Overview of 1990s deadly tsunamis in Indonesia

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Abstract. In the 1990s there were 7 (seven) deadly tsunami events due to earthquakes in Indonesia. There is M 7.8 North-east of Flores island sea earthquake (1992), M 7.6 South of Java island sea earthquake (1994), M 6.8 South of Timor Island sea earthquake (1995), M 7.8 North-west of Sulawesi island sea earthquake (1996), M 7.9 East of Biak island sea earthquake (1996), M 7.7 Taliabu island sea earthquake (1998), and M 7.4 East of Banggai Island sea earthquake (2000). Those earthquake and tsunami disasters events affected the number of casualties and damaged houses in coastal areas. Surely those events present a few lessons learned for future disaster preparedness in Indonesia.

1 Introduction

Between 1990-2000 there were 7 (seven) earthquake events that generated deadly tsunamis in Indonesia. Those tsunamis induce losses that damage houses and the number of casualties. Those tsunami events triggered by earthquakes such as **1)** M 7.8 North-east of Flores Island Sea earthquake (1992); **2)** M 7.6 South of Java Island Sea earthquake (1994); **3)** M 6.8 South of Timor Island Sea earthquake (1995); **4)** M 7.8 North-west of Sulawesi island sea earthquake (1996); **5)** M 7.9 East of Biak island Sea earthquake (1996); **6)** M 7.7 Taliabu island sea earthquake (1998); and **7)** M 7.4 East of Banggai Island sea earthquake (2000) [4,5].

The tsunami hazard triggered the buildings to be damaged and populations to be casualties on the nearest coastal area, even in a far direction or called a distant tsunami. We find interesting information on the 1990s BMKG Tsunamis Catalogue that is one of them is an unfelt earthquake able to generate tsunami which hit the coastal zone, destroy the building and induce casualties [1,2].

In this article, we write the overview of deadly tsunamis information on Indonesia to denote the possible casualties and damages due to tsunami-genic and tsunami earthquakes in the future. We suggest this event be the lesson learned for tsunami specialists to consider the multi-hazard on certain possible areas. According to the recent unexpected multi-hazard event, we also propose to conduct the vulnerable reduction for people and buildings as an initial effort to reach disaster resilience [3,6].

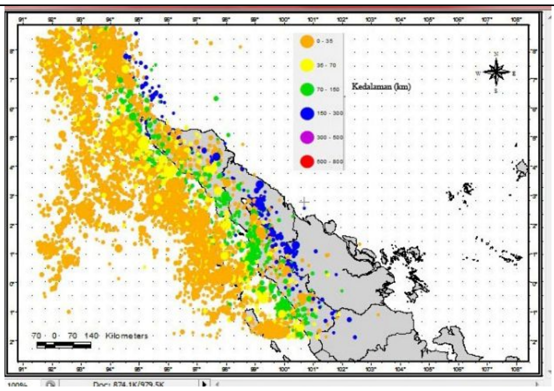	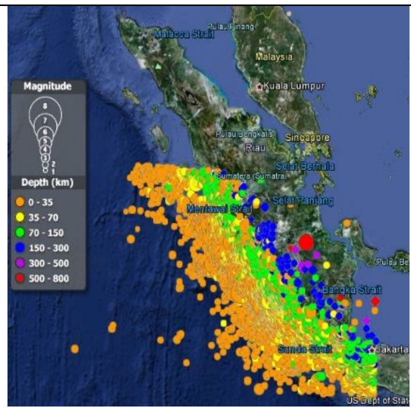
Seismicity map of Northern Sumatra	Seismicity map of Southern Sumatra

Fig. 1. Seismicity map of Sumatra 1973-2012 (USGS) [29]

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2 Data and Method

Since 1990-2000, we have discovered 7 deadly tsunami data in the Indonesia region. We used the data from the BMKG Earthquake and Tsunami Center online repository. We used desk literature study towards the BMKG destructive tsunami catalog, scientific reports, international tsunami bulletin, and earthquake and tsunami newsletter compilation books. The seismicity map dataset was collected from USGS (1973-2012) and processed using the ArcView program [7,8].

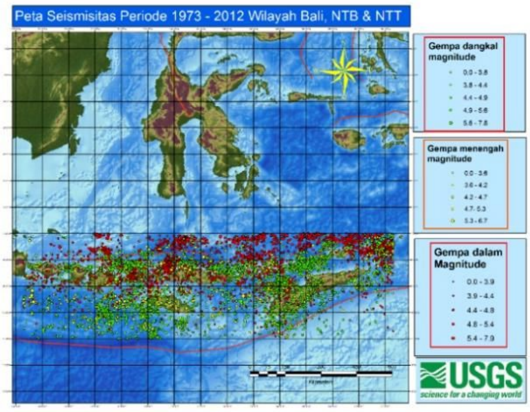


Fig. 2. Seismicity map of Bali and Nusa Tenggara Island 1973-2012 (USGS) [32]

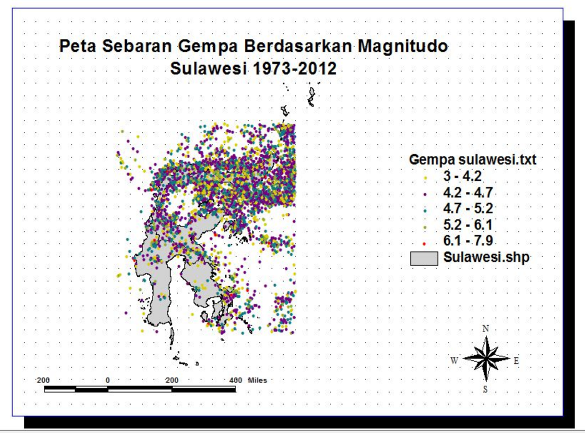
The affected region of the M 6.8 South of Timor Island Sea earthquake (1995) nowadays has left from territorial of Republic of Indonesia to be Timor-Leste or East Timor, while the affected region of M 7.9 East of Biak Island Sea earthquake (1996) was on Irian Jaya province, nowadays has divided into 2 (two) provinces to be Papua and West Papua [9,10].

3 Result and Discussion

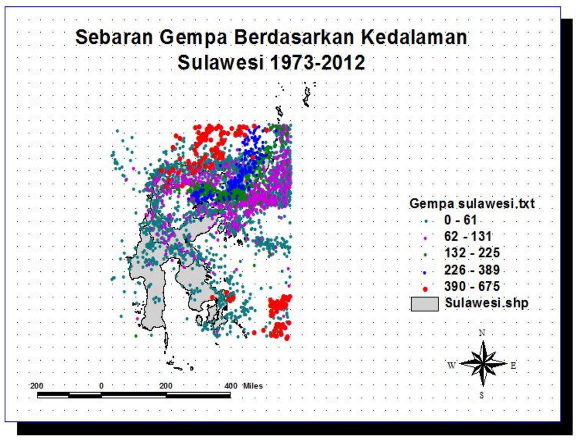
Most tsunamis are generated by earthquakes, we discover all tsunami events in Indonesia in the 1990s were triggered by an earthquake on the following event:

3.1 M 7.8 North-east of Flores Island Sea earthquake (1992)

December 12, 1992, North-east of Flores Island Sea earthquake (M 7.8), which caused a destructive shaking, was located in the 8.340 S - 122.490 E near Babi Island on Sikka regency at 13:29 Central Indonesian Time (Local Time). It occurred on the 20.4 km depth and was felt by people in the half of eastern part of Flores Island and its vicinities island such as in Maumere XI MMI, Ende VIII MMI, Ngada VII MMI, Larantuka VI-VII MMI, Waingapu, Sumba, and Ujungpandang IV MMI. The maximum flood of tsunami inundation can reach 300 m to the land, various run-up measured in villages 20.4 km depth and was felt by people in the half of eastern part of Flores island and its vicinities island such as in Maumere XI MMI, Ende VIII MMI, Ngada VII MMI, Larantuka VI-VII MMI, Waingapu, Sumba and Ujungpandang IV MMI. The maximum flood of tsunami inundation can reach 300 m to the land, various run-up measured in villages such as 1) Ilepadung – East Flores 11 m; 2) Babi island – Sikka 5,5 m; 3) Wuring - Sikka 2,4 - 3,2 m; 4) Mausambi – Ende 3,4 m, and 6) the highest run-up reach 25 m in Riangkroko village near Cape Batumanuk, far end of Flores island [11,12].



Seismicity map of Sulawesi Based on Magnitude



Seismicity map of Sulawesi Based on Depth

Fig. 3. Seismicity map of Sulawesi 1973-2012 (USGS) [35]

The local government noted that the total number of casualties is 1952 deaths, 2126 injuries, and 500 lost. It also noted that more than 20000 buildings including houses were damaged. This phenomenon is related to Flores's back-arc thrust tectonic activities. These earthquake-induced collateral hazards such as submarine landslides, liquefaction, and tsunami. It is strongly possible, considering most of the east of Flores Island were covered by volcanic deposits sourced from volcanic activity such as Mt. Ile Mandiri, Mt. Lewotobi, Mt. Egon, and Mt. Rokatenda. The damage also could be caused by topographical effects considering the coastal village is located on a steep hill. This site condition can amplify the ground motion acceleration to be stronger [15,16].

Two interesting phenomena were reported from the losses on Babi island and Riangkroko village. Most of the evidence of damages and casualties in Babi island was focused on the south part, the opposite of the epicenter source of the tsunami generated. The publication of tsunami modeler answers this question that this phenomenon was due to the reflected wave which hit Flores island, the coastal zone facing the southern part of Babi island. The other interesting question also comes from the far end of east Flores island, one village reported being lost due to being swept by the giant wave. This phenomenon was long discussed due to the anomalous 25 m run-up which struck the coastal zone of Riangkroko village [19, 20].

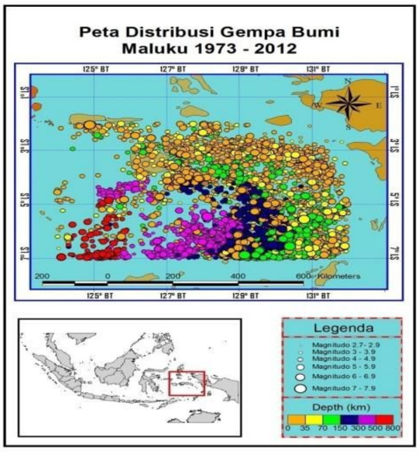
3.2 M 7.6 South of Java island sea earthquake (1994)

On June 2, 1994, at 01:17:34 Western Indonesian Time (Local Time) a slow earthquake (M 7.2) struck south of East Java Sea. It is located 200 km south of Banyuwangi regency - East Java. It occurred at the 18 km depth and was felt by a small number of people in Banyuwangi (III-IV MMI). The local government noted that 720 buildings were damaged, 223 people die, 22 people lost, and 440 people were injured due to the tsunami hit. According to a BMG survey, the flood of tsunami inundation can reach 300 m to the land in some coastal villages [21, 22].

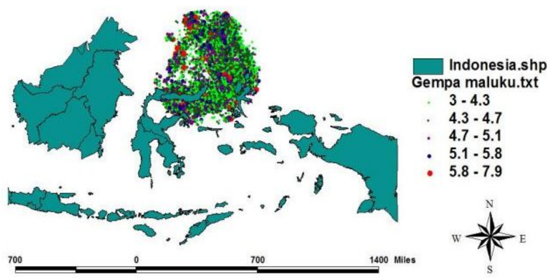
The seismic analysis concluded this tsunami was categorized as the tsunami-earthquake or slow slip earthquake. According to the hypocenter and focal mechanism analysis, this earthquake was generated by thrust faulting in the Indian Ocean south of the Java subduction zone or locally named Sunda trench. The field survey of run up measured in villages such as: **1)** Pancer – Banyuwangi 5,7 - 9,4 m; **2)** Lampon – Banyuwangi 9,3 m; **3)** Rajekwesi - Banyuwangi 13,9 m; **4)** Grajagan – Banyuwangi 4,1 m, and various lower run up in Jember, Tulung Agung, Blitar, Malang, Lumajang and Bali, coastal regencies near Banyuwangi. This phenomenon was focus discussed due to the slow felt shaking based on eyewitnesses or survivor storytelling in the coastal zone, and most houses were not damaged by the earthquake but tsunami waves do [23, 24].

3.3 M 6.8 South of Timor Island sea earthquake (1995)

On May 14, 1995, South of Timor Island sea earthquake (M 6.8), a major earthquake struck deep under the Timor sea, creating tsunami waves that swept houses away and damaged fishing boats in East Timor. 11 people died, 19 people were injured and 15 others were missing. The harbor was badly damaged and several office buildings and homes had gaping cracks and collapsed roofs. Five aftershocks in the hours following the quake initially prevented people from returning to their homes. This affected region has left the administration of Indonesia since 1999 to be an independent country [25, 26].



Seismicity map of Maluku



Seismicity map of Northern Maluku

Fig. 4. Seismicity map of Southern Maluku 1973-2012 (USGS) [31]

3.4 M 7.8 North-west of Sulawesi Island sea earthquake (1996)

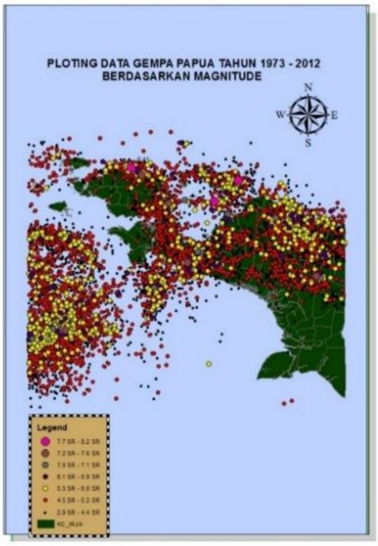
On 1 January 1996 at 16:05 central Indonesian time, an M 7.8 earthquake struck the North-west of the Sulawesi island sea, approximately 180 km north of Palu. It generated a tsunami to the coastal zone of 100 km northeast coastal villages of Sulawesi island in Toli-toli regency. The international Tsunami Survey Team (ITST) conducting field survey of run up measured in villages such as: 1) Pagalaseang 2,28 m; 2) Munte 3,17 m; 3)

Limbosu 2,81 m; 4) Tonggolobibi 1,82 – 3,43 m, 5) Taipah 2,40 – 3,25 m; 6) Siboang 1,78 m; 7) Siwalempu 1,62 m; 8) Balukang 2,52 m; 9) Soni 1,79 m; 10) Dongko 2,39 m; and 11) Simuntu 2,00 m [27, 28].

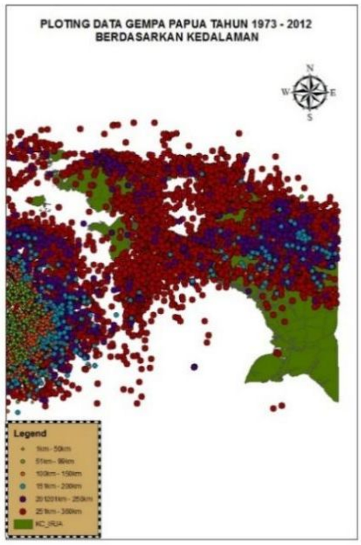
Nine people were killed and 63 were injured in Tonggolobibi village by a 2 m high tsunami, more than 400 houses were destroyed and became unfit for living. In the coastal villages, the earthquake intensity was VI MMI. According to the tectonic setting, this earthquake is associated with the subduction interface under the North Sulawesi arm. The earthquake's source was due to a shallow-dipping thrust fault that roughly coincides with the interface between Sulawesi and the Celebes Sea subduction zone [29, 30].

3.5 M 7.9 East of Biak island Sea earthquake (1996)

On February 17, 1996, at 14:59 Eastern Indonesian Time (Local Time) an earthquake (M 7.9) struck East of the Biak island Sea. It is located 40 km east of Biak island – Irian Jaya. It occurred on the 8 km depth and was felt by people in the whole part of Biak island and its vicinities islands such as VIII-IX MMI in Biak and Supiori regency. The tsunami hit the whole coastal part of Biak island and its vicinity islands such as Yapen island, Owi island, Pai island, also the north part of Papua island coastal zones such as Manokwari and Sarmi. According to the tectonic setting, this earthquake was associated with the Carolina-Pacific plate beneath to Bismarck-Australian plate [31, 32].



Seismicity map of Papua Based on Magnitude



Seismicity map of Papua Based on Depth

Fig. 5. Seismicity map of Papua 1973-2012 (USGS) [33]

The interesting phenomena were discovered to refer to storytelling by eyewitnesses or survivors. The average tsunami arrival time duration approximately was 10-15 minutes since the shaking into tsunami hit in the east part of Biak island, while in the west part of Biak island were only 5 minutes, the opposite part of the earthquake source. The other interesting story is the average run-up in the eastern part was 4-6 m, while 7.7 m in the western part of Biak island. Both novel finds were long discussed due to both anomalous. However, the further approaching research mentioned this anomalous may relate to atypical sources such as submarine landslides in the near coast of the west part of Biak island [33, 34].

The affected coastal villages consist of Mansoben (Supiori), Warsa (Biak Numfor) Korem (Biak Numfor), Sauri (Biak Numfor), Farusi (Biak Numfor), and Wardo (Biak Numfor). The total amount of casualties was 110 people died, 51 people missing, 423 person injuries, more than 10.000 refugees, 5043 houses damaged. The official report on each village noted that 17 persons were dead in Saukobye, 8 persons dead in Andey, 7 persons dead in Rosayendi, and 7 persons dead in Korem [1, 35].

3.6 M 7,7 Taliabu island sea earthquake (1998)

On November 28, 1998, the M 7,7 Taliabu island sea earthquake trigger 3m tsunami waves and killed 34 persons. It is located in the 2.00 S 124.80 E.

3.7 M 7.4 East of Banggai Island sea earthquake (2000)

On May 4, 2000, at 12:21 Central Indonesian Time (Local Time) a strong earthquake (M 7.4) struck east of the Sulawesi and Banggai islands and triggered a tsunami to the Sulawesi coastal zone of Luwuk and the neighbouring islands of Peleng and Banggai. The earthquake centered in the east Sulawesi region about 100 miles (160 km) south-southeast of Gorontalo. It occurred at the 26 km

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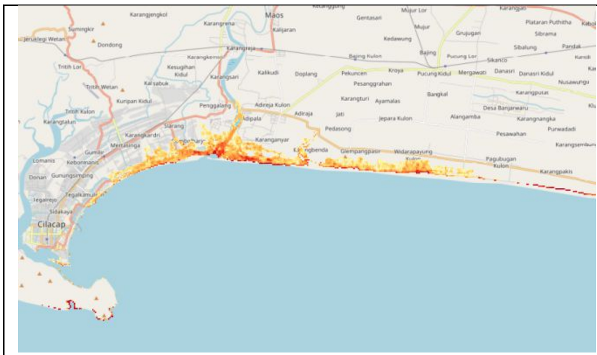
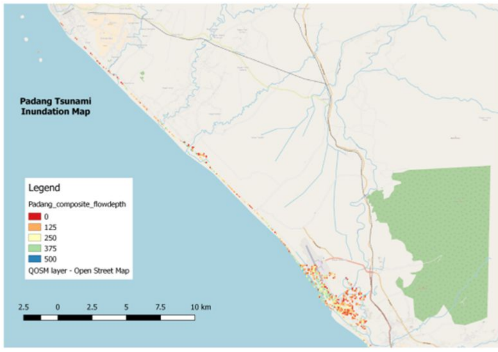
depth and was felt by several people in Banggai and Luwuk [13,14].

The tsunami waves, reportedly measuring up to six meters in height inundated two villages on Peleng Island, Kayuntayo and Uwedikum. In Luwuk (607 kilometers east of Palu, capital of central Sulawesi). Hundreds of homes on Banggai island were destroyed, and at least 54 people were reported dead, 264 injured, and more than 19.000 buildings damaged. Reports indicate that as many as 170.000 people have been made homeless [17,18].



Cilacap Tsunami Inundation Map



Padang Tsunami Inundation Map

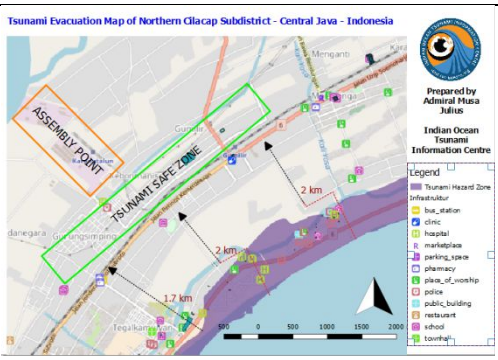
Fig 6. Tsunami inundation map

3.8 Evacuation Map Based on Worst-Case Tsunami Scenario

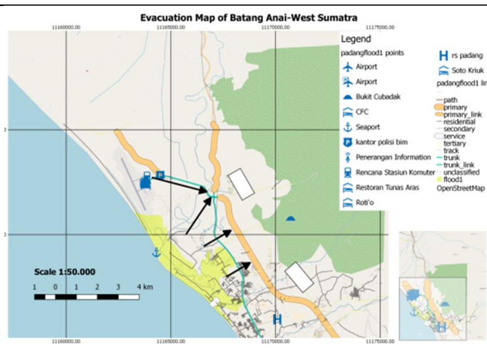
Those 7 tsunami events have their uniqueness and will repeat themselves in the future. One of the Tsunami Ready Indicators (IOTR) Programme for Indonesia is having designated and mapped tsunami hazard zones. The primary source for mapping potential tsunami hazard zones is inundation modelling, which illustrates expected areas to be flooded by a tsunami. In this discussion, we illustrate tsunami inundation modelling for Batang Anai and Cilacap Regency Coastal Zone using the Community Model Interface for Tsunami (ComMIT).

It uses initial conditions from a pre-computed propagation database, has an easy-to-interpret graphical interface, and requires only portable hardware. We used certain worst-case scenarios for each location based on the Indian Ocean Probabilistic Tsunami Hazard Assessment (IO-PTHA) study, those are Mw 9.2 Andaman, Mw 9.2 Nicobar, Mw 9.2 Aceh, and Mw 9.2 South Sumatra earthquakes for Batang Anai, and Mw 8.8 West Java, Mw 9.0 Central Java, Mw 9.0 East Java for Cilacap tsunami hazard maps

The ComMIT server bathymetry dataset is derived from ETOPO1 one arc-minute gridded global relief model and has been interpolated from 60 arc-second to 3 arc-second to match the topography data set produced by NOAA, while the topography dataset is derived from Shuttle Radar Topography Mission (SRTM) 90m created by NASA. Multiple inundation scenarios of each coastal area were stored into a composite. These composites were converted into vector format using open-source QGIS software. Further, these inundation vector files were cleaned and the final inundation area was prepared. These inundation details overlaid on the base data (open street maps, google maps, etc.) along with the locations of safe shelters and evacuation routes. The final evacuation maps detailing the extent of inundation, evacuation routes, and locations of safe shelters were composed in QGIS. This evacuation map will help coastal residence to be more understand the way to save lives facing tsunami potential.



Cilacap Tsunami Evacuation Map



Batang Anai Tsunami Evacuation Map

Fig. 7. Tsunami evacuation map

4 Conclusion

Along the 1990s, Indonesia was hit by 7 deadly and near-field tsunami events generated by M>6.7 earthquakes in the sea of Flores (1992), Java (1994), Timor (1995), Sulawesi (1996), Biak (1996), Taliabu (1998), and Banggai (2000). Besides the tsunami, we saw the earthquake also able to generate other collateral natural hazards such as submarine landslide, rockfall, and liquefaction. We must expect more than one wave. When a tsunami struck the coastal zone, it may strike the nearest coastal zone consisting of threatened people, vulnerable buildings, and the environment. On the mitigation of tsunami risk reduction context, we can use evacuation maps, because they will be handy for the coastal disaster management authority and also used as awareness material to sensitize the administrators and people at risk.

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