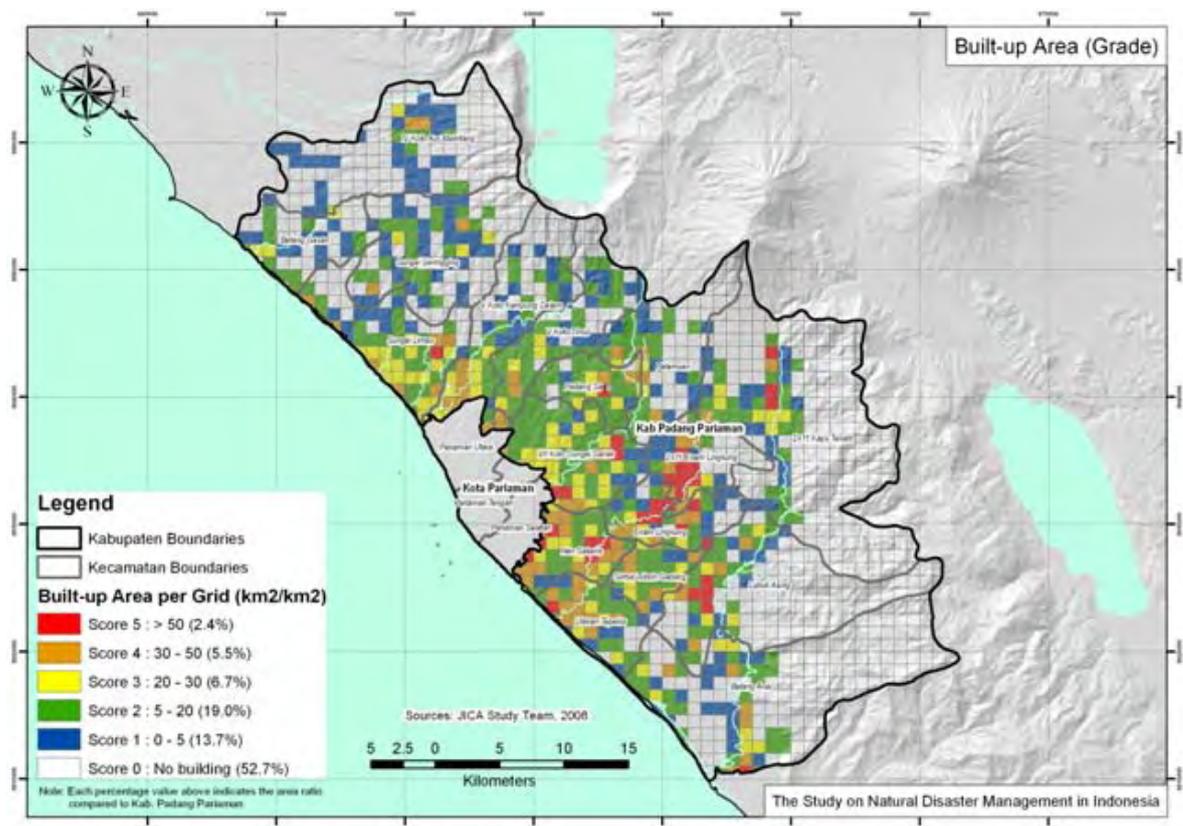


Figure 4.3.22 Built-up Area (V_2)

(3) Distance from coastline (V_3)

“Distance from coastline” was selected as one of the indices of tsunami Vulnerability. The grade and the corresponding scores are as follows:

- i) $0\text{km} \leq L < 1.0\text{km}$ (Serious Damage) . . . Score 5
- ii) $1.0\text{km} < L < 3.0\text{km}$ (Partially Damage) . . . Score 3
- iii) $3.0\text{km} \leq L$ (No Damage) . . . Score 0

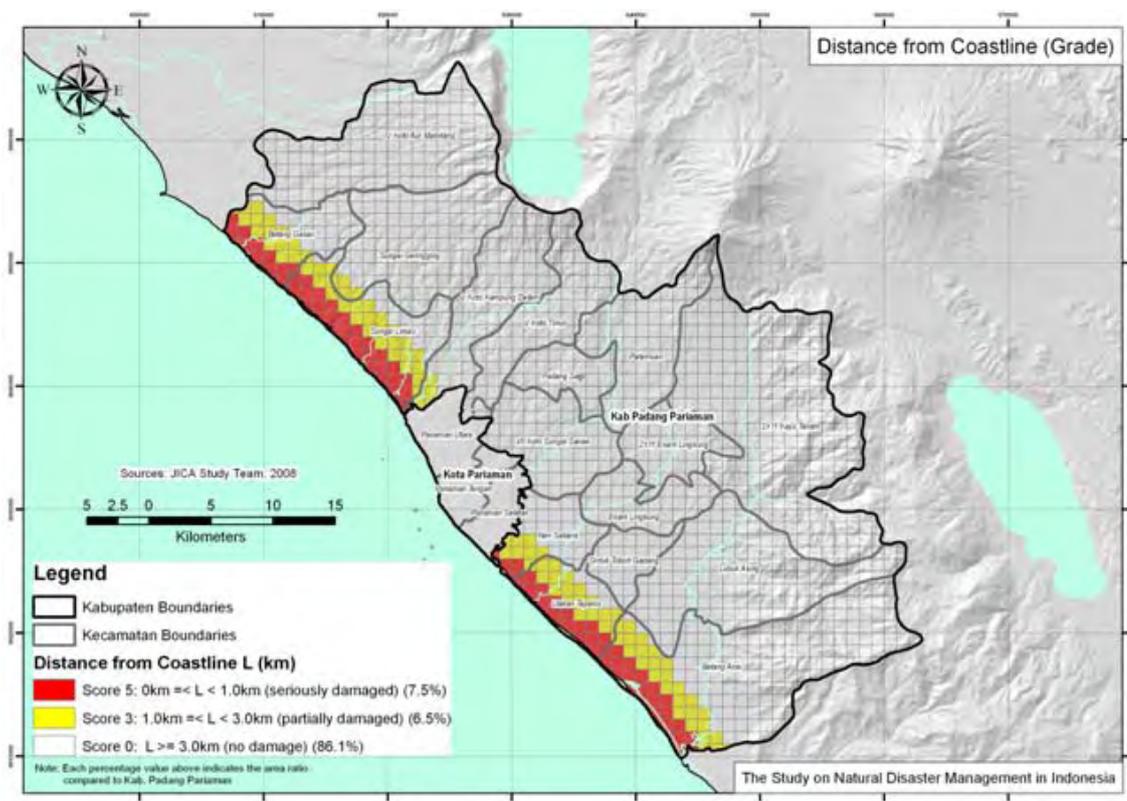


Figure 4.3.23 Distance from the Coastline (V_3)

3) Tsunami Risk Map in Kabupaten Padang Pariaman

Figure 4.3.24 shows the Tsunami Risk map calculated from the formula mentioned above. As indicated in Figure 4.3.24, the values of tsunami hazard were divided into 5 classes indicating relative hazardous classification. “Red” means the highest hazard and “Orange” indicates high hazard. Moderate hazard is shown in “Yellow” while “Green” means low hazard. Further, “Blue” shows the lowest hazard.

Figure 4.3.24 indicates that the tsunami risk is spread out all parts of coastal area of Kabupaten Padang Pariaman. Especially, the damage risk of Pasir Baru, Pilubang and Pasar Sungai Limau in Kecamatan Sungai Limau on which the population and the residential area concentrate is very high. In Kecamatan Batang Gasan which is northern area of Kabupaten Padang Pariaman, the area with high risk is limited to a part of coastal area. In southern area, Ulakan of Kecamatan Ulakan Tapakis has high risk for flood due to tsunami. The risk of the south low-lying area in Kecamatan Batang Anai is low except the residential area of Kataping. Although the house damage and human damage seem to be low in southern area, the actual risk of tsunami hazard is very high because Minangkabau International Airport is located there. The above-mentioned areas are located near the coast and often have fishery port or slipways for fishing boat. Thus the risk of fishery damage is very high. Additionally, even in the inland which is far from the coastline, it is necessary to pay attention to the low-lying area along the river that the tsunami enters easily.

The risks regarding Tsunami disaster were calculated based on Eq.4.3.1.

$$(H_3) \times (V_3) \times (V_1+V_2) \quad \cdot \cdot \cdot \text{Eq. 4.3.1}$$

where, H_3 : Inundation area and depth estimated based on ground elevation, V_1 : Population density, V_2 : Built-up area and V_3 : Distance from the coastline.

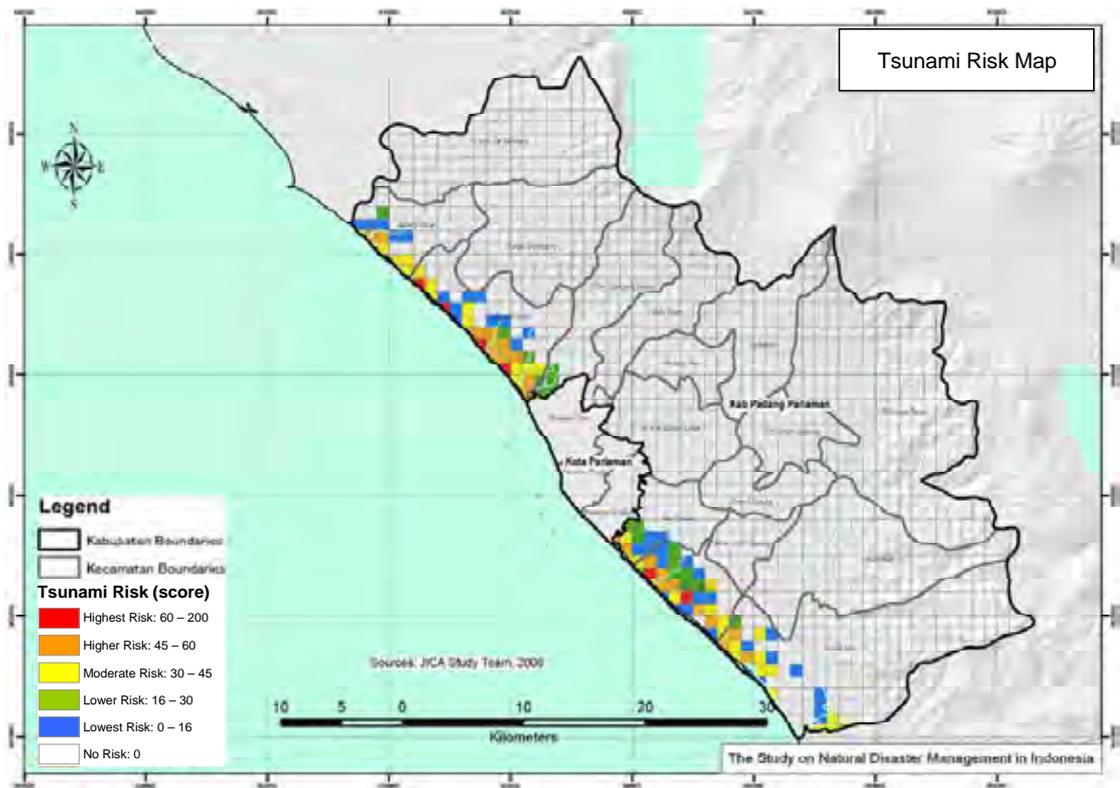


Figure 4.3.24 Tsunami Risk Map

4.3.4 Possible Countermeasures against Tsunami Disaster in Kabupaten Padang Pariaman

1) Recent Tsunami Disaster and the Feature

There are some tsunamis that reached the coast of Kabupaten Padang Pariaman in recent years such as Bengkulu Tsunami in 2007, the most recent one. However, only the tsunamis in 1797 and 1833 caused serious human damage and property damage to the coast of Kabupaten Padang Pariaman.

The following points are given as the topographic features focusing on the places damaged by recent tsunamis such as Bengkulu Tsunami in 2007 and the rising tide which occur often. Almost all of them are low-lying areas in the coastal area, and the damage centered on the geographical weak points such as river mouth where the height of the sand dune is rather low. Moreover, the serious damage occurred due to the rising tide in the area where the sandy beach between the coastline and the residential area is narrow because of erosion etc.

Areas of high Tsunami disaster risk are as follows:

- Beach and Low-lying area(*e.g.* Almost every coastal area, Kataping, Tiram, Ulakan, Pasir Baru, Pilubang, Pasar Sungai Limau)
- The area damaged by rising tide (*e.g.* Ulakan, Kuranji Hilla, Malai V Suku)
- Eroded narrow beach (*e.g.* Ulakan, Pasir Baru, Pilubang)
- River mouth and the part where the height of sand dune is lower than that of other coast (*e.g.* Ulakan, Tiram, Pasir Baru)

2) Countermeasures against Tsunami

The basis to evade tsunami disaster is to go away from the districts mentioned above, since they have high disaster risks. Relocation to higher place, which is one of the most effective means has been recommended for a long time. However, it is often difficult to obtain consent of the residents such as fishermen because a tsunami disaster doesn't occur frequently. Therefore, it is necessary to consider comprehensive measures including the reinforcement of houses against the waves and the evacuation etc. in order to reduce the tsunami hazard. Possible countermeasures against tsunami and its applicability to Kabupaten Padang Pariaman are mentioned as follows.

(1) Structural Countermeasures

A. Tide embankment, Tsunami breakwater, Tsunami floodgate, and River embankment

As structural countermeasures, a few measures are mentioned below.

Tide embankment, Tsunami breakwater, River embankment installed at river mouth, and River embankment to limit the inundation to shore and river run-up physically. But they are not realistic measures for Kabupaten Padang Pariaman because all of them require tremendous amount of investment and time. If a structural countermeasure may be implemented, it is proposed that the road along the coast shall be raised as tide embankment when it is repaired. Or it is proposed that the structural-countermeasures are locally implemented in only high density-populated section near the coast as long-term mitigation.

B. Coastal Forest

All of the coast of Kabupaten Padang Pariaman is sandy beach with small sand dune. Thus, planting of coastal forest is recommended as a countermeasure against tsunami and blown sand, which will also grow the sand dune and enhance the protection function of sand dune on a long term basis. Planting Trees on the beach has already started in Kabupaten Padang Pariaman (Refer to Figure 4.3.25). And it is hoped to continue and maintain these coastal forest. Table 4.3.8 shows the past results and future plan of afforestation.



BadanGasang



Tiram



Kataping



Tiram

Source: Study team

Figure 4.3.25 Planted Trees on the Beach

Table 4.3.8 Afforestation

Year	Location			Afforestation	Type	Remarks
	Desa/Nagari	Kecamatan	Kota/Kabupaten			
2006-2007	Pasirbaru	Sungai Limau	Kab. PD. Pariaman	-	Cemara	-
2006-2007	Ulakan Tapakis	Ulakan Tapakis	Kab. PD. Pariaman	-	Cemara	-
2006-2007	Kataping	Batang Anai	Kab. PD. Pariaman	-	Cemara	-

Source: DKP of Kabupaten Padang Pariaman

C. Wave-proof buildings

In a fishing village, it is difficult to obtain the agreement for the relocation to higher place. Thus, other measures such as improving the wave resistance of the present houses is necessary. Present fishing village and improved house are shown in Figure 4.3.26. High-floored house reinforced against waves have been already installed in Kota Pariaman.



Ulakan

Ampalu Kota Pariaman

Source: Study team

Figure 4.3.26 Present Village of Ulakan (left) and High-floored House Reinforced against Waves of Ampalu (right)

(2) City planning for tsunami disaster prevention

A. Relocation

As described above, the basis of tsunami countermeasures is to go away from the place where tsunami can hit. The most effective method is to move residences to the place where the tsunami doesn't reach. When relocation is difficult, the ground of the dwelling might be raised. In general, it is not easy to gain consensus for the reasons of economic efficiency and convenience to relocate the residents to higher place. In fact, they return to the original location as years go by for similar reasons. However, it is expected to set up important public facilities such as town office, police station, and fire station, and the facilities for vulnerable people such as hospitals and schools in the high ground where the effect of the tsunami doesn't reach. Relocation is recommended in northern area of Kabupaten Padang Pariaman because high ground is near and the effect of relocation is comparatively small.

B. Regulation of land-use

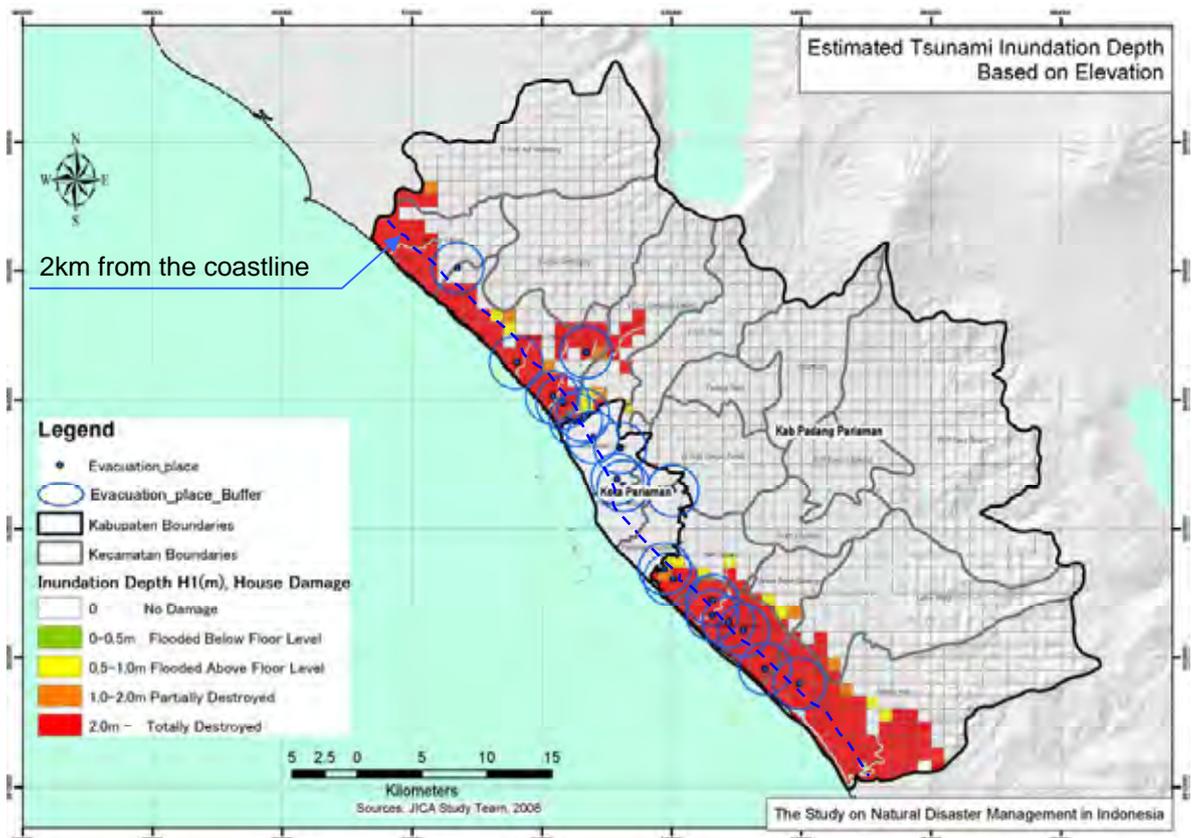
Effective regulatory measures are needed to enforce reconstruction of wave-proof buildings which are stronger in addition to limit the activity and development in tsunami hazard area by regulation of land-use.

(3) Tsunami hazard map

The hazard map is a very useful tool to offer the information for evacuation and education of tsunami disaster to the residents. Also, it can be used to study the location of evacuation site and development of disaster-prevention facilities. The tsunami hazard map is often made from past tsunami flood results and the results of numerical simulation of tsunami to complement it. In this study, it was made from past flood results of 1797 and 1833 tsunamis. Although tsunamis in 1797 and 1833 were the biggest tsunamis for the coast of Kabupaten Padang Pariaman on record, the number of records is not enough to say that a bigger tsunami will not occur. Therefore, there is a possibility that the inundated area could get larger than the area shown in hazard map, and it is necessary to make an ingenious hazard map that prevents the residents from having a fixed image for tsunami disaster risk area.

(4) Maintenance of evacuation site and route

Evacuation when a tsunami hits is necessary and it is very important not to go away from tsunami horizontally but to go up to the places which are higher than the tsunami. As will be appreciated from the formulated tsunami hazard map, there is a possibility of deep flooding to the inland when the tsunami overtopping the sand dune along the coast occurs because the area behind the sand dune is a vast low-lying area especially south part of Kabupaten Padang Pariaman. Therefore, it is necessary to decide the evacuation site with enough height and space and to move the evacuation route in the low-lying area near the coast to a higher area. In addition, the residents would rather decide their own evacuation site and route than let the administration decide it. Figure 4.3.27 shows the distribution of evacuation sites designed by Kabupaten Padang Pariaman and the circle indicating the distance to walk in 30 minutes which is available time to evacuate from earthquake. It is because that the tsunami is estimated to reach the coast of Kabupaten Padang Pariaman from the earthquake. From Figure 4.3.27, the north coast is comparatively near the hill and it is possible to reach the high place in about 30 minutes from the coast. Although the evacuation site in south area is 2km away from the coast, the elevation of it is still low because the vast low-lying area spread inland in south coastal area. Therefore, it is necessary that shelters with high elevation are developed near the south coast.



Source: Study Team

Figure 4.3.27 Distribution of Evacuation Site

(5) Tsunami Drill

The target tsunami arrival time to the coast of Kabupaten Padang Pariaman is estimated about 30 minutes according to previous study of numerical simulation. Since the arrival time is not enough to evacuate without preparation, Tsunami drills are necessary to establish procedures for evacuation of the residents near the coast to higher places promptly without any confusion. In Kabupaten Padang Pariaman, a tsunami drill has already been executed, and it is necessary in the future to improve the evacuation plan while using the regional disaster prevention plan and the tsunami hazard map, and tsunami risk map formulated by this study.

(6) Education

In recent years, huge tsunamis which caused serious damage in coastal area of Sumatra have come in groups in 2004, 2005, and 2007. These waves reached the coast of Kabupaten Padang Pariaman but didn't damage anything, and a large tsunami have not occurred offshore of Kabupaten Padang Pariaman after the tsunami in 1797 and 1833. Accordingly, the area offshore of Kabupaten Padang Pariaman has attracted attention as the area which has high possibility that a huge earthquake and tsunami will occur in the future. Therefore, it is continuously necessary to maintain the opportunity for the education about tsunami disaster and hand down the lessons learned from past tsunami disasters.

3) Possible Countermeasures for each Kecamatan

The geographical features not only differ greatly but also the adaptability and the priority of the above-mentioned measure are different between the north part and south part in Kabuptaen Padang Pariaman. Therefore, the structural countermeasures and non-structural countermeasures were decided based on the characteristics of the region.

The characteristics of the region are as follows:

- Past coastal disaster (rising tide)
- Evacuation places or high places in 2km from the coast
- Coastal Forest in front of settlement
- Possibility of relocation
- Population Density in the coastal area

The recommended disaster mitigation is separately described as follows.

- Short-term Countermeasures
 - Measures that should be implemented now
- Long-term Countermeasures
 - Measures that should be implemented if it is necessary after the effect of short-term countermeasures is evaluated in the future

This is because structural countermeasures such as tide embankment, etc. can have a large impact.

The recommended countermeasures for each Kecamatan are shown in Table 4.3.9

Table 4.3.9 Possible Countermeasures for each Kecamatan

Kecamatan (Oceanfront Kecamatan)	Existing Condition				Possible Countermeasures	
	Past Coastal Disaster (ring tide)	Evacuation places or high places in 2km from the coast	Coastal Forest in front of settlement	Possibility of relocation	Population Density in the coastal area	Structural Countermeasures
1. Brangkal Area	No	No	Yes but thin (Northern Area) No (Southern Area)	Low Adequate relocation site is very far.	Comparatively Low	Non-Structural Countermeasures (1) Coastal Forest (2) Regulation of land-use (3) Tsunami hazard map (5) Tsunami Drill (6) Education (7) Early Warning System
4. Uluhan Tripohla	Yes Serious	No	Yes but thin	Low Adequate relocation site is very far.	Comparatively Low Partly High (Uluhan)	Structural Countermeasures (1) Coastal Forest (2) Regulation of land-use (3) Tsunami hazard map (5) Tsunami Drill (6) Education (7) Early Warning System
5. Men Sebarta	No	(0)	Yes but thin	Low Adequate relocation site is very far.	Comparatively Low	Non-Structural Countermeasures (1) Coastal Forest (2) Regulation of land-use (3) Tsunami hazard map (5) Tsunami Drill (6) Education (7) Early Warning System
14. Sungai Limau	Yes Serious	Yes Northern Area No (Pasi-Banu, Puloang)	Yes but thin	High (Except Southern Area)	Comparatively Low Partly High (Paser Sungai Limau Pasi-Banu Puloang)	Structural Countermeasures (1) Coastal Forest (2) Regulation of land-use (3) Tsunami hazard map (5) Tsunami Drill (6) Education (7) Early Warning System It was already installed partly in southside of Batang Muras.
15. Batang Gusan	Yes Serious	Yes	Yes but thin	High	Comparatively Low	Non-Structural Countermeasures (1) Coastal Forest (2) Regulation of land-use (3) Tsunami hazard map (5) Tsunami Drill (6) Education (7) Early Warning System

4.3.5 Activities for Capacity Development

The work to formulate the hazard maps is helpful for developing the capacity of Community Participation (C/P) and the staff of the organization related disaster prevention. Therefore, the hazard maps were basically formulated with C/P, and the techniques involved were transferred. The activities for capacity development are as follows:

- Joint field survey
- Workshop

The activities for capacity development in Kabupaten Jember are shown in holding situation of the combination locale survey and the workshop is shown in Table 4.3.10.

Table 4.3.10 Joint Field Survey and Workshop

Date	Time	Location	Participants (CP)	Participants (Study Team)	Agenda
June 19, 2008	13:00–15:00	JICA Study Office in Pariaman city	C/P DISASTER COUNTERMEASURES TEAM	Kato, Hayashi, Fujisawa, Nagasawa, Watanabe	[Workshop] –Introduction of Tsunami Management in Japan
July 3, 2008	7:00–17:00	JICA Study Office in Pariaman city Field survey	C/P DISASTER COUNTERMEASURES TEAM	Kato, Hayashi, Fujisawa, Nagasawa, Watanabe	[Field Trip] –Briefing –Discussion on physical characteristics of each disaster in the field
July 10, 2008	10:00–17:00	Pasir baru Pilubang Ulakan Tapakis river Anai river	Kota Pariaman PU Mr. Nopriyadi Sukri	Kato, Nagasawa	–Joint Survey with C/P –Elevation Survey
July 16, 2008	10:00–17:00	Pasir baru Pilubang Tiram	Kab. PD. Pariaman Mr. Ir. Abd. Halim, M. Si	Nagasawa	–Joint Survey with C/P –Actual condition and future plan of Countermeasures against Tsunami
July 25, 2008	10:00–12:00	JICA Study Office in Pariaman city	C/P DISASTER COUNTERMEASURES TEAM	Nagasawa	[Workshop] Formulation of Tsunami Hazard Map

4.4 Disaster Characteristics of Tsunami Disaster and Countermeasures in Kota Pariaman

4.4.1 Disaster Characteristics of Tsunami Disaster in Kota Pariaman

1) Tsunami Disaster in the past

(1) Past Tsunami Disaster in Sumatra Island

Refer to the section 4.3.1.

(2) Target Tsunamis in Kota Pariaman

The recurrent earthquakes and tsunamis in 1797 and 1833 are fixed as the Target of tsunami disaster in Kota Pariaman in this plan.

As for the detail of explanation of target tsunamis, refer to the section 4.3.1.

A. Distribution of Tsunami Height

The distribution of the target tsunami height along the coast in Kota Pariaman is shown in Figure 4.4.1. Kota Pariaman doesn't have historical tsunami records. As for the flood damage there is only one record that the boats were washed away by the tsunami in 1833, which is not enough to estimate the tsunami height or inundated depth. Therefore, we referred to the records of Kota Padang which is adjacent to the south of Kota Pariaman in order to fix the expected tsunami height of target tsunami. According to the tsunami records of 1797 and 1833 in Kota Padang, the height of 1797 tsunami is 5-10m and the height of 1833 tsunami is 5m or less. In view of these records and other previous study of numerical simulation of target tsunami, the height of target tsunami is fixed 5m above mean sea level in this study. Hence, when the evacuation sites are installed, it is preferable to develop them at the elevation over 10m considering the maximum tsunami height and the uncertainty of assumptions.

Cross section of coast in Pondok Kechamatan Pariaman Utara with target tsunami height is shown in Figure 4.4.2. The Figure indicates that a tsunami can completely overflow the top of sand dune along the coast.

B. Inundated Area

Although there are no records of inundation area of a target tsunami in Kota Pariaman, there are some records in Kota Padang. According to these records, 1797 tsunami intruded about 2km inland from the coast and also 1833 tsunami intruded about 1km inland from the coast. Comparing the elevation of low-lying area of Kota Padang and that of Kota Pariaman, both elevations are considered similar at that time. Thus, it is guessed that there were no big differences in the flood situation and the inundation distance between both regions.

C. Damage due to Tsunami

The historical damage records of target tsunamis are shown in Table 4.3.4. The human and house damage due to tsunamis are small considering the flood situation. The reason was guessed that the center of Padang city with old records was one kilometer more inland from the coast. Additionally, there are no clear records about the number of heavily damaged house and boats.

Currently, there are many houses, offices, schools, rails and station near the coast and the land-use of coastal area have changed from that of 1797 and 1833. Therefore, it is necessary to consider the damages in terms of present land-use, etc.

2) Factors for Damages due to Tsunami

Refer to the section, 4.3.1.

4.4.2 Tsunami Hazard Map in Kota Pariaman

1) Overview of formulation of Tsunami Hazard Map

Refer to the section, 4.2.2.

2) Applicability evaluation of inundation in Kota Pariaman

Table 4.4.1 shows the applicability of each inundation prediction method in Kota Pariaman. Although there is some data for carrying out each method, it is not enough to get the correct results for each method.

Basically, tsunami hazard map shall be developed by Estimation based on ground elevation because it is comparatively simple method to determine the hazard area and the level from only relation between possible tsunami height given by numerical simulation and the ground elevation.

Table 4.4.1 Applicability of Each Inundation Prediction Method in Kota Pariaman

Method	Data for conducting each method	Applicability	Remarks
a. Numerical simulation method	Not enough	Not practicable (for ocean area)	Some previous results exists for ocean area.
b. Level filling method	Not enough	Partly Practicable	There are no accurate data of the height levee/sand dune along the coast.
c. Method based on historical inundation records	Not enough	Not practicable	1797, 1833 Tsunami
d. Estimation based on ground elevation	Enough	Practicable	

3) Indices of Hazard Map for Tsunami Disaster

(1) Inundation area and depth estimated by level filling method (H_1)

Refer to the section 4.2.2.

A. Calculation of water volume intruding from the coast

The water volume intruding from the coast was calculated for 1797 and 1833 tsunamis. The basic data of tsunami was setted based on the records and previous study of numerical simulation of tsunami. They are shown in Table 4.4.2 and Figure 4.4.3. In addition, the temporal alteration of tsunami was modeled as shown in Figure 4.2.13 in order to calculate the water volume overtopping the coast. In this model the wave pattern was approximated by linear regression and the duration time was divided 5 in order to water volume. The calculated amount of the overflow is shown in Table 4.4.2.

Table 4.4.2 Tsunami Data for Calculating Water Discharge Intruding Inland

Item	Value	Source
Tsunami Height	5.0 (m) above mean sea level	Records of 1797 and 1833 Tsunami in Kota Padang
Period	1,260 (sec)	Some previous results of reconstruction of 1797 and 1833 Tsunami by the numerical simulation
Length of coast line intruded by tsunami	14.8 (km)	Topographical data
Height of sand dune	2.5 (m) above mean sea level	Topographical data and Field survey
Number of the waves overtopping the top of sand dune	3 waves	

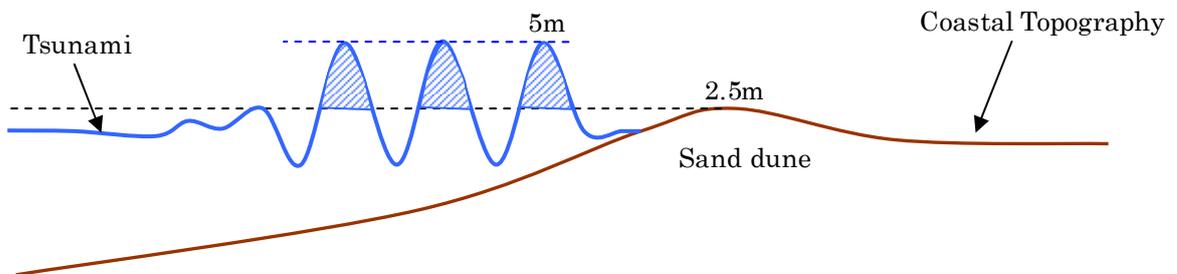


Figure 4.4.3 Cross Section of Model

Table 4.4.3 Water Volume Intruding by Tsunami

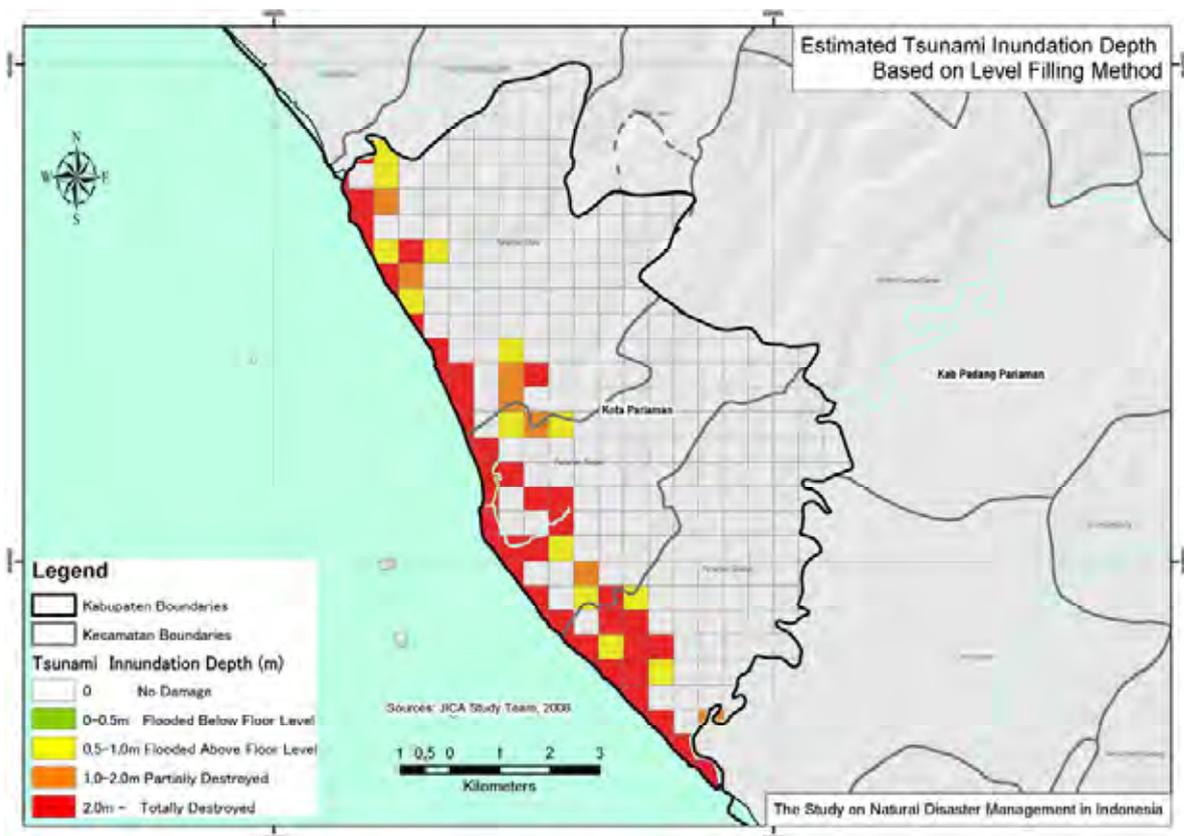
No.	(A) Tsunami Height	(B) Sand dune Height	(A)-(B) -	(D) Q1 (m ² /sec)	(E) Δt (sec)	(D)*(E) Q2 (m ²)
1	1.0	2.5	-1.5	0.00	126	0.00
2	3.0	2.5	0.5	0.55	126	69.03
3	5.0	2.5	2.5	6.13	126	771.75
4	3.0	2.5	0.5	0.55	126	69.03
5	1.0	2.5	-1.5	0.00	126	0.00
Summation				(per 1 wave and 1m)		909.80
				(per 3 wave and 1m)		2729.41

B. Inundation area and depth

The expected inundation map based on water volume overtopping the coast shown in Table 4.4.3 is presented in Figure 4.4.4. The grade and the corresponding scores are as follows:

- i) 2.0m < (Totally destroyed) Score 4
- ii) 1.0m < H ≤ 2.0m (Partially destroyed) Score 3
- iii) 0.5m < H ≤ 1.0m (Flooded above floor level) Score 2
- iv) 0.0m < H ≤ 0.5m (Flooded below floor level) Score 1
- v) H = 0.0m (No damage) Score 0

Level filling method requires a structure or landform that prevents the waves from overtopping it along the coast. However, there are no structures along the coast and the landform such as sand dune doesn't cover all of the coast in Kabupaten Padang Pariaman. Therefore, the expected inundation area might be underestimated at the river mouth where the sand bar is lower than the height (=2.5m) given by the above-mentioned model.



Source: Study Team

Figure 4.4.4 Inundation Area and Depth Estimated by Level Filling Method (H₁)

(2) Inundation area based on historical inundation records (H₂)

There were no historical record found for the past Tsunami disaster in Kota Pariaman.

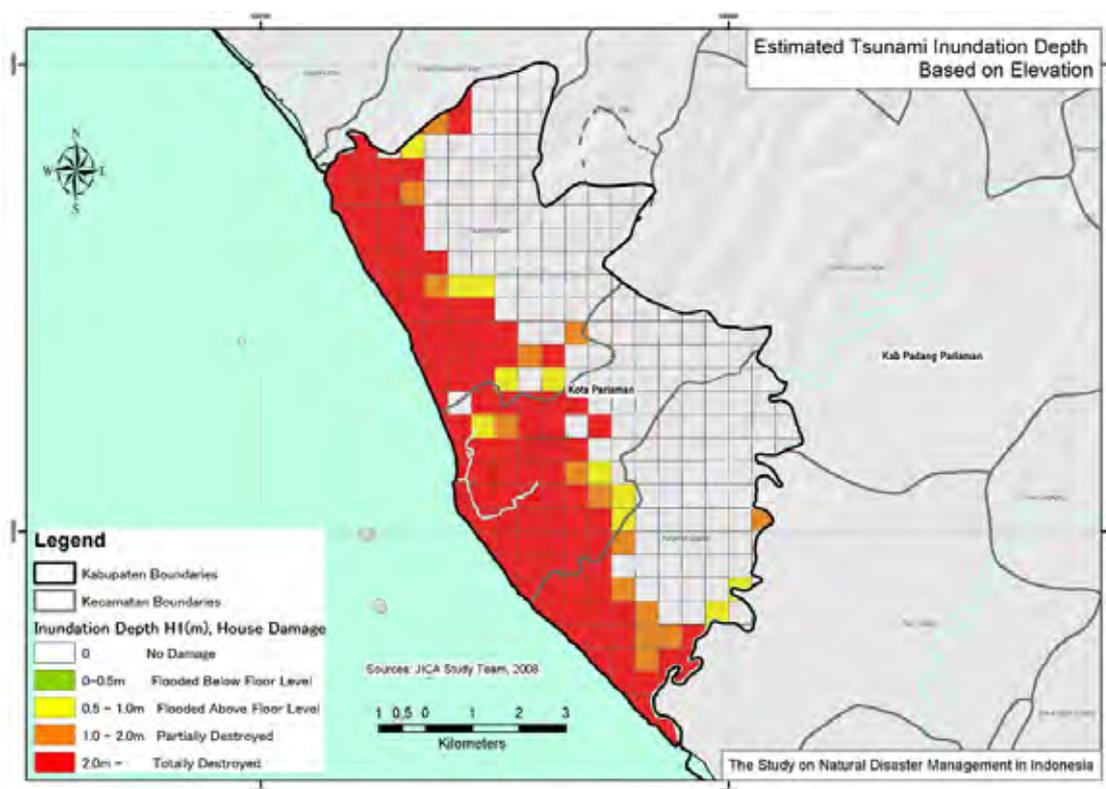
(3) Inundation area and depth estimated based on ground elevation (H₃)

Estimation based on ground elevation is comparatively simple method to determine the hazard area and the level based only on the relation between possible tsunami height given by numerical simulation and the ground elevation³. The maximum run-up height of the recurrent earthquake and tsunami in 1797 and 1833 was 5m or less. Therefore, 5m above sea level was set to standard height of the expected tsunami run-up. The grade and the corresponding scores are as follows:

³ The ground elevation data are made from the calibrated SPOT DEM. It is calibrated using the several actual elevations obtained by the leveling which was conducted by Study Team. A SPOT DEM is a digital elevation model produced by automatic correlation of stereopairs acquired by the [HRS](#) instrument on SPOT 5, which is the fifth satellite in the SPOT series, placed into orbit by an Ariane launcher.

- | | | | |
|------|-------------|-----------------------------|-----------------|
| i) | 2.0m< | (Totally destroyed) | • • • • Score 4 |
| ii) | 1.0m<H≤2.0m | (Partially destroyed) | • • • • Score 3 |
| iii) | 0.5m<H≤1.0m | (Flooded above floor level) | • • • • Score 2 |
| iv) | 0.0m<H≤0.5m | (Flooded below floor level) | • • • • Score 1 |
| v) | H=0.0m | (No damage) | • • • • Score 0 |

Compared with the historical tsunami records of Padang in 1833 which describes that the tsunami intruded at least 1km from the coast, the expected tsunami hazard area has extended more than this. Thus the expected tsunami flood area based on ground elevation is judged to be a little overestimated, which is the dangerous side of the estimation.



Source: Study Team

Figure 4.4.5 Inundation Area and Depth Estimated Based on Ground Elevation (H₃)

4) Tsunami Hazard Map in Kota Pariaman

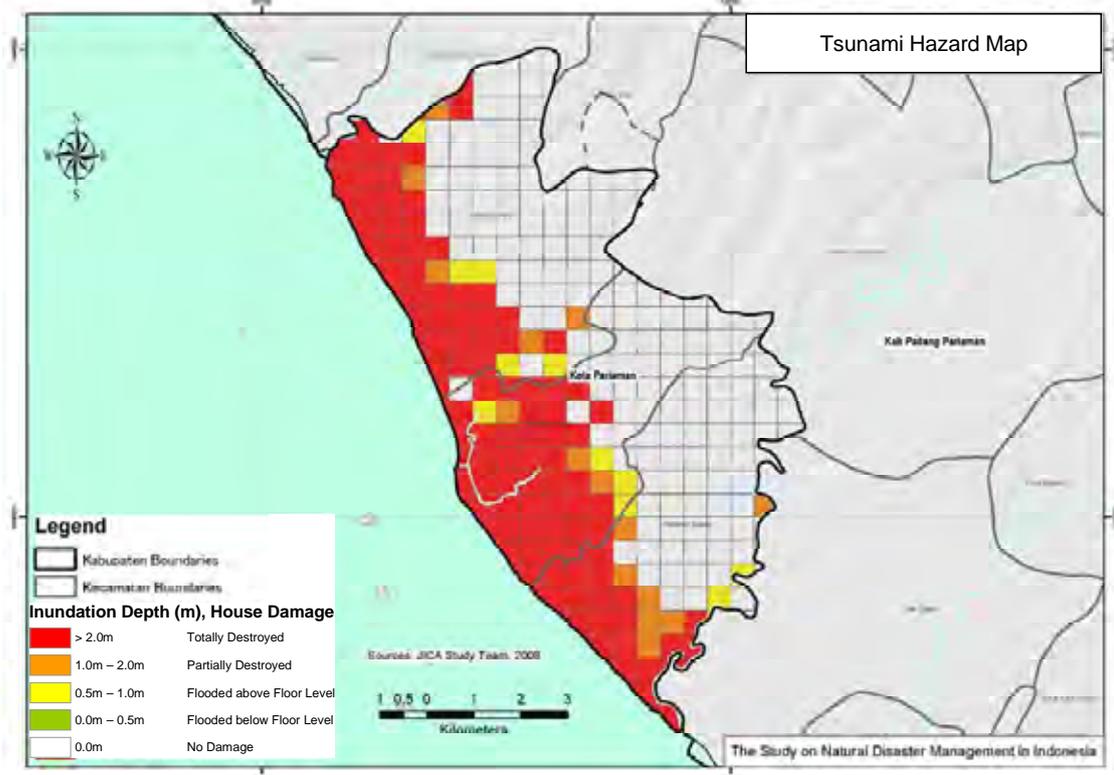
When the above-mentioned three indices are compared, the result on a dangerous side is given in order of the inundation area based on ground elevation (H₃) and the inundation area estimated by level filling method (H₁). Essentially, it is better to adopt the prediction method with the highest accuracy. In this study, the inundation area based on ground elevation (H₃), which gives the result on the most dangerous side and is comparatively easy to formulate, shall be adopted because all

prediction methods have a problem with accuracy which depends on available data and its accuracy. An inundation map with higher accuracy can be formulated after the various data are maintained and available.

The hazard map for tsunami disaster was created based on Expected Inundation Depth (H_3). As indicated in Figure 4.4.6, the values of tsunami hazard were divided into 4 classes as shown below.

- i) $2.0m < H$ (Totally destroyed) Score 4 (Highest hazard)
- ii) $1.0m < H \leq 2.0m$ (Partially destroyed) Score 3 (High hazard)
- iii) $0.5m < H \leq 1.0m$ (Flooded above floor level) Score 2 (Moderate hazard)
- iv) $0.0m < H \leq 0.5m$ (Flooded below floor level) Score 1 (Low hazard)
- v) $H = 0.0m$ (No damage) Score 0 (No damage)

Figure 4.4.6 indicates that the tsunami hazard is concentrated on the low-lying area near the coast. And the expected tsunami flood area has extended from the coast to inland widely in accordance with the vast low-lying area which extends about 2-3km from the coast to inland in Kota Pariaman.



Source: Study Team

Figure 4.4.6 Tsunami Hazard Map

4.4.3 Tsunami Risk Map in Kota Pariaman

1) Basis of Risk Map Creation for Tsunami Disaster

For 4.4.3 1), refer to 4.3.3 Basis of Risk Map Creation for Tsunami Disaster, 1) Basis of Risk Map Creation for Tsunami Disaster.

2) Vulnerability indices

For 4.4.3 2), refer to 4.3.3 Tsunami Risk Map in Kabupaten Padang Pariaman, 2) Vulnerability indices.

(1) Population density (V_1)

The population density was calculated based on the population in the residential area. The population density was divided into five ranks and the scores were set up as follows:

- i) $50 \text{ (pop./km}^2\text{)} <$ Score 5
- ii) $25 \sim 50 \text{ (pop./ km}^2\text{)}$ Score 4
- iii) $10 \sim 25 \text{ (pop./ km}^2\text{)}$ Score 3
- iv) $5 \sim 10 \text{ (pop./ km}^2\text{)}$ Score 2
- v) $\leq 5 \text{ (pop./ km}^2\text{)}$ Score 1

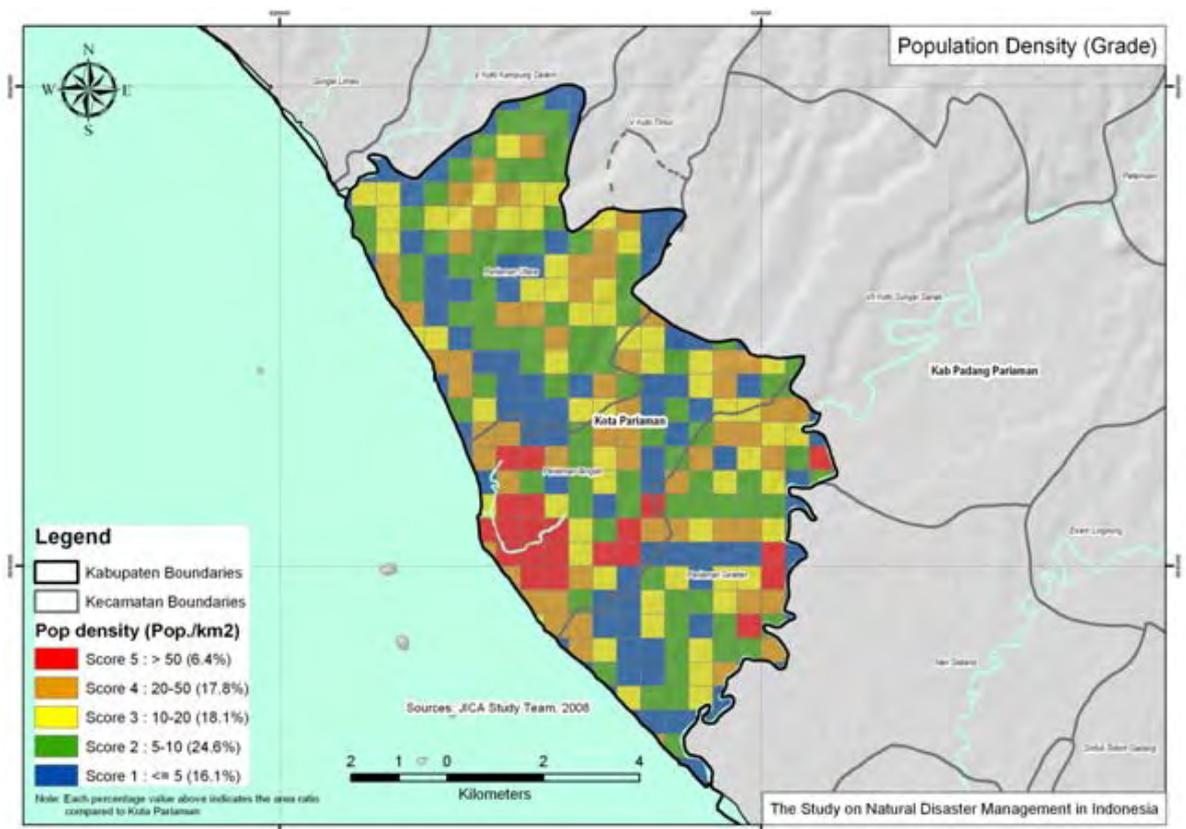


Figure 4.4.7 Population Density (V_1)

(2) Built-up area (V_2)

Built-up area can be regarded as the disaster vulnerable area which was created based on the existing land use map of Kota Pariaman. The classification was ranked by the area of built-up area per a unit (1 km^2).

- i) $50 \text{ (km}^2/\text{km}^2) <$ Score 5
- ii) $30 \sim 50 \text{ (km}^2/\text{km}^2)$ Score 4
- iii) $20 \sim 30 \text{ (km}^2/\text{km}^2)$ Score 3
- iv) $5 \sim 20 \text{ (km}^2/\text{km}^2)$ Score 2
- v) $0 \sim 5 \text{ (km}^2/\text{km}^2)$ Score 1

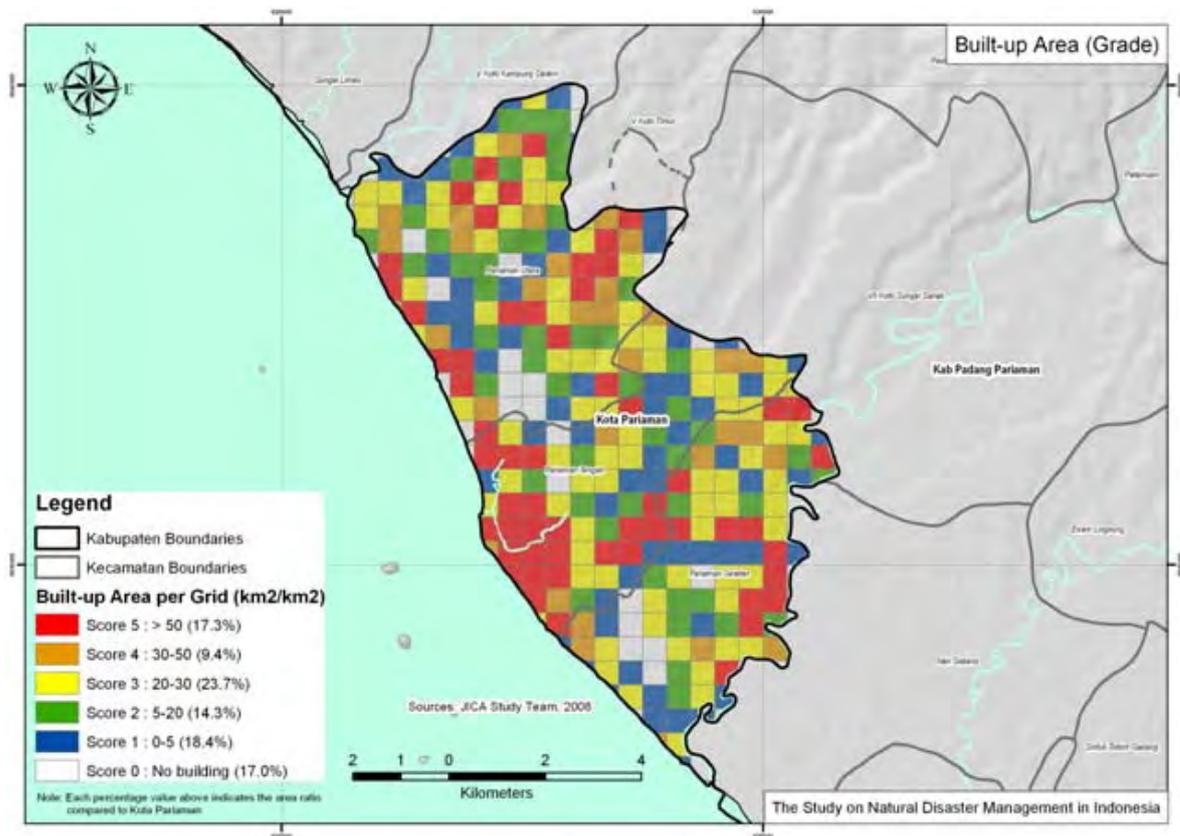


Figure 4.4.8 Built-up Area (V_2)

1) Tsunami Risk Map in Kota Pariaman

Figure 4.4.10 shows the Tsunami Risk map calculated from the formula mentioned above. As indicated in Figure 4.4.10, the values of tsunami hazard were divided into 5 classes indicating relative hazardous classification. “Red” means the highest hazard and “Orange” indicates high hazard. Moderate hazard is shown in “Yellow” while “Green” means low hazard. Further, “Blue” shows the lowest hazard.

Figure 4.4.10 indicates that the tsunami risk is spread out all parts of coastal area in 1-2km width. Especially, the damage risk of Central Pariaman on which the population and the residential area concentrate is very high. Additionally, Central Pariaman has a lot of important installations, which are government buildings such as City Hall, transportation facilities such as railways, roads and bridges, port facilities, fishery port facilities, in the range of 1km from the coastline, Thus the damage risk of infrastructure is very serious in Central Pariaman.

The risks regarding Tsunami disaster were calculated based on Eq.4.4.1.

$$(H_3) \times (V_3) \times (V_1+V_2) \quad \cdot \cdot \cdot \text{Eq. 4.4.1}$$

where, H_3 : Inundation area and depth estimated based on ground elevation, V_1 : Population density. V_2 : Built-up area and V_3 : Distance from the coastline.

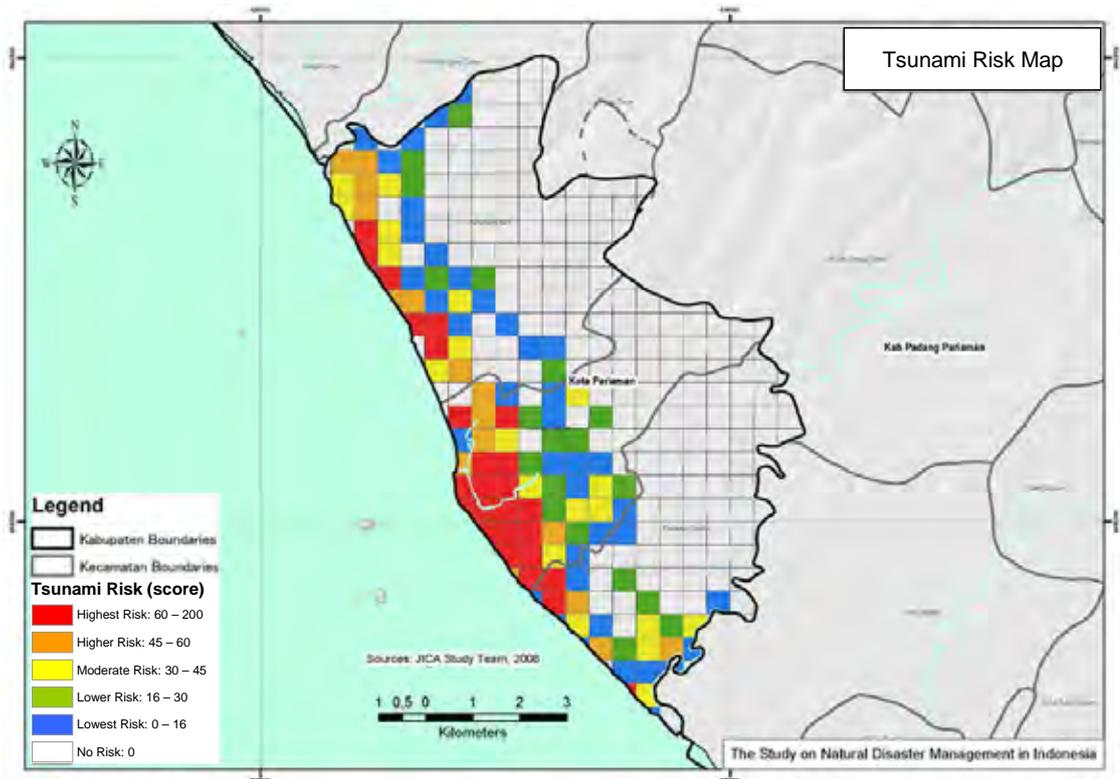


Figure 4.4.10 Tsunami Risk Map

4.4.4 Possible Countermeasures against Tsunami Disaster in Kota Pariaman

1) Recent Tsunami Disaster and the Feature

There are some tsunamis that reached the coast of Kota Pariaman in recent years such as Bengkulu Tsunami in 2007, the most recent one. However, only the tsunamis in 1797 and 1833 caused serious human damage and property damage to the coast of Kota Pariaman.

The following points are given as the topographic features focusing on the places damaged by recent tsunamis such as Bengkulu Tsunami in 2007 and the rising tide which occur often. Almost all of them are low-lying areas in the coastal area, and the damage centered on the geographical weak points such as river mouth where the height of the sand dune is rather low. Moreover, the serious damage occurred due to the rising tide in the area where the sandy beach between the coastline and the residential area is narrow because of erosion etc.

Areas of high Tsunami disaster risk are as follows:

- Beach and Low-lying area(*e.g.* Almost every coastal area)
- The area damaged by rising tide (*e.g.* Pauh Barat, Central Pariaman)
- Eroded narrow beach (*e.g.* Pasir, Pauh Barat, Marunggi, Pasir Sunur, Taluak)
- River mouth and the part where the height of sand dune is lower than that of other coast (*e.g.* Central Pariaman)

2) Countermeasures against Tsunami

The basis to evade tsunami disaster is to go away from the districts mentioned above, since they have high disaster risks. Relocation to higher place, which is one of the most effective means has been recommended for a long time. However, it is often difficult to obtain consent of the residents such as fishermen because a tsunami disaster doesn't occur frequently. Therefore, it is necessary to consider comprehensive measures including the reinforcement of houses against the waves and the evacuation etc. in order to reduce the tsunami hazard. Possible countermeasures against tsunami and its applicability to Kota Pariaman are mentioned as follows.

(1) Structural Countermeasures

A. Tide embankment, Tsunami breakwater, Tsunami floodgate, and River embankment

As structural countermeasures, a few measures are mentioned below.

Tide embankment, Tsunami breakwater, River embankment installed at river mouth, and River embankment to limit the inundation to shore and river run-up physically. But they are not realistic measures for Kota Pariaman because all of them require tremendous amount of investment and time. If a structural countermeasure may be implemented, it is proposed that the road along the coast shall be raised as tide embankment when it is repaired. Or it is proposed that the structural-countermeasures are locally implemented in only high density-populated section near the coast as long-term mitigation.

B. Coastal Forest

All of the coast of Kota Pariaman is sandy beach with small sand dune. Thus, planting of coastal forest is recommended as a countermeasure against tsunami and blown sand, which will also grow the sand dune and enhance the protection function of sand dune on a long term basis. Planting Trees on the beach has already started in Kota Pariaman (Refer to Figure 4.4.11). Also, it is hoped to continue and maintain these coastal forest. Table 4.4.4 shows the past results and future plan of afforestation.



Naras



Pantai Kata



Pantai Kata



Pantai Kata

Source: Study team

Figure 4.4.11 Planted Trees on the Beach

Table 4.4.4 Afforestation

Year	Location			Afforestation	Type	Remarks
	Desa/Nagari	Kecamatan	Kota/Kabupaten			
2006	Talu K	Pariaman Tengah	Kota Pariaman	1,000	Mangrove	residual ratio=30%, in 2008
2006	Mangsung	Pariaman Utara	Kota Pariaman	1,000	Mangrove	residual ratio=60%, in 2008
2008	-	-	Kota Pariaman	4,500	Mangrove	plannig phase

Source: DKP of Kota Pariaman

C. Wave-proof buildings

In a fishing village, it is difficult to obtain the agreement for the relocation to higher place. Thus, other measures such as improving the wave resistance of the present houses are necessary. Present fishing village and improved house are shown in Figure 4.4.12. High-floored house reinforced against waves have been already installed in Kota Pariaman.



Source: Study team

Figure 4.4.12 High-floored House Reinforced against Wave in Ampalu

(2) City planning for tsunami disaster prevention

A. Relocation

As described above, the basis of tsunami countermeasures is to go away from the place where tsunami can hit. The most effective method is to move residences to the place where the tsunami doesn't reach. When relocation is difficult, the ground of the dwelling might be raised. In general, it is not easy to gain consensus for the reasons of economic efficiency and convenience to relocate the residents to higher place. In fact, they return to the original location as years go by for similar reasons. However, it is expected to set up important public facilities such as town office, police station, and fire station, and the facilities for vulnerable people such as hospitals and schools in the high ground where the effect of the tsunami doesn't reach.

B. Regulation of land-use

Effective regulatory measures are needed to enforce reconstruction of wave-proof buildings which are stronger in addition to limit the activity and development in tsunami hazard area by regulation of land-use.

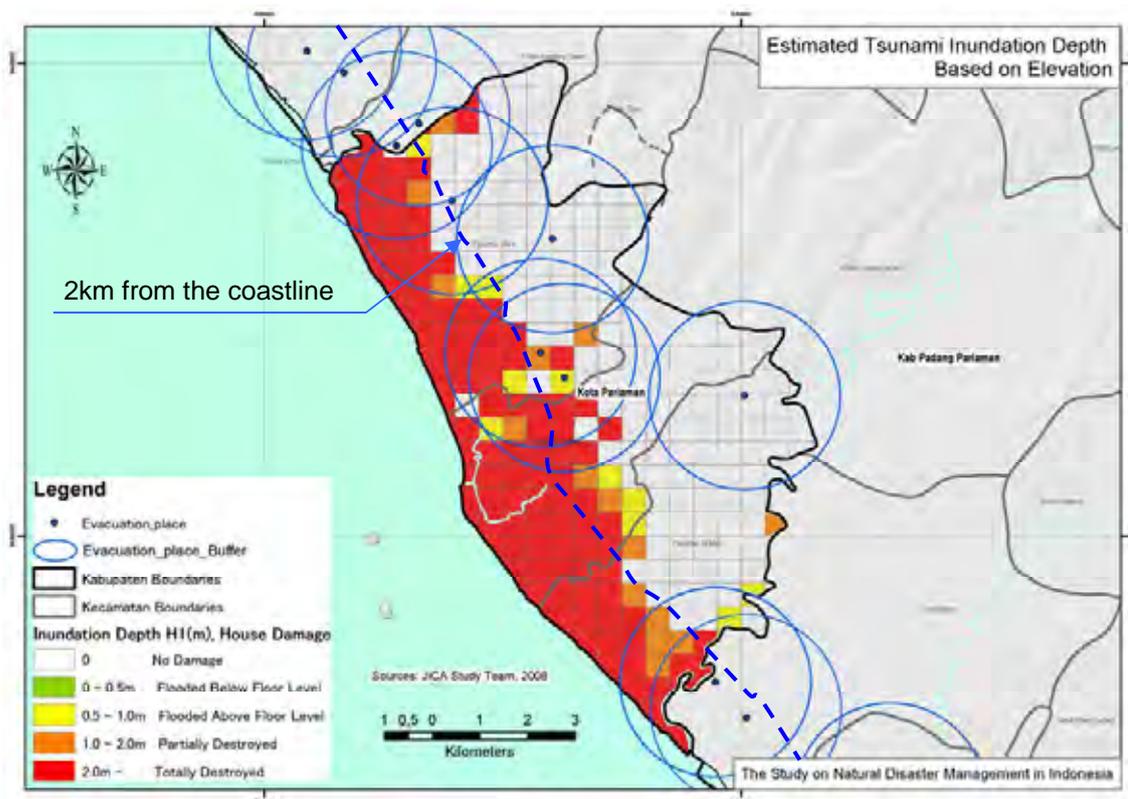
(3) Tsunami hazard map

The hazard map is a very useful tool to offer the information for evacuation and education of tsunami disaster to the residents. Also, it can be used to study the location of evacuation site and development of disaster-prevention facilities. The tsunami hazard map is often made from past tsunami flood results and the results of numerical simulation of tsunami to complement it. In this study, it was made from past flood results of 1797 and 1833 tsunamis. Although tsunamis in 1797 and 1833 were the biggest tsunamis for the coast of Kota Pariaman on record, the number of records is not enough to say that a bigger tsunami will not occur. Therefore, there is a possibility that the inundated area could get larger than the area shown in hazard map, and it is necessary to

make an ingenious hazard map that prevents the residents from having a fixed image for tsunami disaster risk area.

(4) Maintenance of evacuation site and route

Evacuation when a tsunami hits is necessary and it is very important not to go away from tsunami horizontally but to go up to the places which are higher than the tsunami. As will be appreciated from the formulated tsunami hazard map, there is a possibility of deep flooding to the inland when the tsunami overtopping the sand dune along the coast occurs because the area behind the sand dune is a vast low-lying area especially south part of Kota Pariaman. Therefore, it is necessary to decide the evacuation site with enough height and space and to move the evacuation route in the low-lying area near the coast to a higher area. In addition, the residents would rather decide their own evacuation site and route than let the administration decide it. Figure 4.4.13 shows the distribution of evacuation sites designed by Kota Pariaman and the circle indicating the distance to walk in 30 minutes which is available time to evacuate from earthquake. It is because that the tsunami is estimated to reach the coast of Kota Pariaman from the earthquake.



Source: Study Team

Figure 4.4.13 Distribution of Evacuation Site

(5) Tsunami Drill

The target tsunami arrival time to the coast of Kota Pariaman is estimated about 30 minutes according to previous study of numerical simulation. Since the arrival time is not enough to evacuate without preparation, Tsunami drill are necessary to establish procedures for evacuation of the residents near the coast to higher places promptly without any confusion. In Kota Pariaman, a tsunami drill has already been executed, and it is necessary in the future to improve the evacuation plan while using the regional disaster prevention plan and the tsunami hazard map, and tsunami risk map formulated by this study.

(6) Education

In recent years, huge tsunamis which caused serious damage in coastal area of Sumatra have come in groups in 2004, 2005, and 2007. These waves reached the coast of Kota Pariaman but didn't damage anything, and a large tsunami have not occurred offshore of Kota Pariaman after the tsunami in 1797 and 1833. Accordingly, the area offshore of Kota Pariaman has attracted attention as the area which has high possibility that a huge earthquake and tsunami will occur in the future. Therefore, it is continuously necessary to maintain the opportunity for the education about tsunami disaster and hand down the lessons learned from past tsunami disasters.

1) Possible Counter measures for each Kecamatan

The geographical features not only differ greatly but also the adaptability and the priority of the above-mentioned measure are different between the north part and south part in Kabuptaen Padang Pariaman. Therefore, the structural countermeasures and non-structural countermeasures were decided based on the characteristics of the region.

The characteristics of the region are as follows:

- Past coastal disaster (rising tide)
- Evacuation places or high places in 2km from the coast
- Coastal Forest in front of settlement
- Possibility of relocation
- Population Density in the coastal area

The recommended disaster mitigation is separately described as follows.

- Short-term Countermeasures
 - Measures that should be implemented at present
- Long-term Countermeasures

- Measures that should be implemented if it is necessary after the effect of short-term countermeasures is evaluated in the future

This is because structural countermeasures such as tide embankment etc. can have a large impact.

The recommended countermeasures for each Kecamatan are shown in Table 4.4.5.

Table 4.4.5 Possible Countermeasures for each Kecamatan

Kecamatan (Coastfront Kecamatan)	Existing Condition					Possible Countermeasures	
	Past Coastal Disaster (rising tide)	Evacuation places or high places in 2km from the coast	Coastal Forest in front of settlement	Possibility of relocation	Population Density in the coastal area	Structural Countermeasures	Non-Structural Countermeasures
1 North Pariaman	Yes slightly	Yes	Yes but thin	Low Adequate relocation site is very far.	Comparatively High	<p>Short-term Countermeasure</p> <ul style="list-style-type: none"> - Wave-proof building - Some houses are already constructed. - Maintenance of Evacuation site and Route - Installation of Evacuation sign board <p>Long-term Countermeasure</p> <ul style="list-style-type: none"> - Tide embankment 	<p>(1) Coastal Forest</p> <p>(2) Regulation of land-use</p> <p>(3) Tsunami hazard map</p> <p>(5) Tsunami Drill</p> <p>(6) Education</p> <p>(7) Early Warning System</p>
2 Central Pariaman	Yes slightly	No	Yes but thin	Low Adequate relocation site is very far.	High	<p>Short term Countermeasure</p> <ul style="list-style-type: none"> - Wave-proof building - Some houses are already constructed. - Maintenance of Evacuation site, Route - Construction and Designation of adequate building as Tsunami shelter - Installation of Evacuation sign board <p>Long term Countermeasure</p> <ul style="list-style-type: none"> - Tide embankment, Tide barrier - Tsunami floodgate 	<p>(1) Coastal Forest</p> <p>(2) Regulation of land-use</p> <p>(3) Tsunami hazard map</p> <p>(5) Tsunami Drill</p> <p>(6) Education</p> <p>(7) Early Warning System</p> <p>It was already installed partly.</p>
3 South Pariaman	Yes slightly	No	Yes but thin	Low Adequate relocation site is very far.	Comparatively High	<p>Short term Countermeasure</p> <ul style="list-style-type: none"> - Wave-proof building - Some houses are already constructed. - Maintenance of Evacuation site, Route - Construction and Designation of adequate building as Tsunami shelter - Installation of Evacuation sign board <p>Long term Countermeasure</p> <ul style="list-style-type: none"> - Tide embankment 	<p>(1) Coastal Forest</p> <p>(2) Regulation of land-use</p> <p>(3) Tsunami hazard map</p> <p>(5) Tsunami Drill</p> <p>(6) Education</p> <p>(7) Early Warning System</p> <p>It was already installed partly.</p>

4.4.5 Activities for Capacity Development

Refer to 4.3.5.