

## The Influence of Coastal Conditions to Tsunami Inundation of Bima Bay, West Nusa Tenggara

### *Pengaruh Kondisi Pantai Terhadap Landaan Tsunami di Teluk Bima, Nusa Tenggara Barat*

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**ABSTRACT:** Area along the coast that includes the territorial waters of the Bima Bay, West Nusa Tenggara, is prone to tsunamis, evidenced by the historical tsunamis record in 1815 due to the volcanic eruption of Tambora, 1818, 1836 and 1992 caused by earthquakes associated with tectonic system in the north of the island of Sumbawa, and 1892 were sourced from a distant source. Based on the coastal characteristics, the research area was divided into four types of beaches, namely: Steep rocky beach; Coastal walled plain; Flat coastal mangroves; and Flat sandy beaches. According to the lateral measurement, houses were built in the plains with a minimum height difference of 0.04 m at Rababuntu beach and a maximum of 22.63 m in New Asakota area. The settlement closest distance to the coastline is 10.3 m in Rababuntu, while the farthest extent is at Kawananta 194.58 m from the shoreline. The local bathymetry range between 1 and 42.5 m, where the inside of the very shallow waters of the Bay of Bima, gradually steeper at the mouth of the bay to the open sea. This conditions will influence the wave when entering the bay. It will come with large enough speed at the mouth of the bay, spread along the coastal waters of the eastern and continue spreading to all parts with the diminishing velocity, but the height increasing when it reaches shallow water, especially in the waters of the western Gulf of Bima. Several factors can affect the amount of risk that would be caused by the tsunami, in the research area include are: (1) The research area is located in an enclosed bay; (2) The local sea floor depths around the bay is relatively shallow waters; (3) Coastal characteristics of the research area is dominated by a gently sloping beach morphology with low relief, especially in the area of ??Bajo, Rababuntu and Bontokape and other beaches in the city of Bima; (4) Residential location very close to the shoreline; (5) Minimal vegetation cover; and (6) The presence of the artificial protective are inadequate. Based on tsunami modeling using the 1992 Flores earthquake parameter which is placed perpendicular to the research area obtain the maximum tsunami height around 4-5 m at Sowa and Kolo, near to the mouth of Bima Bay, while the minimum is at Kalaki, about 0,2 m which is at the inner bay.

Keywords: Tsunami, coastal characteristics, bathymetry, factors influenced to tsunami inundation.

**ABSTRAK:** Lokasi di sepanjang pantai yang mencakup wilayah Perairan Teluk Bima, Nusa Tenggara Barat, rentan terhadap tsunami, dibuktikan oleh catatan sejarah tsunami tahun 1815 karena letusan gunung berapi Tambora, 1818, 1836 dan 1992 disebabkan oleh gempa bumi yang terkait dengan tektonik sistem di bagian utara pulau Sumbawa, dan 1892 yang bersumber dari sumber yang jauh. Berdasarkan karakteristik pantai, daerah penelitian dibagi menjadi empat jenis pantai, yaitu: Pantai terjal berbatu; Pantai datar berinding; Pantai datar berbakau; dan Pantai datar berpasir. Berdasarkan hasil pengukuran kemiringan pantai secara lateral, rumah dibangun di dataran pantai dengan perbedaan ketinggian minimal 0,04 m di Rababuntu dan maksimal 22,63 m di daerah Asakota Baru. Jarak terdekat bangunan terhadap garis pantai adalah 10.3 m di Rababuntu, sedangkan jarak terjauh adalah di Kawananta 194,58 m dari garis pantai. Rentang batimetri di perairan Teluk Bima berkisar antara 1 dan 42,5 m. Bagian dalam Perairan Teluk Bima sangat dangkal, secara bertahap makin dalam dan curam di mulut teluk hingga ke laut terbuka. Kondisi ini akan mempengaruhi gelombang ketika memasuki Teluk. Gelombang akan datang dengan kecepatan yang cukup besar di mulut teluk, tersebar di sepanjang perairan pantai timur dan terus menyebar ke seluruh bagian dengan kecepatan berkurang, namun ketinggian meningkat saat mencapai perairan dangkal, terutama di perairan barat Teluk Bima. Beberapa faktor yang dapat mempengaruhi jumlah risiko yang akan disebabkan oleh tsunami, di daerah penelitian meliputi: (1) Daerah penelitian terletak di teluk tertutup; (2) Kedalaman dasar laut di sekitar Teluk adalah perairan yang relatif dangkal; (3) Karakteristik Pantai daerah penelitian didominasi oleh pantai morfologi landai dengan relief rendah, terutama di daerah Bajo, Rababuntu dan

Bontokaŕe dan pantai-pantai lainnya di Kota Bima; (4) Lokasi perumahan sangat dekat dengan garis pantai; (5) Minimalnya vegetasi penutup; dan (6) Keberadaan pelindung buatan tidak memadai.

**Kata Kunci:** Tsunami, karakteristik pantai, batimetri, faktor yang mempengaruhi landaan gelombang tsunami.

## INTRODUCTION

Sumbawa Island is one of the islands which belong to the region of West Nusa Tenggara. Sumbawa is a part of the cluster of islands located in the northern of Indian Ocean and located at the south of the Flores Sea. Bima city is the capital of Bima district, located at the coast around the bay, named the Bima Bay.

Bima Bay has areas along the coast which has a very dense urban population with all activities and districts serve the residential areas, industrial estates, and being a tourism destination, both domestic and foreign.

Tectonically, the Bima Bay region is affected by the tectonic system of back arc thrusting located at the Flores Sea (Hamilton, 1979), which is shown by seismic activities dominated by shallow depth earthquakes. Seismic activity which has a shallow depth hypocenter under the seafloor with a magnitude of more than Mw 7.0 will have the potential to cause a tsunami.

Historically, the Bima Bay was experienced hit by the tsunami caused by earthquakes originating from other regions, such as the December 12, 1992 earthquake has epicenter in the north of Flores, with a magnitude of 7.8 on the Richter Scale, at a depth of 28 km below the sea floor. Other tsunami ever hit occurred in 1818 and two events in 1836 due to the eruption of Tambora Volcano in 1815 also informed has led to sea level rise in the bay of Bima.

Mapping of coastal characteristics was conducted and beach profile measurements was carried out to get information on coastal conditions, its profiles and other data were collected to understand about the potential vulnerability owned by the bay of Bima region in term of tsunami hazard. The results of field data will combine with seismic data, tsunami modeling and other data displayed in a tsunami-prone area map that illustrates the vulnerability of the research area to the harmful of a tsunami. References used in the determination of tsunami vulnerability region is also based on the modeling results with the model parameters of Flores earthquake in 1992 which is placed perpendicular to the research area.

The research result is expected to be an initial data to provide an overview as an effort to mitigate impacts that may be caused by the tsunami and particularly is to provide contributions for local government in spatial planning for tsunami-prone regions.

The research area is the area along the coast that belongs to the region and the city of Bima, Sumbawa Island, West Nusa Tenggara Province, which is geographically located between coordinates of 118° 00'E-119° 00'E and 8° 00'S-9° 00'S. Administratively, the Bima Bay area is bordered by the Ranggo sub-district and Dompu District on the west, Flores Sea to the north, Wera sub-district on the east and the Tongga sub-district to the south (Figure 1).

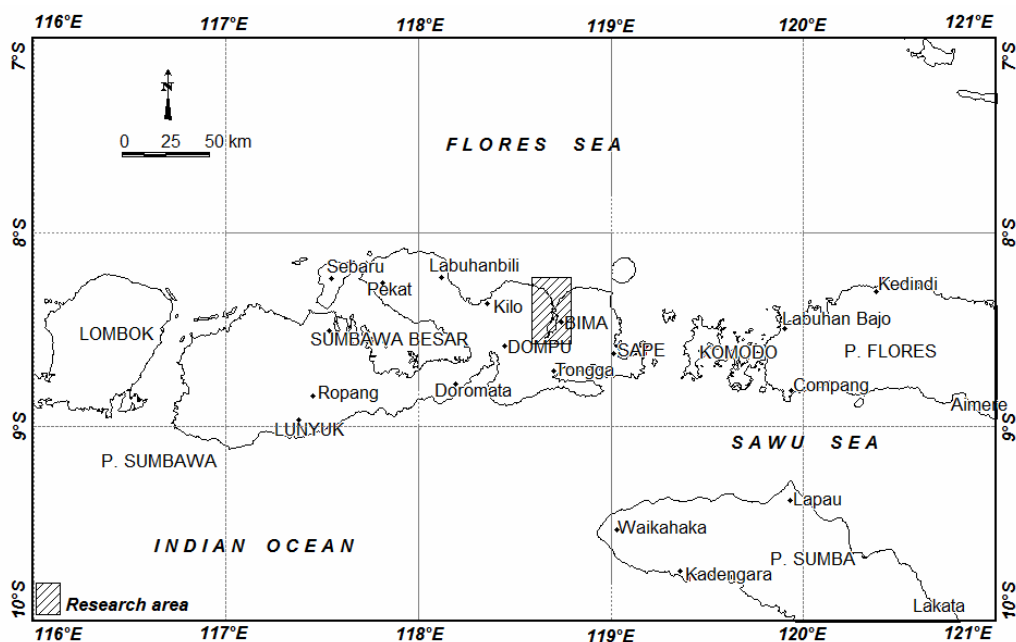


Figure 1. The research area (inset)

## Regional Geology

According to Satyana (2010) Sumbawa island is an oceanic island which is emerging from an isolated oceanic crust of the continental crust as a result of the subduction of the oceanic to oceanic crust. Oceanic islands in Nusa Tenggara formed in the volcanic arc and non-volcanic, and Sumbawa Island was an oceanic volcanic islands. The ages of the oceanic islands in Nusa Tenggara islands are generally younger than the mid-Miocene (15 million years).

The Sumbawa Island is the inner island arc which has a volcanic in nature (inner volcanic island arc). All these island arcs in the structure is the simplest in Nusa Tenggara, an oceanic volcanic islands young (<15 Ma), often overgrown with coral reefs at the edges or sedimentary material derived from the erosion of the main part of the island and piled (accumulated) in between the tongues of lava and other volcanic material extrusion.

Tambora volcano (2850 m) as well as Rinjani volcano (3726 m) in Lombok is a second generation product of volcanoes moving to the north. It can be concluded that the volcanic arc in the most eastern Sunda arc system derived from subduction between the Indian Ocean crust with the oceanic crust which restricts Sundaland in the southeast, so that the island of Sumbawa be ideal an island arc (different from the Sumatra-Java-Bali which is a product of subduction of oceanic crust under the edge of the Eurasian continental crust-transition).

The boundary between the continental crust, Eurasian transition and oceanic crust that limits Sundaland in the southeast is the Lombok Strait, a deep waterway (Satyana, 2010).

Based on hillslope and lithology, the Bima Bay morphology and its surroundings are grouped into two morphological units, those are intermediate hills and flatland morphological units. The intermediate hills morphological unit is characterized by a gently sloping hills that slope ranges from 2% -15% were composed by the Tertiary volcanic rocks, in the form of breccia, lavas and tuffs. The flatland morphological is scattered among the surrounding hills, composed by Quaternary to recent alluvium.

Seismicity of Sumbawa island and its surroundings are affected by two major tectonic system and the system of active subduction zone of the Indo-Australian plate against the Eurasian plate is moving relative to the north, and thrusting behind the arc (back arc thrusting) in the Flores Sea which is moving relative to the south. This condition causes the islands of Sumbawa and surrounding areas have a very intense seismic activity.

Based on the depth the Indo-Australian plate (Wadati-Benioff Zone) which is perpendicular to the

Sumbawa island, the island has depth between 100 and 200 km (Kertapati et al., 1998). That is why earthquakes in Sumbawa Island generally has a shallow to medium depths, between 100 and 200 km, with focal mechanisms trending east-west directions and has maximum compression of north-south direction.

In general, earthquakes the northern of Bima bay region showed reverse fault mechanism with the fault strikes of west - east or follow the tectonic system of back arc thrusting which has also reverse fault mechanisms. Mostly the maximum compression comes from the north and south.

This condition shown that that the Bima bay and its surrounding getting a substantial contribution from the tectonic system of back arc thrusting compared with the tectonic system of subduction zone in the south of Sumbawa island represented by earthquake focal mechanism retrieved from Harvard CMT Catalog (2011) (Figure 2).

According to the tsunami catalog of Soloviev and Go (1974), tsunamis those impacted the research area (Table 1) are caused by different sources, such as earthquakes and volcano eruptions.

According to Table 1, tsunamigenic which is influenced to the coast of Bima Bay, are come from the northern part of research area. Especially the tectonic system of back arc thrusting, volcano eruptions, and far field tsunami from distance sources. While the southern source of Sumbawa island will not give significant impact to the Bima Bay.

## Methods

### Coastal Characteristics Mapping

Secondary data was collected prior to implementation of field activities in the Bima Bay, West Nusa Tenggara such as geological map, bathymetric maps, seismic data, and the historical tsunamis .

The aim of coastal characteristics mapping is to determine the condition and coastal dynamics. Data collection was performed visually throughout the research area. Some of the data were taken, including: coastal morphology, coastal geology, shoreline characteristics such as vegetation, coastal structures and dominantly energy which influence of coastal area (Dolan et al, 1972).

Measurements of laterally beach profile were performed using Total Station equipment. Horizontal distance measured is the distance used coastal plain residents in performing activities, placing settlements and other coastal structures to the average sea level (mean sea level); get the height difference of the coastal plain and the sea front center seat shoreline slope (slope). The measurement results will be corrected by

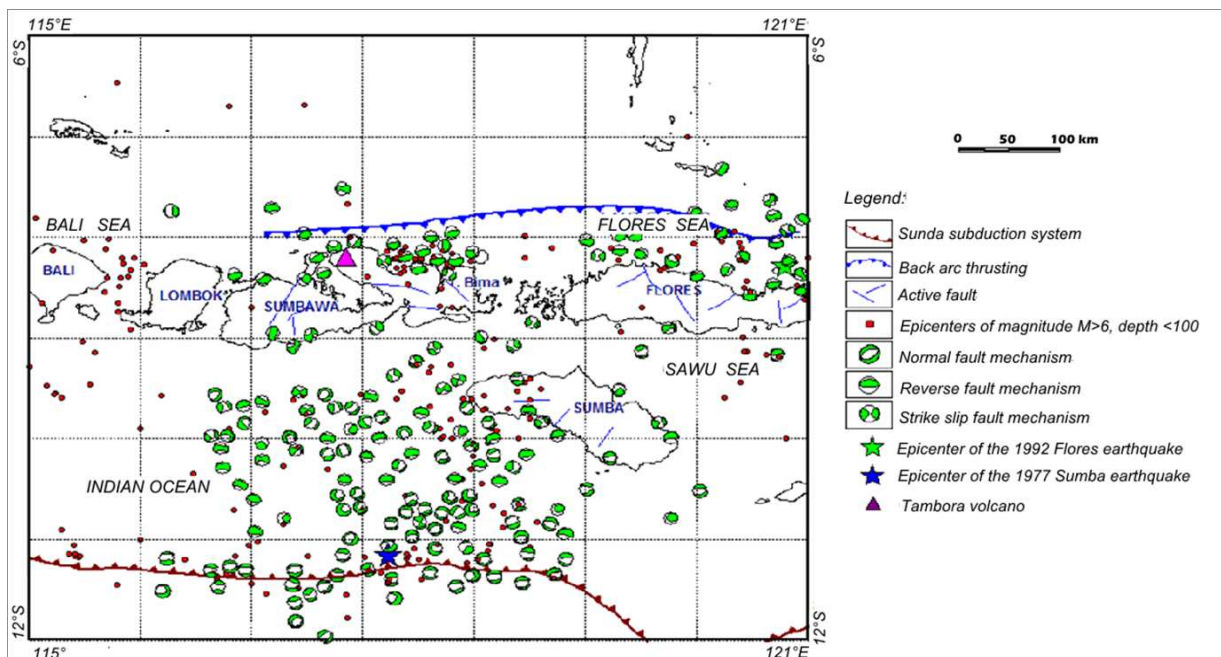


Figure 2. Seimotectonic Map of West Nusa Tenggara (Yudhicara et al., 2011)

Table 1. Historical tsunamis those attacked Bima and its surroundings (Soloviev and Ch. N. Go, 1974)

No.	Events	Descriptions
1.	10 April 1815	The eruption of Mount Tabora has caused sea-level rise in the waters of Sumbawa with a height of about 0.5 to 3.5 m. A large wave burst into the mouth of the river and immediately jumped back into the sea. In many places houses and trees were washed away. On the beach Bima, boats torn and detached from the anchors. Tsunami heights observed at Mount Satonda estimated to reach up to 10 m.
2.	8 November 1818	An earthquake with a period that lasted for ~ 3 minutes occurred in Bima and caused an increase in sea level of 3.5 m, based on information from Wichmann (1918) and Cox (1970), a tidal wave was flooded the town of Bima on that event.
3.	5 March 1836	Strong earthquakes followed by a tidal wave that flooded the Bima City locally.
4.	28 November 1836	A powerful earthquake in the city of Bima followed by rising sea levels.
5.	7 June 1892	Volcanic Eruption of Awu in Sangihe Islands has caused the far field tsunami and affected to the city of Bima approximately 9-11 hours after the eruption. Tsunami was <i>remotely sent</i> by sea and felt by the people of Bima which is located along the coast.

the value of mean sea level which are taken from the tidal data for investigations in the field.

**Tsunami modeling**

Tsunami modeling includes the preparation of the calculations, extract and analyze data on bathymetry, determination of seismic parameters and then the two inputs are used in modeling the propagation of tsunami to get the data tsunami height and distance from the waves reach the shoreline. Then the results of this modeling combined with field data and the basis for determining the level of tsunami-prone areas in the research area.

Land topography and bathymetry data were used as input were obtained from global Shuttle Radar

Topography Mission (SRTM) and General Bathymetric Chart of the Ocean (GEBCO) with an accuracy of 1 minute. The first step is extracting the global bathymetric data in accordance with the limit calculation, interpolated to have smaller grid sizes, and put into the tsunami modeling program. Bathymetry data were divided into three grid sizes, such as grid A, grid B and C. Grid A is the coarser, B is finer than A grid size with accuracy rather detailed. is for the area to be calculated tsunami heights and, while C is the finest, which is include to the area of Bima Bay.

The source used for tsunami modeling referred to a source parameters of Flores earthquake (December 12, 1992) ; (Figure 3), but location is shifted perpendicular to the research area. The following are the parameters (Table 2).

Tabel 2. Flores Earthquake parameter

Earthquake Parameter	Values
Reference point	118.17°E and 7.71°S
Rupture Length (km)	95
Rupture Width (km)	60
Depth (km)	20.4
Strike (°)	80
Dip (°)	40
Vertical displacement (m)	5.2
Rake (°)	95

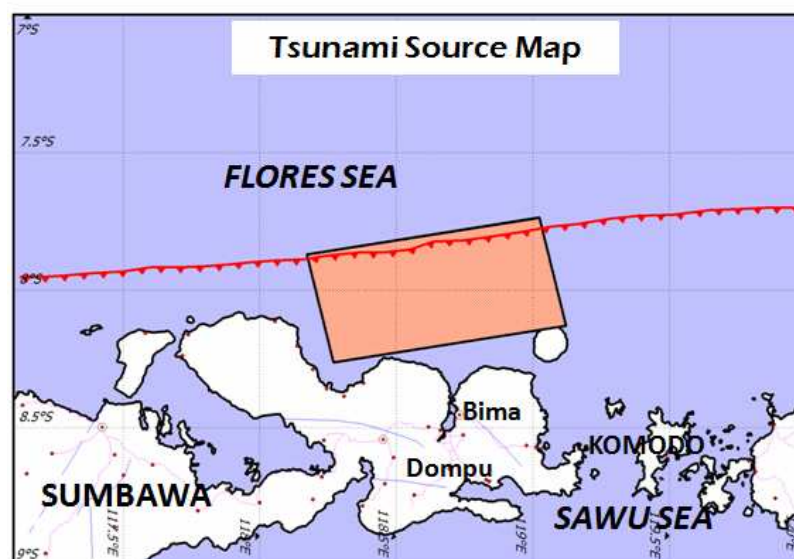


Figure 3. Tsunami source model (orange box) associated with back arc thrusting system (jagged line)

The next step is to enter the input parameters and land - ocean topography data into a numerical program that uses the basic shallow water theory. Shallow water theory is based on two basic equations, those are equation of motion and equation of continuity:

$$\frac{\partial u}{\partial t} + u \frac{\partial u}{\partial x} + v \frac{\partial u}{\partial y} + g \frac{\partial \eta}{\partial x} + \frac{\tau_x}{\rho} = 0 \quad (1)$$

$$\frac{\partial \eta}{\partial t} + \frac{\partial [u(h + \eta)]}{\partial x} + \frac{\partial [v(h + \eta)]}{\partial y} = 0 \quad (2)$$

$$\frac{\partial v}{\partial t} + u \frac{\partial v}{\partial x} + v \frac{\partial v}{\partial y} + g \frac{\partial \eta}{\partial y} + \frac{\tau_y}{\rho} = 0 \quad (3)$$

Where  $x$  and  $y$  is horizontal coordinate,  $t$  is time,  $h$  is water depth,  $\eta$  is water height movement above sea level.,  $u$  and  $v$  are velocity of water particles in  $x$  and  $y$  directions,  $g$  gravitational acceleration,  $\frac{\tau_x}{\rho}$  and  $\frac{\tau_y}{\rho}$  are seabottom friction in  $x$  and  $y$  direction.

Seabottom friction are expressed by:

$$\frac{\tau_x}{\rho} = \frac{1}{2g} \frac{f}{D} u \sqrt{u^2 + v^2} \quad \text{and} \quad \frac{\tau_y}{\rho} = \frac{1}{2g} \frac{f}{D} v \sqrt{u^2 + v^2}$$

Where  $D$  is total depth from sum of  $h + \eta$  and  $f$  is friction coefficient. This program is refer to Manning roughness ( $n$ ):

$$n = \sqrt{\frac{fD^{1/3}}{2g}}$$

seabottom roughness is expressed by

$$\frac{\tau_x}{\rho} = \frac{gn^2}{D^{4/3}} u \sqrt{u^2 + v^2} \quad (4)$$

and

$$\frac{\tau_y}{\rho} = \frac{gn^2}{D^{4/3}} v \sqrt{u^2 + v^2} \quad (5)$$

The next step is to introduce the release of the flux in the  $x$  and  $y$  directions, in  $M$  and  $N$  are associated with velocity  $u$  and  $v$ .

$$M = u(h + \eta) = uD \quad \text{and} \quad (7)$$

$$N = v(h + \eta) = vD$$

Integrated equation (1) and (3) from seabottom to the surface, then *shallow water theory* resulted from flux release will be as the following:

$$\frac{\partial \eta}{\partial t} + \frac{\partial M}{\partial x} + \frac{\partial N}{\partial y} = 0 \quad (8)$$

$$\frac{\partial M}{\partial t} + \frac{\partial}{\partial x} \left( \frac{M^2}{D} \right) + \frac{\partial}{\partial y} \left( \frac{MN}{D} \right) + gD \frac{\partial \eta}{\partial x} + \frac{gn^2}{D^{7/3}} M \sqrt{M^2 + N^2} = 0 \quad (9)$$

$$\frac{\partial N}{\partial t} + \frac{\partial}{\partial x} \left( \frac{MN}{D} \right) + \frac{\partial}{\partial y} \left( \frac{N^2}{D} \right) + gD \frac{\partial \eta}{\partial y} + \frac{gn^2}{D^{7/3}} N \sqrt{M^2 + N^2} = 0 \quad (10)$$

Those third equations are used in the calculation of the tsunami modeling (Ortiz and Tanioka, 2005).

## Results

### Coastal Characteristics

In general, the coastal area is composed by alluvium, which is divided into three types, namely brownish yellow sandy beaches, white sandy beaches and grayish iron sandy beaches.

In hilly terrain composed by old volcanic rocks dominated by breccias, tuffs, lavas and sedimentary rocks, commonly used as arable land. On the slopes generally encountered shrubs, grassland and reeds used for herding cattle. In this area the water is rather hard to find because the area is bumpy, the depth of dug wells are less than 3 m from the local water table.

Based on geological conditions, morphology and topography, coastal relief, vegetation and community activities, the research area was divided into four types of beaches, namely: Steep rocky beach; Coastal walled plain; Flat coastal mangrove; and Flat sandy beach.

### Steep rocky beach

The first beach type occupies the northern part of the research area, morphology are steep undulating hills that form in this region as composed by old volcanic products (Figure 5). Population mostly built their houses far away from the coast, usually occupies the hill slope. Such as at Kawananta and New Asakota villages. Buildings constructed by wood with stage type on the base.

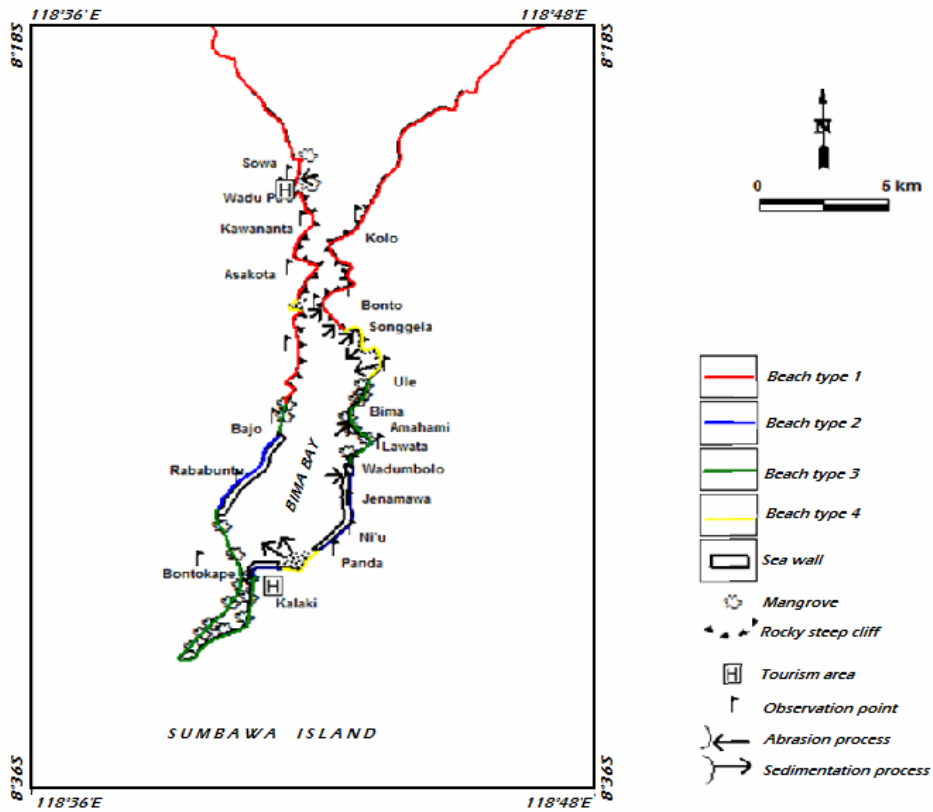


Figure 4. Coastal characteristic map of Bima Bay (Yudhicara et al., 2011).



Figure 5. Houses at New Asakota built on the hillslope.

Vegetations are mangrove, bushes, cattapa, and other hard trees. The coastal dynamics in this region are abrasion to stable. The beach slope ranges from 1 to 7°. Some parts of the beach have sea walls with a height of 1-1.5 m, serves as a protective barrier from the waves and beach erosion.

#### Coastal walled plain

The second beach type has low land morphology, partly very close to the sea water. Mostly have abrasion coastal process (Figure 6). The beach has sea wall with height of 1 to 2 m. The population mostly built their

houses near to the sea. So it is very vulnerable to the dangerous come from the ocean waves.

The coastal area are usually used as tourism area, such as at Kalaki beach (Figure 7). Vegetation such as angšana, randu, waru dan a little bit of mangroves.

This beach type occupies area in the southern part of the research area, from the Bajo village, beach Kalaki, Panda, Ni'u, Jenamawa, Lawata and Amahami (Figure 7). The beach has been reclaimed as thick as ~ 2m, so that the initially narrow beach becomes wider, it has caused the origin sea wall has been displaced. Vegetation are gingko biloba, acid and coconut. There is a small wooden boats moored at this location.



Figure 6. The second beach type at Amahami



Figure 7. Tourism area at Kalaki beach.

### Flat Coastal mangrove

This third beach type is composed by organic silt and sandy mud, has vegetation of mangrove. Covering the southern regions of the Bima Bay and Bima River estuary area (Figure 8).

Morphology is generally sloping beach with low relief and swampy. Settlements are behind the road or even far from the beach. Coastal dynamics is stable up to abrasion. In some place we could find sea wall with a height of 1 m, but not in a good condition. Residents use the land as fields and ponds (Figure 9A). There are salt ponds at Bontokape (Figure 9B). Houses are made ??by



Figure 8. The third type at dusun Rababuntu.





Figure 9. Salt ponds (A) and houses (B) at Bontokape village

wood with a bottom made of the stage, which serves as preventing the entry of sea water into the house at high tide.

**Flat Sandy Beach**

The beach is characterized by brownish sand, fine to coarse sand size, indicates that the area is close to the sediment sources (Figure 10). This area occupies the river mouth of Daru and some east coast (near the river Raba).

The beach has a ramps up wavy morphology, composed by a fine gray sand which is containing shells, gravel, gravel to boulders, with a beach slope of 1°. Hills behind the beach are composed of volcanic rocks.

People are generally makes their home near to the beach, even very close to the shoreline. majority of the population work as fishermen, characterized by many

fishing boats moored on the beach. The vegetation is very less, some consisting of coconut and Angsana. Beach dynamics is accretion. Most beaches have been reclaimed as found in Bonto village. Sea wall are find at some places as high as 1-2m.

**Land Uses**

Land use in the research area are used such as a tourism area like in Kalaki and Wadu Pa'a, port in Bima city which is accompanied by the fish auction (TPI), steam power plant found in the east end of the city of Bima, salt ponds in the South Bay of Bima, including in Bontokape. Settlements scattered along the coast of the research area.

**Beach Profile Measurements**

Coastal morphology is one of the factors that can affect the run-up height of the tsunami wave as it



Figure 10. The fourth type beach at Bonto village.

Table 3. Results of measurements of lateral beach (Yudhicara, et al., 2011)

No.	Name of Location	Position		BeachSlope (°)	Horisontal Distance (m)	Height Diff. (m)
		Long (°E)	Lat (°S)			
1	Sowa	118.69047	08.36114	7	22.53	3.51
2	Southern Sowa	118.69106	08.37134	1	60.85	4.31
3	Kawananta	118.69533	08.37875	2-3	194.58	10.28
4	New Asakota	118.69049	08.39771	4	92.16	22.63
5	Bajo	118.68507	08.45571	2	38.22	1.3
6	Rababuntu	118.67232	08.47954	12	10.3	0.04
8	Kalaki Beach	118.68094	08.51693	2	17.85	1.47
9	Panda	118.69050	08.51753	2	39.12	1.1
10	Nipa	118.79765	08.28962	4	53.83	3.85
11	Ambalawi	118.80692	08.28640	6	27.83	3.25
12	Mawu	118.83599	08.28204	6	51.81	5.7
13	Sangiang	118.93338	08.29524	3	21.96	1.67
14	Ule	118.72458	08.43515	5	42.41	3.53
15	Ule-Asakota	118.71719	08.42783	3	40.15	2.58
16	Songgela	118.71396	08.42421	4	66.37	4.97
17	Northern Songgela	118.70884	08.42019	4	17.04	1.78
18	Bonto	118.71207	08.40608	3	38.56	2.49
20	Kolo	118.71471	08.37696	3	55.46	3.62
21	Panda	118.70663	08.50686	2	39.76	1.54
22	Eastern Ni`u	118.71268	08.49881	7	11.96	1.97
23	Jenamawa	118.71160	08.48736	4	25.2	2.25
24	Wadumbolo	118.71086	08.47696	4	14.73	1.51
25	Lawata	118.71396	08.47337	15	27.25	2.77
26	Amahami	118.72273	08.46570	9	48.43	2.48
28	Port of Bima	118.71381	08.44753	0.2	25.31	0.67

reaches the mainland. The creeping wave flatness of the beach followed by a relatively fast speed and sweep, knocking down the houses and dragging objects to the mainland. Table 3 shows the results of beach profile measurements.

Based on the results, shows that the subsidence in the research area is generally found in the plains with a minimum height difference of 0.04 m at Rababuntu beach and a maximum of 22.63 m in New Asakota area. The subsidence closest distance to the coastline is 10.3 m in Rababuntu, while the farthest extent is at Kawananta 194.58 m from the shoreline. This condition indicates that the ideal settlement which is safe from the tsunami wave is Kawananta, while the area is prone to tsunamis is Rababuntu. The average beach slopes are ranged from 1° to 7°.

Observation results will include defining the coastal shape, coastal morphology, and coastal geology. Beach shape elongated without curvature would have run up heights lower than gulf beaches and pockets. Beaches with gentle sloping morphology can produce

inundation distances farther ashore than the steep and rugged coast. this is due to the sloping beach, the waves will come a long break before finding a barrier that exceeds the height of the tsunami wave came, while the rugged steep coast, the waves will first be broken before it reaches the coast further inland. Coastal hilly, rocky, with coral reefs or closed vegetation can reduce the energy of tsunami waves. Similarly, the beach has a natural levee due to sedimentation in estuaries and dunes will reduce the energy of tsunami waves. While the beach which is composed by alluvium and sand-sized beach sediment with no vegetation less able to reduce the energy of tsunami waves

#### **Bathymetry Analysis**

Tsunami waves is strongly influenced by the ocean floor depth, which will affect the speed of propagation of tsunami waves. Tsunami waves through the deep seabed will have a greater velocity than when through the shallow sea floor. The amplitude of tsunami waves will be higher in the shallower than the deep sea. The

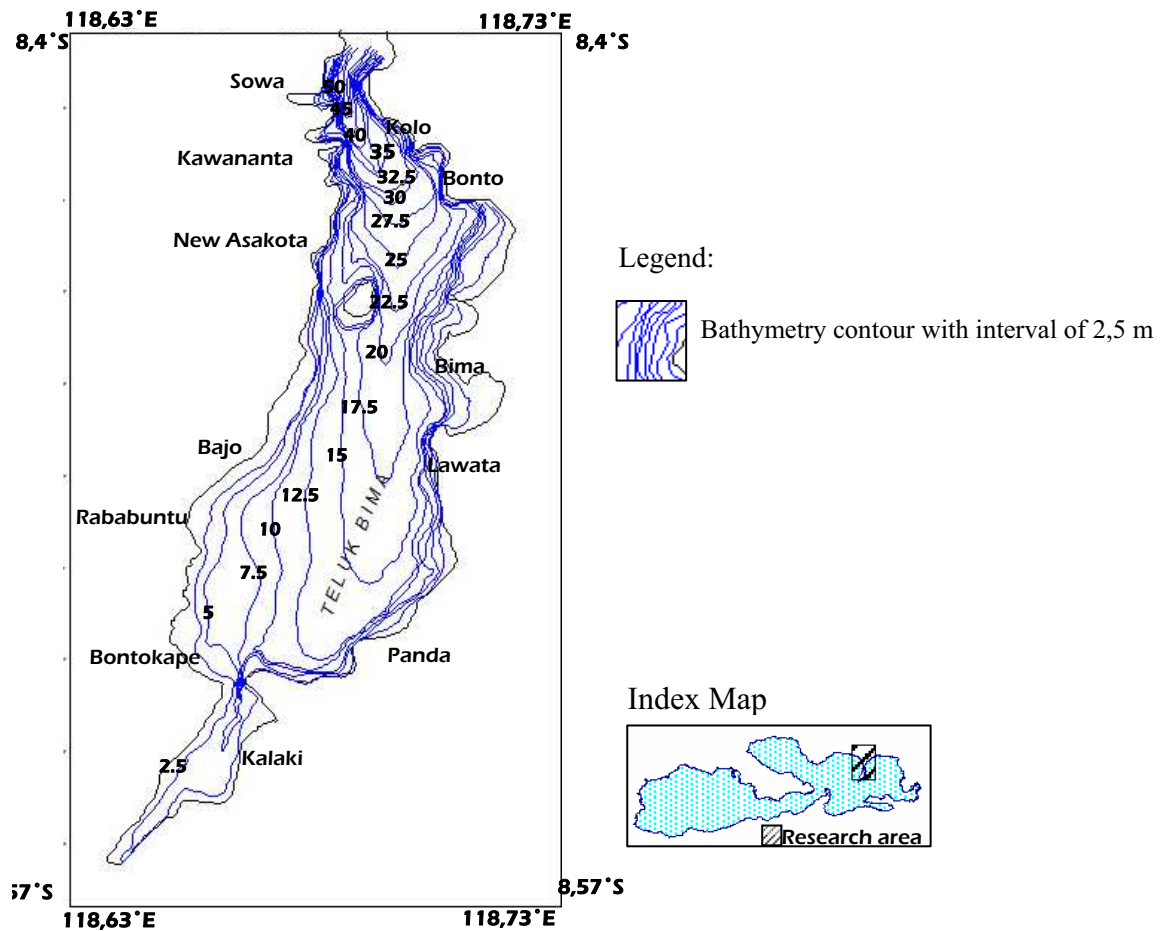


Figure 11. Bathymetry map of Bima Bay (Dharmawan, et al., 1997)

tsunami velocity is the square root of the sea depth multiplied by gravity.

Based on the bathymetric map that was resulted by Marine Geology Institute in 1996, shows that the seabed depth range between 1 and 50 m, where the inside of the very shallow waters of the Bay of Bima, gradually steeper at the mouth of the bay to the open sea (Figure 11).

Figure 11, it is known that the depth of seafloor at the mouth of the bay is deeper, while the inside it looks more gentle and shallower. The topography of eastern waterfront has a greater steepness than the western part. This condition will be very influential with the tsunami waves when it enters into the waters of the bay. In that conditions, the wave will come with large enough speed entering the mouth of the bay. The diminishing of velocity spread along the coastal waters of the eastern and continue to all parts. The wave height increasing when it reaches shallow water, especially in the waters of the western of Bima Bay. It can be ascertained, that the maximum tsunami wave height will be found in the western part of the bay, more or less in area Bontokape,

Rababuntu to Bajo which have a relatively flat and low land coastal morphology.

## Discussion

### *Tsunami Modeling Result*

Tsunami waves will be strongly influenced by the **geometry of the coast** (lateral direction); in the coastal belt or pocket-shaped bay have potentially a higher wave height compared with the elongated beach with no indentation. This is caused by accumulation the mass of water that occurred in the bay or pocket beach. While on the straight beach, the mass of water will spread in all directions when it reaches the shoreline. Research area has those both beach shape, which are an enclosed and elongated bay. Influx access comes from the mouth of the bay, which would have delayed the return of the waves out of the bay, thus accumulating the next wave comes, it will make the wave height increases in the waters of the research area.

**Flatness of the beach** (the vertical direction); tsunami waves will have height greater and increases in

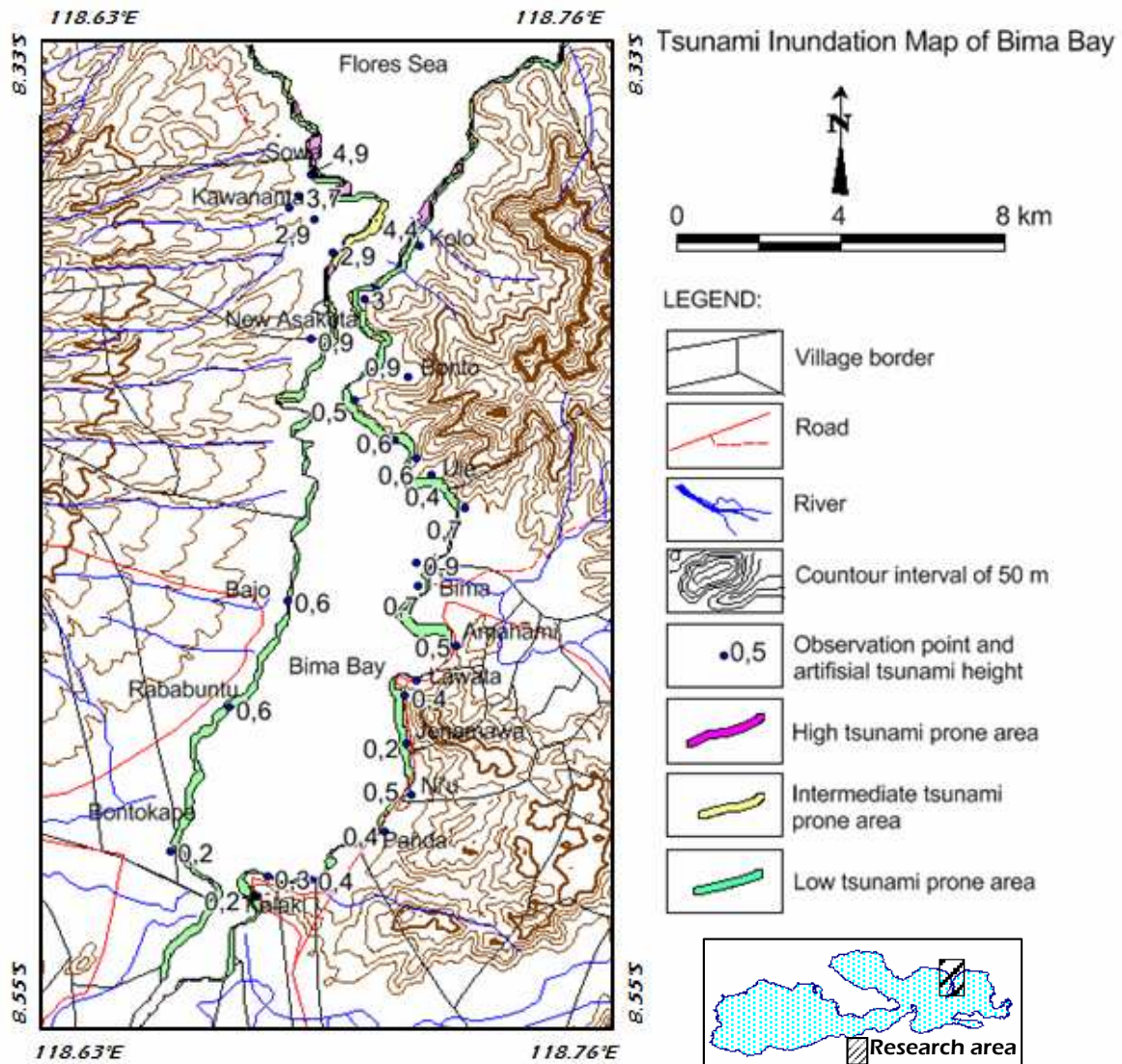


Figure 12. Tsunami inundation map of Bima Bay (Yudhicara et al., 2011)

coastal areas which has relatively gentle slope compared to the deep and steep morphology or that have greater beach slopes. The beach slope of the research area ranged from 1 to 7 and along the Bima Bay and composed by alluvium with ramps, such at Bajo, Soromandi, Rababuntu, Bontokape, Kalaki and other beaches around Bima City, will potentially have a distance range of the tsunami that would inundate coastal plain, and halted at the edge of the hills that are behind the beach or behind the highway. The hills will put a halt to the wave, so that the existence of these hills is very beneficial as a point of evacuation and temporary refugee camps.

The achievement of the tsunami waves will be determined by the location of the tsunami source. If the source is far from the research area, then the scope of

the tsunami waves will be smaller than if the location of the tsunami source is located perpendicular to the research area. The tsunami modeling was made the worst case scenario, in order to have the worst result, to get better plan and solution to mitigate the tsunami risk (Figure 12).

#### **High Tsunami Prone Area**

High tsunami prone areas have the potential damage to assets and greater safety risk of population. Coastal region including the region has a height of between 4-5 m tsunami, the northern part of the research area, Sowa and northern of Kolo. The morphology of this region including undulating hilly. Other areas have different morphology and high plains sloping towards the mean sea level between 0 to 5 m.

The maximum tsunami inundation reached about 400 m inland from the shoreline.

#### ***Intermediate Tsunami Prone Area***

Intermediate tsunami prone areas have the potential risk of damage to property and safety of the population is still quite large. Coastal areas, including the area affected by the tsunami had a height between 1-3 m at southeast of Kawananta. The morphology of this region including undulating hilly. The maximum distance the tsunami impacted reaches about 270 m from the shoreline.

#### ***Low Tsunami Prone Area***

Low tsunami prone areas which have lowest damage potential safety risk assets and the population. Coastal region including the region has a height of less than 1 m tsunami, located along the research area, exceptually : Sowa, Kawananta and Kalo. The tsunami wave will reached a maximum distance of 350 m from the shoreline.

#### ***Green Belt***

The most effective and safer for reducing the impact of the tsunami risk is by planting along the coastal areas. Besides, the cost is relatively cheap and very easy maintenance. The presence of the green line at the tsunami is quite beneficial because it can:

- Stopping the rate of floating objects (boats, wood or construction debris) that is carried away by the tsunami waves ashore.
- Reduce the speed of the water flow and reduce the height of inundation.
- Saving people drift (stuck in a tree).
- Reduce wind that carry material (sand) to form a

fine-sized sand dunes (dune) that can be prohibitive tsunami.

In the research area along the coast where the vegetation is less adequate, although there are mangrove plants in several places, but planting a more orderly and planned will contribute to better prevent tsunami inundation. The coastal plant types suitable for planting in the areas include palm trees, Cattapa, hibiscus, pandanus, pineapple beaches and mangroves.

#### ***Natural and artificial Beach Protection***

The existence of such a natural protective mangrove plants along the coast or at the sea would protect the coastline (Figure 13A), so that its presence must be maintained and preserved. Sea wall and breakwater are effective as artificial protector reducing wave (Figure 13B), can be built along the coast with a few of securing the coastal areas, residential and other buildings from abrasion caused by the pounding waves and currents along the coast (longshore current). Preparation on build sea wave barrier, would have to follow the rules, especially to build a tsunamis barrier in the mouth of the Bima Bay will be more effective to withstand tsunami waves entering the territorial waters of the bay.

#### ***Evacuation Route and Sites***

The research area generally formed by morphological hills, where the height of the sea surface elevation higher behind the beach. Under these conditions, evacuation routes and evacuation site can be directed to a place or location that has a higher elevation of the sea surface, or on the hills behind the beach along the research area (Figure 14 A & B)



Figure 13. Mangroves as natural barrier at Rababuntu (A) and Sea wall conditions at Lawata (B)



Figure 14. Hills behind the beach is a good location for evacuation route and sites in the area of Songgela (A) and Bonto (B)

Evacuation routes are equipped with signs pointing routes should be prepared as early as possible in an effort to minimize risk to tsunami hazard in the research area.

### CONCLUSIONS

Area along the coast that includes the territorial waters of the Bima Bay, West Nusa Tenggara, is prone to tsunamis, evidenced by the historical tsunamis record in 1815 due to the volcanic eruption of Tambora, 1818, 1836 and 1992 caused by earthquakes associated with tectonic system in the north of the island of Sumbawa, and 1892 were sourced from a distant source.

Several factors can affect the amount of risk that would be caused by the tsunami, in the research area include are: (1) The research area is located in an enclosed bay; (2) The local sea floor depths around the bay is relatively shallow; (3) Coastal characteristics of the research area is dominated by a gently slope beach morphology with low relief, especially in the area of Bajo, Rababuntu, Bontokape and other beaches in the city of Bima; (4) Residential location very close to the shoreline; (5) Minimum vegetation cover; and (6) The presence of the artificial protective are inadequate.

Based on tsunami modeling using the 1992 Flores earthquake parameter which is placed perpendicular to the research area obtain the maximum tsunami height around 4-5 m at Sowa and Kolo, near to the mouth of Bima Bay, while the minimum is at Kalaki, about 0.2 m which is at the inner bay.

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