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The Scenario of Tsunami Propagation at the Celebes Sea and the Disaster Impacts to Tawau District

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This paper presents extreme tsunami scenarios in the Celebes Sea, which potentially can be generated by a large earthquake of magnitiude 9.5 along the subduction zone of the North Sulawesi Trench and Cotabato Trench. The tsunami wave height and arrival time were simulated using Tunami-N2. Based on the simulation it is predicted that the coastal area of east Sabah and especially the Tawau town area, will be exposed to tsunami waves as high as 5 m in 60 minutes from the North Sulawesi Trench and up to 2 m in height within 80 minutes from the Cotabato Trench.

Keywords: tsunami, TUNAMI-N2, Tawau

I. INTRODUCTION

The 2004 Indian Ocean tsunami record surprised the world with magnitude 9.0 Richter scale earthquake shocks and generating a tsunami wave that billed about 231,452 casualties and 2,089,883 injured. This natural dynamics process has a profound impact on the country involved. Malaysia was located on stable Sunda Stage is no longer a guarantee to escape the tsunami threats. So the existence of this situation requires a prophecy approaching the realistic case of tsunami propagation in Celebes Sea and can be used to predict the tsunami threats in the district of Tawau.

The tsunami is a great wave of ocean waves generally due to the disruption of the body of water in which the power is converted to the waveform. Most of the tsunami-generated resources are due to seismic activity through earthquakes and tectonic activities. However, the disruption of water bodies due to volcanic eruptions and undersea landslides can also contribute to the tsunami, it is also identified as non-seismic activity (ITIC, 2007). The tsunami incidents were a tough-to-date event as most of the incidents were recorded in unexpected intervals.

Sabah is tectonically surrounded by the Eurasian Plate, the Indo-Australian Plate, the Pacific Plate, and the Philipine Plate. The activity of this plate has formed several active faults that contribute to the creation of a series of great earthquakes (Figure 1). The Eurasian plate is recorded as having an annual average of 5cm towards the southeast, the Indo-Australian Plate moves 7cm per year to the North while the Pacific Ocean Platinum is 10cm per year (Mitchel *et al*., 2000).

Among the active faults formed around the Celebes Sea are the Cotabato Parit, North Parit North and Parit Sanghe. It has been recorded 166 series of Mw 6.0 scale earthquakes up to Mw 9.0 that have occurred around the Celebes Sea (Figure 2). Most of the earthquakes hit the active faults of Parit Cotabato and the North Parit Sulawes which also generated several series of tsunamis (Figure 3).

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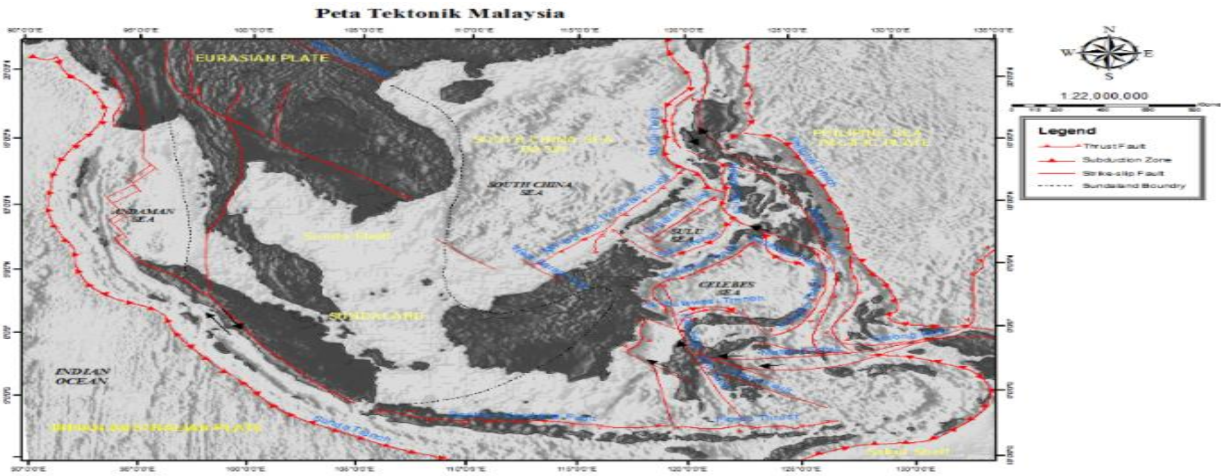

Figure 1. Tectonic plate activity around Malaysia and Southeast Asia Region.

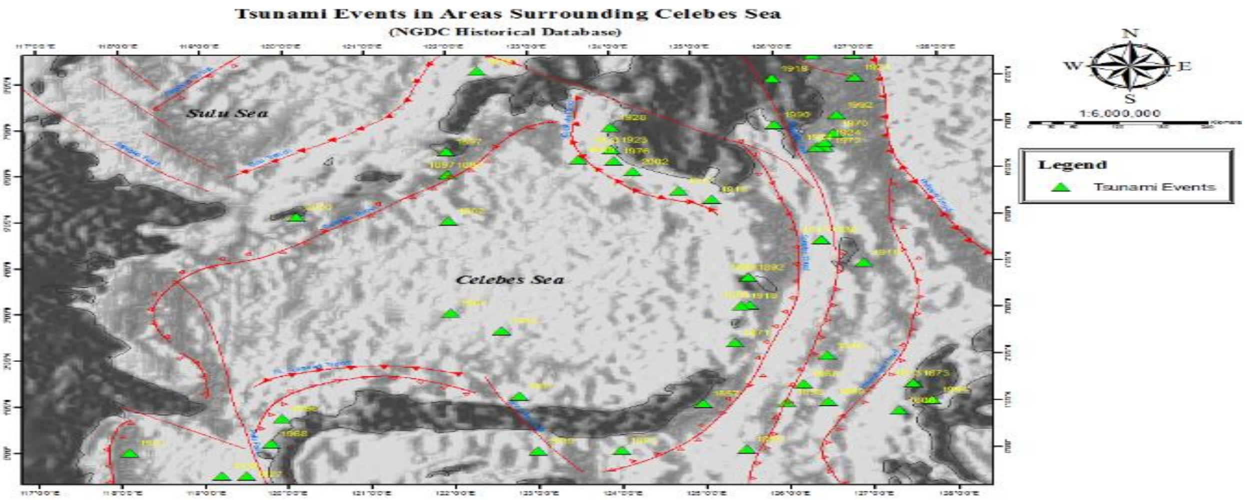

Figure 2. Past tsunami events surrounding the Celebes Sea.

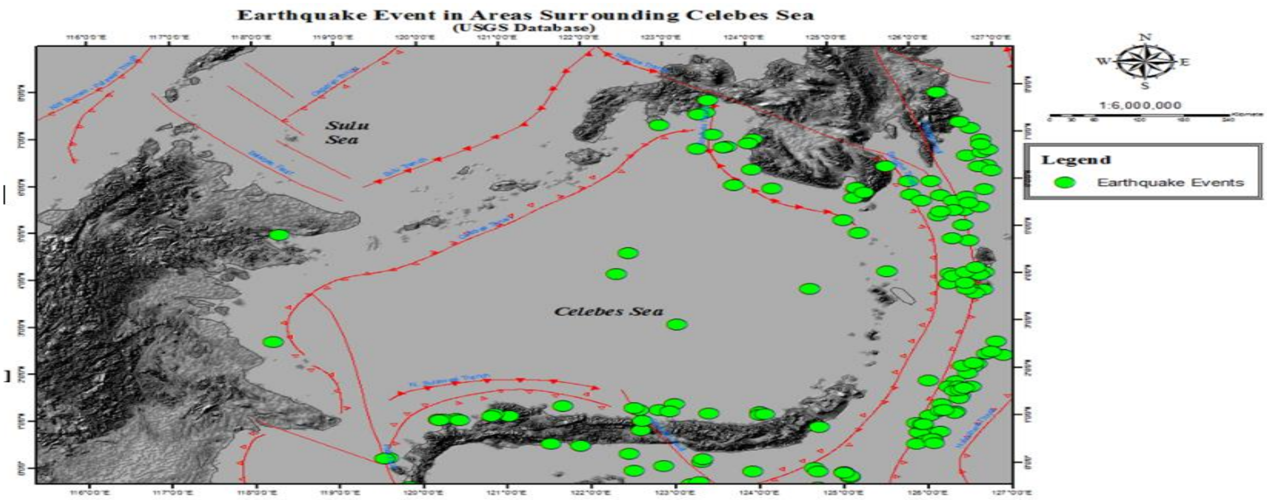

Figure 3. Earthquake events (Mw6.0 – Mw9.0) in Celebes Sea (1973-2010) (Sources:USGS).

II. TSUNAMI PROPAGATION MODEL

The tsunami propagation model used in this study is TUNAMI-N2. This model is basically developed by the Disaster Control Research Center (Tohoku University, Japan) through the Tsunami Inundation Modeling Exchange (TIME) program (Goto *et al.,* 1997). TUNAMI-N2 has been intensively applied in Japan in the study of propagation and tsunami implications against coastal areas in different scenarios (Goto and Ogawa, 1992; Imamura and Shuto, 1989; Shuto and Goto 1988; Shuto *et al.,* 1990).

This modeling has also been implemented extensively to simulate propagation and inundation in the Pacific Ocean, the Atlantic Ocean and the Indian Ocean (Yalciner *et al.,* 2000, 2001, 2002; Yalciner, 2004; Zahibo et al., 2003; Tinti *et al.,* 2006).

The tsunami modeling in the Celebes Ocean is considering the shallow water wave theory (Goto and Ogawa, 1982 in Imamura, 2006) where the tsunami propagation simulation is carried out taking into account the elemental friction element. Air friction is neglected because of its very small value and almost no impact. Changes in sea level due to tidal activity are also negligible as the change is very little compared to the high tsunami occurrence. Changes in data entry and detailed analysis were conducted to obtain a simulation scenario of the Tsunami propagation in the Celebes Sea approaching realistic cases.

III. TSUNAMI SOURCE

The study attempted to bring a realistic picture of the actual scenario of the tsunami generation process from earthquake sources to realistic cases. The determination of generator factor sources in the tsunami model database is very important. This study is confronted with information about poor earthquake parameter data around the Celebes Sea. So to overcome this problem, a hypothetical determination of the earthquake source (Figure 4). Based on the NGDC record on the accessibility of tsunami wave propagation, there are two areas where the region's tsunami can be generated through the Celebes Sea, along the North Parit of North Sulawesi and Parit Cotabato. The magnitude of the earthquake that was simulated in this study was the realization of realistic cases in extreme situations that could be achieved and identified. There are two earthquake scenarios, the first scenario of the earthquake in the North Sulawesi Parit area and the second scenario of the earthquake in Parit Cotabato area where both earthquakes are characterized by Mw 9.5 earthquakes.

IV. SENARIO OF TSUNAMI PROPAGATION IN CELEBES SEA

For the first scenario tsunami generation model in which extreme earthquake is generated in North Sulawesi Trench, the propagation of the tsunami wave is rapidly occurring. From the simulation of the tsunami wave propagation, it is expected that tsunami waves moving from the source to the East Coast of Sabah will be less than 60 minutes. The tsunami waves spread throughout the Celebes Sea in 50 minutes (Figure 4). The wave propagation velocity is spread because the energy transferred from the earthquake activity to the body of the water is high. Through this earthquake, tsunami wave formation can reach up to 5 meters in some coastal areas of the East Coast of Sabah, North Sulawesi near Toli-toli and parts of East Kalimantan and Tarakan (Figure 5a).

The propagation of the tsunami wave in the second scenario takes place a bit slowly. Simulation of tsunami wave propagation shows the tsunami wave distribution from the source of the generator in Parit Cotabato and spread to Celebes Sea takes 80 minutes (Figure 5b). The maximum height of the tsunami wave is also 5 meters wide and is largely concentrated on the Cotabato Coast, part of Sulu Islands, and North Sulawesi such as Sumalata, Boroko, Lolak, Ongkaw,

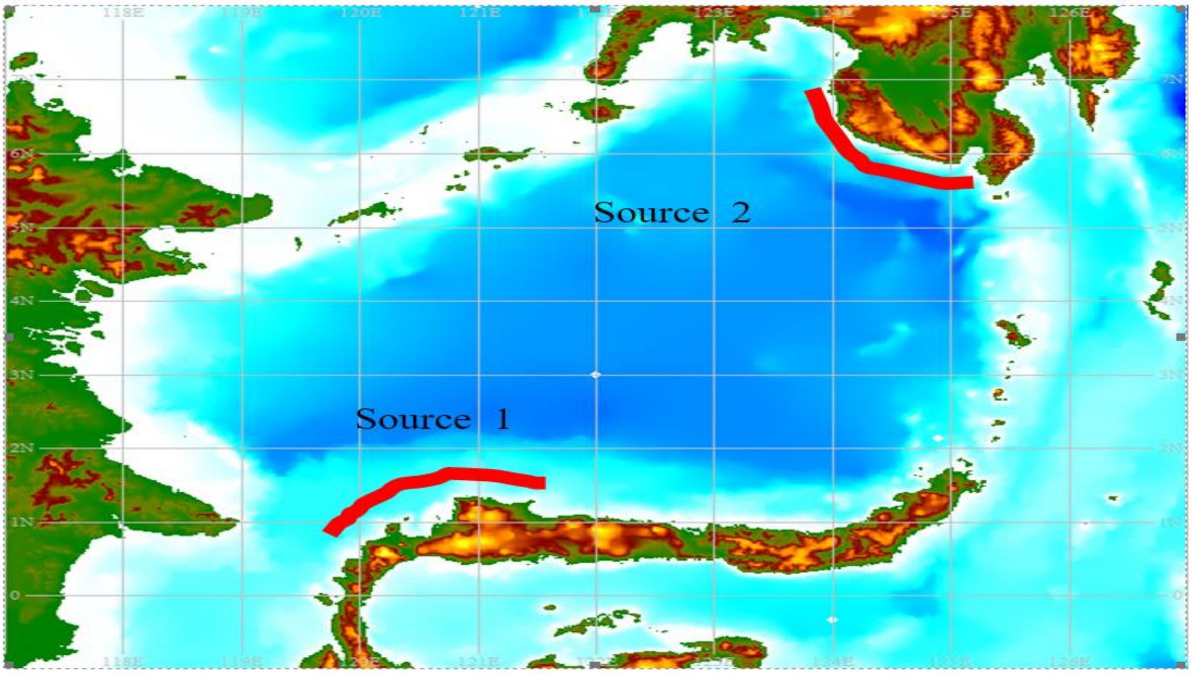

Figure 4. Determination of hypothetical earthquake sources.

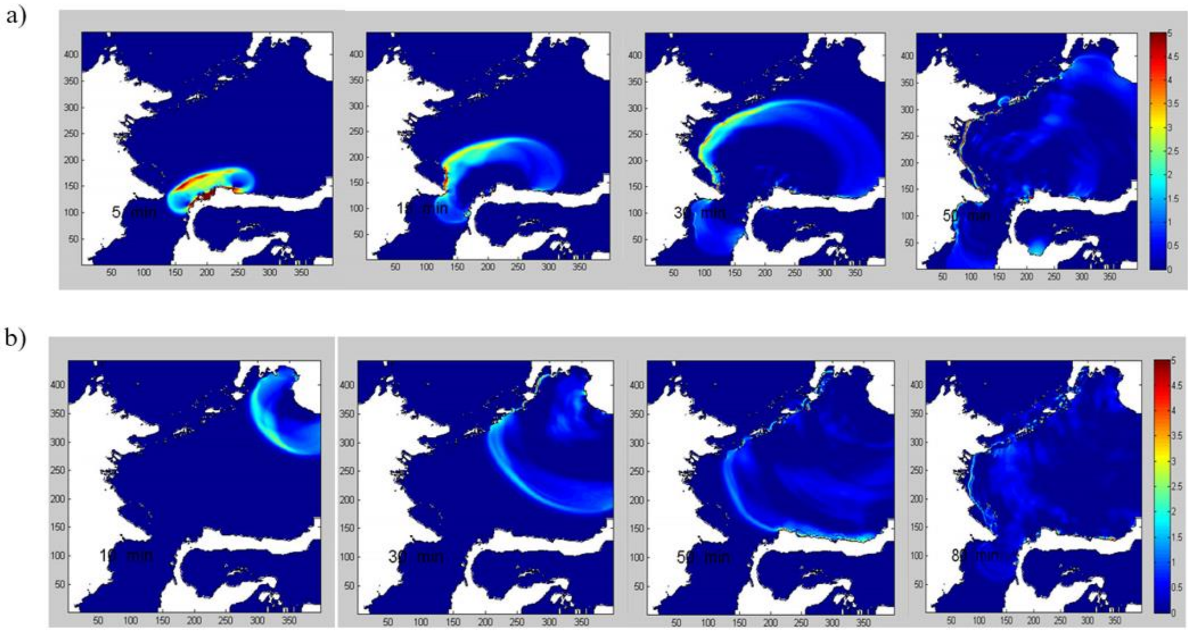

Figure 5: a) The propagation scenario of the Tsunami wave in the Celebes Sea at the source of the North Sulawesi Trench at a time of 5 minutes, 15 minutes, 30 minutes and 50 minutes from the start of the earthquake. b) The propagation scenario of the tsunami waves at the Celebes Sea at the Cotabato Trench source at a time of 10 minutes, 30 minutes, 50 minutes and 80 minutes from the start of the earthquake.

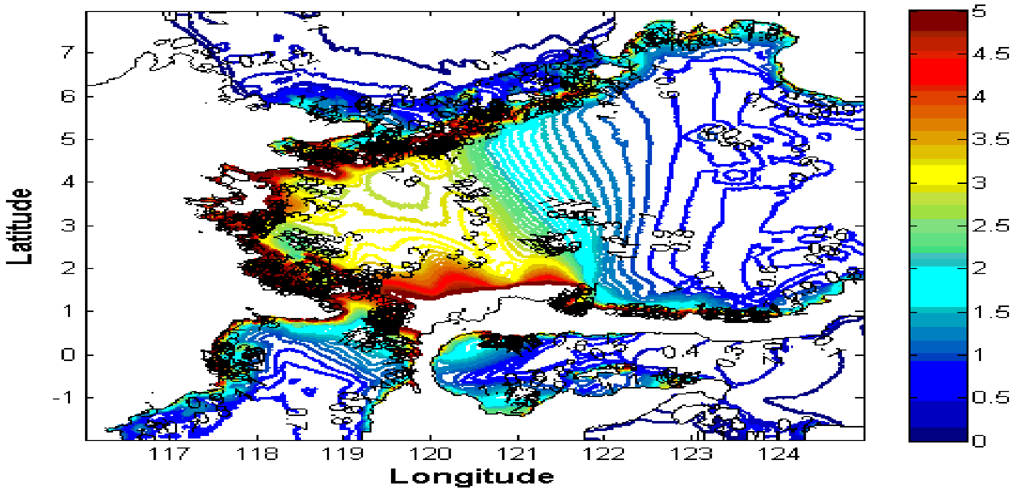

Figure 6. The maximum height of the tsunami wave formed around the Celebes Sea from the earthquake source of the North Sulawesi Trench.

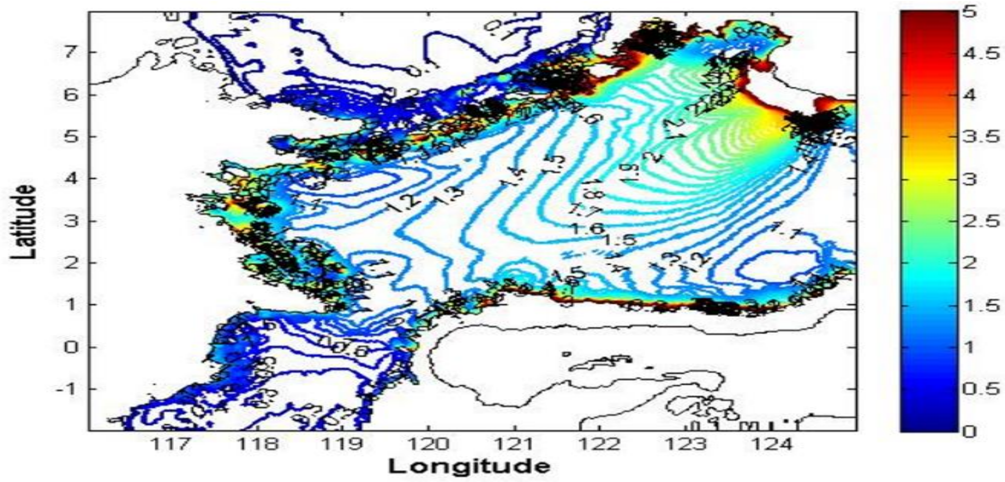

Figure 7. The maximum height of a tsunami wave formed around the Celebes Sea from the earthquake source of the Cotabato Trench.

and Tenga (Figures 6 & 7). Some of the resulting waves lead to the Sulu Sea and experience a reduction in energy as tsunami waves are characterized by islands that exist along southern Philippines.

V. TSUNAMI THREATS IN TAWAU AREA

Simulations of both scenarios suggest that the wave generated from earthquakes in the Parit of North Sulawesi and Parit Cotabato poses a tsunami threat to the Celebes Sea (Figure 8). The Tawau district, located on the east coast of the State of Sabah, is also included in potential areas to experience the tsunami threat of the region.

The observation station 1 in scenario 1 records the maximum wave value of 4.9 meters with station position less than 5km from the coastline. This is followed by station 2 as high as 3.9 meters and station 3 as high as 3.5 meters (Table 1).

The difference in the first wave period of each station for scenario 1 and scenario 2 differs from where the duration of the wave period from the origin of scenario 1 is shorter than scenario 2. This is influenced by the distance of the earthquake source where the scenario 1 is 451,625 km southeast of Tawau City while the scenario 2 is 766,799 km to the northeast of Tawau City.

The amplitude of this tsunami wave fluctuates for each station, the higher the position of the observation station the higher the amplitude of the wave recorded by the observation station.

This scenario is not directly affected by the distance of the observation station from the source of the earthquake, because the amplitude of the tsunami wave can change depending on the environmental morphology in which the transient wave is moving. Tsunami waves that occur on the deep sea are able to move at speeds of 500 to 1,000 kilometers per hour. While approaching the shores of tsunami geolocation speeds change up to tens of kilometers per hour. Changes in the height of the tsunami also depend on the depth of water. The tsunami wave formed in the deep sea at a height of 1 meter can reach tens of meters when it reaches coastal speculation. The observation station position 1 at a depth of 3 meters below the water level receives a higher wave of 4.9 m compared to station 2 and station 3 3.9 m and 3.5 m respectively. Such a thing is different from the ocean waves resulting from wind and storm events that occur only on the surface of the sea. When approaching the coast of the wave energy will be concentrated in the vertical direction due to the reduced depth of water and this will change to the horizontal wave due to the slow motion wave propagation process (ITIC 2007). In addition, the increasingly narrow sea level between Tawau City and Sebatik Island, as if it would be added, will further increase the tsunami wave power through it.

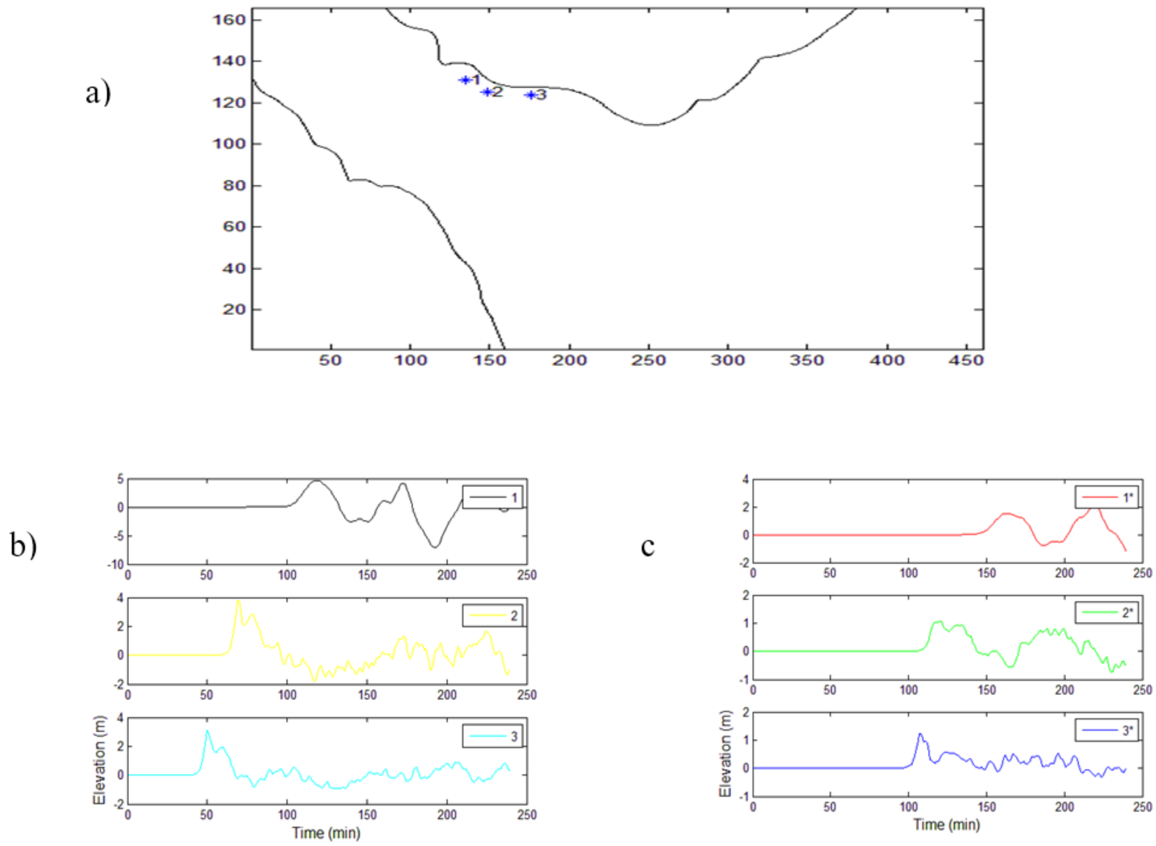

Figure 7. a) Position of offshore observation stations of Tawau City, b) sinusoidal wave recorded at scenic observation station 1, c) sinusoidal wave recorded at scenario observation station 2.

Table 1. Maximum first and maximum wave periods recorded at each observation station for scenario 1 (North Sulawesi Trench) and scenario 2 (Cotabato Trench)

	The first wave period arrives at the observation station (m)			The highest wave value (m)		
Observation Station	1	2	3	1	2	3
Depth (meter)	3	4	7	3	4	7
Scenario 1	70	60	40	4.9	3.9	3.5
Scenario 2	140	110	90	2.1	1.2	1.5

VI. CONCLUSION

The study provides a real picture of the tsunami propagation scenario in the Celebes Sea by conducting numerical simulation based on hypothetical sources generated along the Parit North Sulawesi and Parit Cotabato by using TUNAMI-N2. Earthquake generation in extreme conditions with the power of Mw 9.5 has generated the region's tsunami around the Celebes Sea. The earthquake in the North Sulawesi Parit can threaten the region's tsunami to Tawau City with a height of 5 m. This scenario is also due to the narrow morphology of coastal waters of Tawau City which is also a driving factor for tsunami wave power. The quake at Parit Cotabato with Mw 9.5 strength was also recorded at the station with a maximum height of 2.1m. The wave refraction that occurred during wave propagation leading to the southern Philippine archipelago reduces the tsunami wave power through the Celebes Sea. Tawau City has the potential to experience the tsunami threats caused by the earthquake around the Celebes Sea.

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