ISSN 8755-6839

SCIENCE OF **TSUNAMI HAZARDS**

Journal of Tsunami Society International

Volume 40 **Number 4** **2021**

IMPACT ANALYSIS OF THE 2018 TSUNAMI ON SULAWESI ISLAND USING SATELLITE IMAGERY

Andrey Zaytsev[1], Pavel Pronin[2], Adel Giniyatullin[2], Efim Pelinovsky[1,3] and Marina Zaytseva[2]

[1] *Special Research Bureau for Automation of Marine Researches, Yuzhno-Sakhalinsk, Russia*
[2] *Nizhny Novgorod State Technical University n.a. R.E. Alekseev, Nizhny Novgorod, Russia*
[3] *Institute of Applied Physics, Nizhny Novgorod, Russia*

ABSTRACT

On September 28, 2018, a strong earthquake and tsunami occurred on the island of Sulawesi (Indonesia), which turned out to be the most destructive this year (more than 2,000 people died). The magnitude of the earthquake was 7.5. Its epicenter was located at the base of the Minahasa Peninsula, about 78 km from the city of Palu, the administrative center of the province of Central Sulawesi, at a depth of 10 km. A strong earthquake set in motion several submarine landslides and the departure into the sea of sections of the coast. As a result, the coastal zone and its ecology have been changed that confirmed by analysis of satellite imageries before and after the event.

Key words: *landslide, earthquake, environmental damage, Indonesia*

1. INTRODUCTION

On September 28, 2018, a strong earthquake and tsunami occurred on the island of Sulawesi (Indonesia), which turned out to be the most destructive in the world in 2018 (more than 2,000 people died). The magnitude of the earthquake was 7.5 and tremors were felt almost throughout the island of Sulawesi, as well as in the Indonesian province of East Kalimantan and in the East Malaysian state of Sabah [Heidarzadeh et al, 2019; Goda et al, 2019]. The US Geophysical Agency (https://earthquake.usgs.gov) defined the type of earthquake as "slip-strike" when the fault axis is along the meridians and the fault movement occurs along it. Usually, in such an earthquake, less energy is transferred to the water surface, so the tsunami warning, originally issued by the Indonesian Center, was canceled. Nevertheless, the height of the tsunami waves on the shore in the area of the administrative center of Palu reached 11 m and the tsunami led to significant destruction and casualties along the coast of Palu Bay [Omira et al, 2020].

Several field missions were conducted on the island of Sulawesi, which made it possible to measure wave heights along the coast and assess the nature of destruction and environmental changes [Omira et al, 2020; Zaytsev et al, 2019a ; Zaytsev et al, 2019b]. The authors of this work as part of an international group of scientists took part in these expeditions. The research was carried out on the island of Sulawesi in the Gulf region of Palu from November 7 to 11, 2018 together with scientists from Indonesia, Turkey, Austria, Italy, Morocco, Portugal under the auspices of the Government of Indonesia and UNESCO-IOC.

It should be noted that surveys of tsunami traces are always laborious and costly, so it is important to use modern means of observing our planet from spacecraft. The purpose of this article is to analyse satellite images of the island of Sulawesi and compare them with direct coastal zone survey methods.

2. SATELLITE IMAGES OF SULAWESI ISLAND atellite images of Sulawesi Island

First of all, we note that a satellite image of the earth's surface of the northwestern island of Sulawesi, presented in Figure 1 from the NASA website (https://disasters.nasa.gov/sulawesi-island-indonesia-earthquake-and-tsunami-2018/aria-along-track-deformation-map-m75-september), shows that the eastern part of Palu Bay dropped to a height of 3 m., the western part rose. Such residual displacements over the epicenter of the earthquake, which are difficult to measure by direct methods, are well traced in satellite images and give an idea of the scale of vertical displacements in the tsunami focus. Even if land areas were not covered by water during the tsunami, their displacement changes the landscape of the coastal zone and affects the ecological state of the area. Flooding the coast with tsunami waves only exacerbates the situation.

Tremors during the earthquake caused several large landslides in the bay, which caused a strong tsunami [Zaytsev et al, 2019b; Sassa S. and Takagawa, 2019; Nakata et al, 2020]. The descent of two such landslides in the areas of Benteng (Buenteng) and Tamunggu (Tamungu) was captured (Figure 2) by the pilot Icoze Mafella (https://www.youtube.com/watch?v=WkrBP9bnTcw) of Batik Air, who by a fluke took off a minute before the earthquake. Note that the airport was partially destroyed by an earthquake and this affected the speed of restoration work.

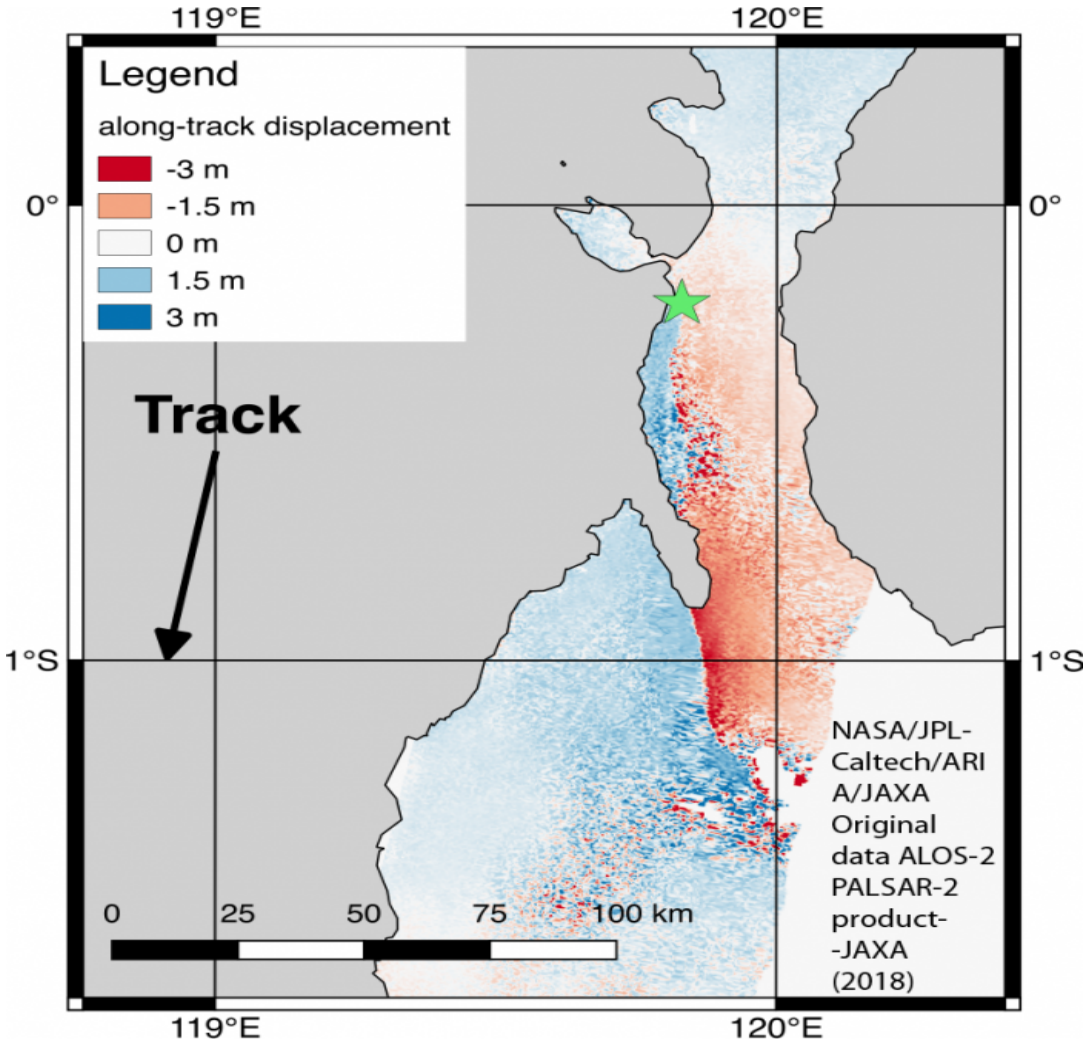

Fig. 1 Displacement of the earth's surface after the earthquake on 28 September, 2018. The position of the epicenter of the earthquake was marked with a star. (https://disasters.nasa.gov/sulawesi-island-indonesia-earthquake-and-tsunami-2018/aria-along-track-deformation-map-m75-september)

Fig. 2 Photo of landslide in Benteng - left and Tamunggu - right

Below, we will discuss in more detail the comparison of satellite imagery with field surveys in some coastal locations following the earthquake and tsunami on Sulawesi Island. Figure 3 shows a map of the island of Sulawesi with marked coastal points, where direct measurements of tsunami wave heights were made [Omira et al, 2020]. Given the possible problems with the correct translation of Indonesian names into Russian, we will mainly use the English coastal names shown in figure 3. Space images made it possible to obtain panoramic images of sections of the coast, which is almost impossible to do during surveys.

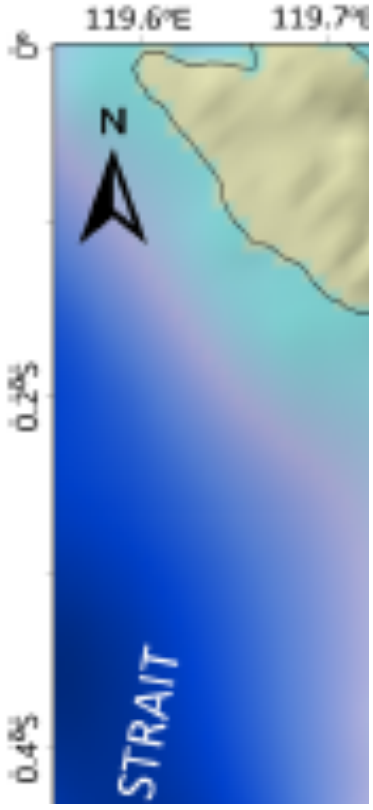

Fig. 3. Map of Palu Bay with marked points of the tsunami wave heights measurements

2.1 BENTENG (0.8464S 119.8226E)

Satellite images and of the tsunami wave heights measurements in the area of the Benteng village showed that a large part of the coast, more than 500 m length and a maximum width of about 120 m, move to sea (Figure 4). Note that a significant part of the landslide was probably under water and therefore the volume of the landslide can be estimated after additional sonar hydroacoustic studies. The height of the tsunami waves at this point reached of 9 m. Tsunamis of landslide origin are usually local in nature and lead to maximum heights in the area of the landslide. Note that this landslide was located in the area of the river bed, like almost all the others that were discovered during the expedition. The layer of bottom precipitation in the river accumulates for a long time and then is driven by external influence.

Fig 4. Benteng region

2.2 LOLI-PESUA (0.70137S 119.84438E)

Satellite images of the Lolli Pesua village area, taken before and after the tsunami, showed that a large part of the coast more than 500 m length and with a maximum width of about 200 move to sea (Figure 5). The height of the tsunami waves at this point reached a height of 4.9 m.

Fig 5. Loli-Pesua area, left satellite picture before earthquake, right after earthquake and tsunami

2.3 TONGGE (0.70137S 119.84438E)

At this point, according to satellite images, a strong displacement of the coastline by 100 meters on land is observed (Figure 6). The black line shows the GPS track along the modified coastline. A photograph of this coast is shown in the same figure, and the measured height of the tsunami wave run up in this area is 4 m.

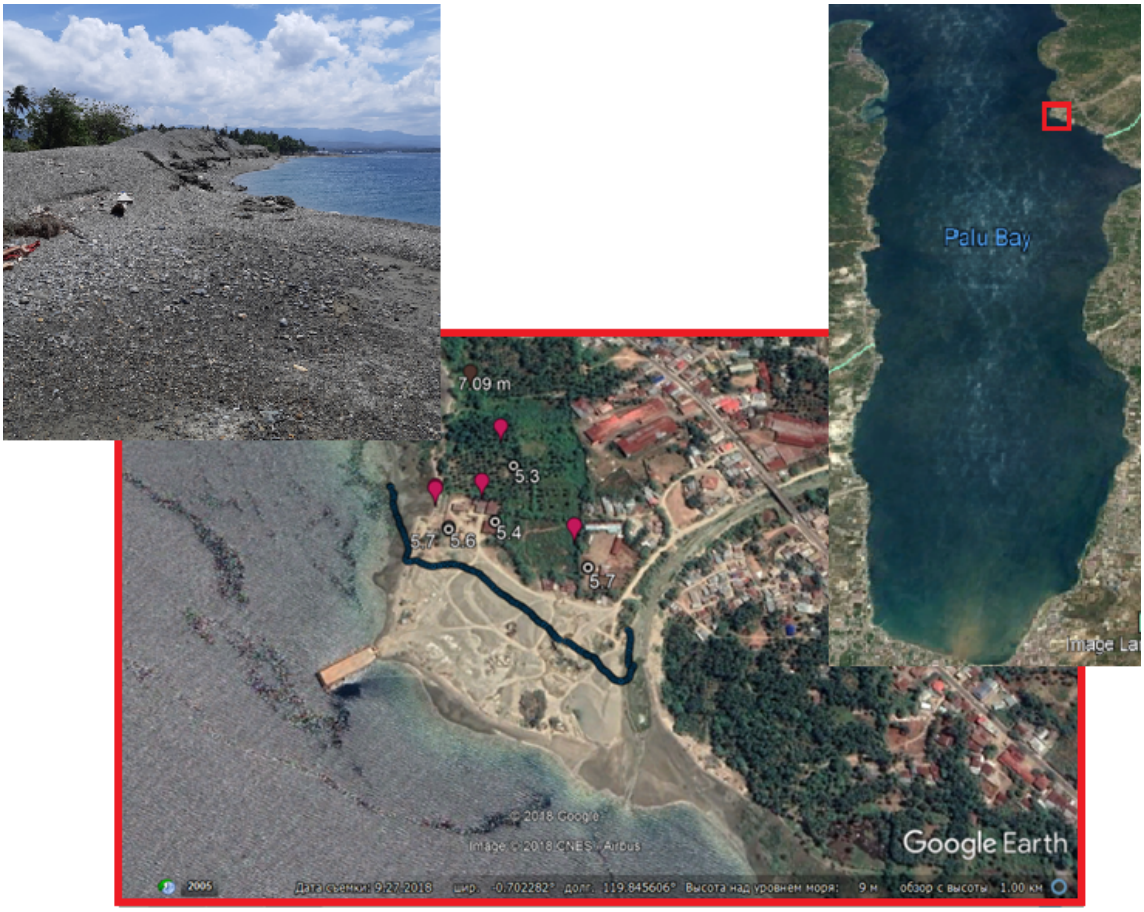

Fig. 5. Tongge area

2.4 BAMBA (0.7408S 119.8548E)

Witnesses reported that the first wave arrived 2-3 minutes after the earthquake. The height of the splashes reached a height of 4.5 m, and the height of the tsunami wave run-up was 2.9 m. The height of the water flow near the structure was 1 m. In this area, part of the coast was submerged by 2 m, which can be seen in the satellite image (Figure 7), and this is practically observed on the entire eastern coast of Palu Bay.

Fig. 7. Bamba region

2.5 PALU (0.8860S 119.8612E)

A survey of tsunami traces was carried out in the affected part of the city of Palu. Located in the center of Palu Bay, with a population of about 350,000, this town has an airport that has been damaged. The city was badly damaged after the earthquake and tsunami (Figure 8). A large bridge was destroyed and a park with buildings along the coastline was destroyed, which is especially clearly visible on satellite images (Figure 9). The height of the tsunami waves here reached a height of 11 m. After the earthquake, part of the coastal zone plunged into the sea to a depth of 2 m. Satellite images of the affected part of the city of Palu before and after this catastrophic event (Figure 9) show that most of the coastal zone is destroyed and soil erosion after the tsunami is observed in a significant area.

Fig. 8. Palu region

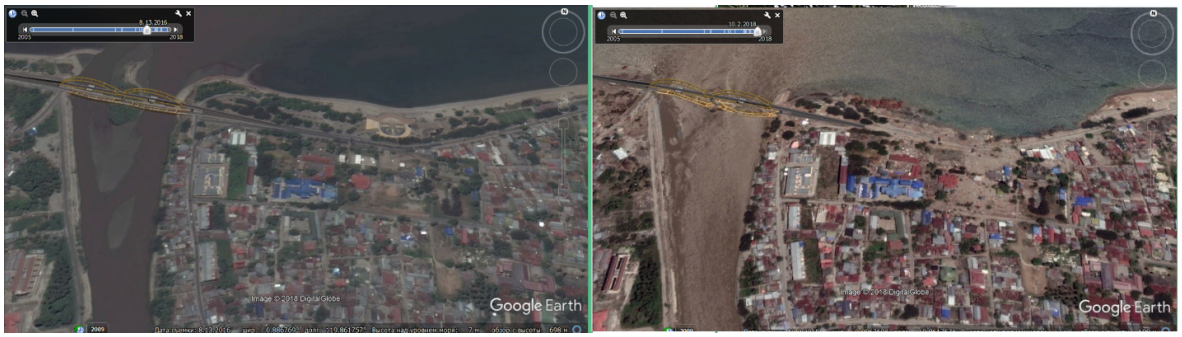

Fig. 9. Satellite image of Palu in the bridge area (left 2017, before the earthquake; October 2018, right, after the earthquake)

3. CONCLUSIONS

The paper presents data from satellite images of Sulawesi before and after the catastrophic earthquake and tsunami in 2018. These images allowed for better planning of the field survey of tsunami trails, in which the authors of the article participated. The importance of satellite images in their panoramic view, allowing you to see the characteristic changes in the landscape and understand their impact on the ecology of the coastal zone. The images show the rise and fall of the level to a height of up to 3 meters, depending on the position of the site from the fault. Detailed characteristics of the tsunami wave heights were obtained in the course of field studies. The earthquake and tsunami have been confirmed to have caused significant environmental changes in the region.

ACKNOWLEDGMENTS

The grants of President of the Russian Federation for the state support of Leading Scientific Schools of the Russian Federation (grant No. NSH- 2485.2020.5) and Young Russian Scientists – Doctors of Sciences (MD-148.2020.5) and RFBR 20-05-00162.
The grants of President of the Russian Federation for the state support of Leading Scientific Schools of the Russian Federation (grant No. NSH- 2485.2020.5) and Young Russian Scientists – Doctors of Sciences (MD-148.2020.5). Grant RFBR 20-05-00162.

REFERENCES

Heidarzadeh M., Muhar A., Wijanarto A.B., 2019. Insights on the Source of the 28 September 2018 Sulawesi Tsunami, Indonesia Based on Spectral Analyses and Numerical Simulations. *Pure Appl. Geophys*. 176 (2019), 25–43

Goda K., Mori N., Yasuda T., Prasetyo A., Muhammad A., Tsujio D., 2019. Cascading Geological Hazards and Risks of the 2018 Sulawesi Indonesia Earthquake and Sensitivity Analysis of Tsunami Inundation Simulations. *Frontiers in Earth Science* 2019, Volume 7, Article 261

Nakata K., Katsumata A., Muhari A. Submarine landslide source models consistent with multiple tsunami records of the 2018 Palu tsunami, Sulawesi, Indonesia Nakata *et al. Earth, Planets and Space (2020) 72:44* https://doi.org/10.1186/s40623-020-01169-3

Omira R., Dogan G.G., Hidayat R., Husrin S., Prasetya G., Annunziato A., Proietti C., Probst P., Paparo M.A., Wronna M., Zaytsev A., Pronin P., Giniyatullin A., Putra P.S., Hartanto D., Ginanjar G., Kongko W., Pelinovsky E., Yalciner A.C., 2020. The September 28th, 2018, tsunami in Palu-Sulawesi, Indonesia: A post-event field survey. *Pure and Applied Geophysics*, 2019, vol. 176, 1379 – 1395.

Sassa S., Takagawa T. 2919a. Liquefied gravity flow-induced tsunami: first evidence and comparison from the 2018 Indonesia Sulawesi earthquake and tsunami disasters. *Landslides* (2019a) 16:195–200. DOI 10.1007/s10346-018-1114-x

Zaytsev A.I., Pronin P.I., Giniyatullin A.R., Kurkin A.A., Pelinovsky E.N., 2019a. 28th September 2018 tsunami influence on an ecological situation at the Sulawesi island (Indonesia) *Ecological systems and devices.* 2019b No. 5, P. 25-29. DOI: 10.25791/esip.05.2019.624

Zaytsev A.I., Pelinovsky E.N., Yalciiner A., Susmoro H., Prasetya G., Hidayat R., Dolgikh G.I., Dolgikh S.G., Kurkin A.A., Dogan G., Zahibo N., Pronin P.I. , 2019b. Generation of the 2018 Tsunami on Sulawesi Island: Possible Sources *Doklady Earth Sciences*. 2019. V. 486. Iss. 1. P. 588-592. DOI: 10.1134/S1028334X19050295.