

Potential tsunami hazard in Ujung Kulon National Park

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Abstract. Ujung Kulon National Park (UKNP) is a natural world heritage site located at the western tip of Java Island and on the edge of the Indian Ocean. This area of 122,956 ha has the potential for tsunami hazard originating from Mount Anak Krakatau and the Sunda Arc subduction zone. Almost no residents live in the UKNP region, however, it is the only place on earth that remains a habitat for the Javan rhino (*Rhinoceros sondaicus*) whose population is less than 100. This study aims to discuss the potential for tsunami hazards in UKNP originating from the earthquakes in Indian Ocean. The shallow water equation model was used to simulate the generation and propagation of tsunami waves. A total of 50 numerical gauges with intervals of 4 km were used as assessment points placed along the 190 km coastline of UKNP. From the simulation it can be seen that the height of the tsunami reaches 12.9 m around the coast of UKNP causes this area is vulnerable to tsunami hazards. This information can be used as consideration for the management of the UKNP area so that it can continue to preserve flora and fauna, especially to avoid the extinction of the Javan rhino.

1. Introduction

A peninsula located at the western end of the island of Java has become the home of one-horned rhinoceros that remains on earth. Actually this area is also a habitat for other animals such as Java bulls, monkeys, deer, and mouse deer [1]. However, the one-horned rhino or Javan rhino (*Rhinoceros sondaicus*) is the animal that gets the most attention because its population is very vulnerable to extinction. Therefore UNESCO established this area as a natural world heritage site in 1992 [2]. Previously this area had long been designated as a national park by the Indonesian government with the official name Ujung Kulon National Park.

Historically, this region was not a safe area from natural hazards. Earthquakes often occur but did not directly affect the life of plants and wildlife. While the more obvious influence was the eruption of volcanoes and tsunamis that have struck several times. During the Krakatoa eruption in 1883 which was one of the most severe eruptions on earth, this area was reported to have suffered severe environmental damage [3]. The traces of the tsunami in Ujung Kulon due to the 1883 eruption were proven by Paris et al through the study of tsunami deposits [4]. Likewise in the latest tsunami event in 2018 [5][6], this region also experienced the highest tsunami wave runup compared to other coastal areas in the Sunda Strait as reported by [6]. [7] and [8] also stated that this area was at risk of experiencing a tsunami that could affect the lives of protected animals in the national park. The scenario that fits the 2018 tsunami in the Sunda Strait was simulated in 2012 by [9]. Based on these simulations, the tsunami caused by the flank collapse of Mount Anak Krakatau directed radially until



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it reached the coast at the southern tip of the island of Sumatra (Lampung Province) and the western end of the island of Java (Banten Province).

Javan rhinos are often near the beach to meet the needs of salt minerals. Plants as Javan rhino food exist in the distance of 0-600 m from the beach. In addition, 61.9% distribution of Javan rhinos is 0-1000 m from the coast [10]. Figure 1 is a photo report of the death of a rhino in 2018 [2]. Whereas Figure 2 illustrates the destruction of forests in the UKNP due to the 2018 tsunami [6]. The tsunami can directly hit an individual Javan rhino to cause its death, besides that an important thing is the possibility of forest destruction which is a food source for wildlife, especially Javan rhino. In the effort to conserve the Javan rhino, tsunami risk analysis is one of the factors that need to be considered in addition to other factors that have been analyzed, for example regarding the quality of food [11] and habitat suitability [12].



Figure 1 Death of a Javan rhino on Ujung Kulon beach (courtesy: UKNP 2018)



Figure 2 Forest destruction as a habitat for Javan rhinos in the UKNP due to the 2018 tsunami (photo is the result of a survey by Widiyanto et al 2018)

This article discusses the potential for tsunami hazard in the UKNP due to earthquakes obtained from simulations. In this study only tsunamis originating from earthquakes were simulated. The results of modeling and analysis can be used as consideration for the management of the national park, especially in realizing a safer second habitat outside the existing national park that is prone to tsunamis.

2. Method

In this study, tsunami waves propagation were calculated by the long wave equation or shallow water equation. Considering that the simulation area is large enough, a spherical coordinate system was applied. The nonlinear shallow water equation using spherical coordinates can be stated:

$$\frac{\partial \eta}{\partial t} + \frac{1}{R \cos \varphi} \left\{ \frac{\partial P}{\partial \psi} + \frac{\partial}{\partial \varphi} (\cos \varphi Q) \right\} = -\frac{\partial h}{\partial t} \quad (1)$$

$$\frac{\partial P}{\partial t} + \frac{1}{R \cos \varphi} \frac{\partial}{\partial \psi} \left\{ \frac{P^2}{H} \right\} + \frac{1}{R} \frac{\partial}{\partial \psi} \left\{ \frac{PQ}{H} \right\} + \frac{gH}{R \cos \varphi} \frac{\partial \eta}{\partial \psi} - fQ + F_x = 0 \quad (2)$$

$$\frac{\partial Q}{\partial t} + \frac{1}{R \cos \varphi} \frac{\partial}{\partial \psi} \left\{ \frac{PQ}{H} \right\} + \frac{1}{R} \frac{\partial}{\partial \psi} \left\{ \frac{Q^2}{H} \right\} + \frac{gH}{R \cos \varphi} \frac{\partial \eta}{\partial \psi} - fP + F_y = 0 \quad (3)$$

Where η is the water surface elevation; (P, Q) denote the volume fluxes in X (West-East) direction and Y (South-North) direction, respectively; (φ, ψ) denote the latitude and longitude of the Earth; R is the radius of the Earth; g is the gravitational acceleration and h is the water depth. And the term $-\partial h / \partial t$ reflects the effect of transient seafloor motion, can be used to model landslide-generated tsunamis. F represents the Coriolis force coefficient due to the rotation of the Earth

Equations (1) - (3) are then solved by the COMCOT (Cornell Multi-grid Coupled Tsunami model) [13]. This model is one of the most widely used tsunami models and has successfully modeled many tsunami cases. Tsunami generation originating from seabed deformation was modeled with elastic finite fault plane theory proposed originally by Mansinha and Smylie (1971) and then improved by Okada (1985) [13]. This approach requires input in the form of epicenter, focal depth, fault length and width, strike angle, dip angle, rake angle, and slip.

The tsunami propagation model from source to points assessed requires bathymetric data. This study uses Batnas (6 arcsec resolution) as bathymetry data. These data are sourced from the Geospatial Information Agency (Indonesian: BIG). Bathymetry data were used to form the simulation layer. In this study, three layers of simulation are used which form a nested grid system. COMCOT uses explicit staggered leap-frog finite difference schemes to solve numerical equations (1) - (3). From this simulation a tsunami wave height will be obtained in the assessed area, in this study the Ujung Kulon National Park.

The simulation domain is shown in Figure 3 where the observed coastal area is part of the UKNP area. At Ujung Kulon Peninsula and Panaitan Island, 50 numerical gauges were placed at intervals of 4 km along the coastline to review tsunami wave heights that occurred due to an earthquake with magnitudes of Mw 8 and Mw 8.7. Selection of earthquake magnitude based on historical and potential earthquake that can occur due to ruptures in the Sunda Strait segment.

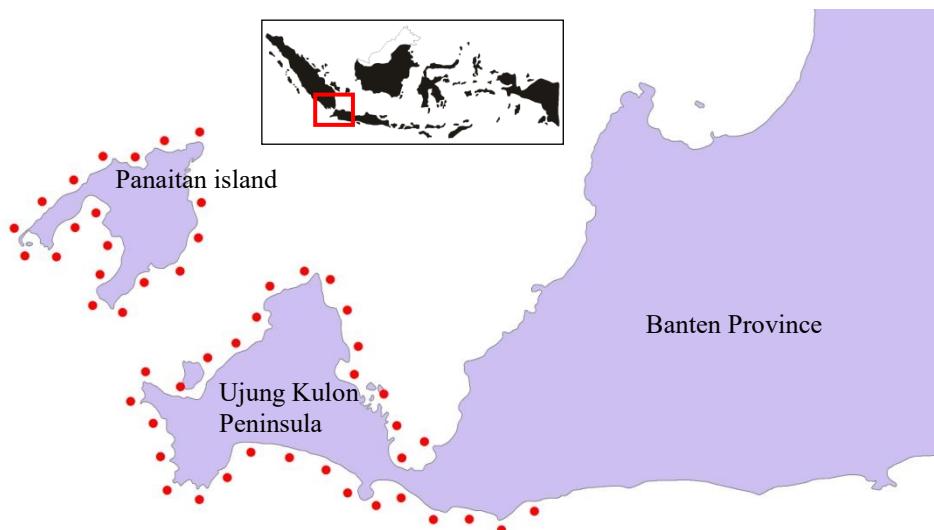


Figure 3. Study area covering a small part of Indonesia, east side of Sunda Strait and west tip of Java Island. Red-dots are numerical gauges for detecting water surface elevation.

3. Result

Figure 4 is a visualization of the results of the COMCOT model simulation. For the first simulation, an Mw 8 magnitude earthquake with epicenter at coordinates 104.547612 E and -7.277303 S was simulated occurring in the middle of the Sunda Strait tectonic segment. This magnitude selection is based on the history of tsunamis that occurred along the subduction zone of southern Java. Two tsunamis in modern era occurred in 1994 in the south of Banyuwangi with a magnitude of Mw 7.8 and in 2006 in the south of Pangandaran with a magnitude of Mw 7.7. Although the magnitude is not so large to generate a tsunami, in reality the wave heights and runups that occur were significant. In addition, the epicenter was determined randomly but according to historical earthquake data in the tectonic segment. Rupture due to earthquake with magnitude was estimated by scaling relation [14] as shown in Equation 4-5:

$$\log L = a + b M_w \quad (4)$$

$$\log W = a + b M_w \quad (5)$$

where L is rupture length, W is rupture width, a and b are regression coefficient and M_w is moment magnitude.

Calculation using the equations obtained length and width of 155 km and 66 km respectively. Deformation of the seafloor with this area is significant enough to change the sea level above it so that it can be the beginning of a tsunami generation (Figure 4). Changes in sea level then spread towards the coast as a tsunami wave, and arrived around Ujung Kulon Peninsula and Panaitan Island earlier before the tsunami entered the Sunda Strait (Figure 5). The direction of propagation is influenced by the angle of direction of the rupture (strike angle) and bathymetry.

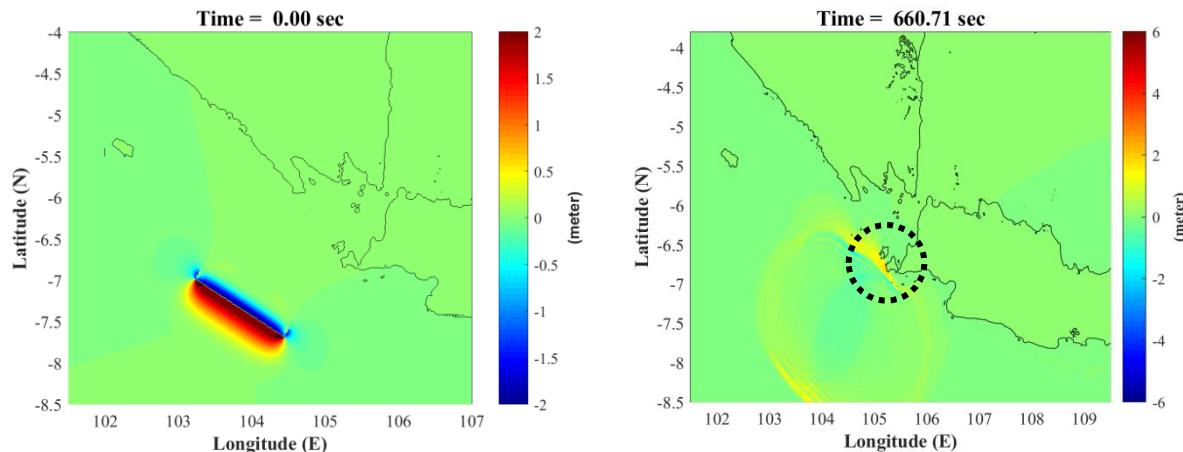


Figure 4 A sea floor deformation due to the M_w 8 earthquake produced changes in the surface of the water which would propagate as a tsunami wave.

Figure 5 Tsunami propagation from the Indian Ocean entering the Sunda Strait. Ujung Kulon Peninsula and Panaitan Island were seen to have been hit by the tsunami even though in this case the waves were not so high.

The second simulation used a greater earthquake magnitude of M_w 8.7 with the same epicenter as the first simulation. The choice of magnitude corresponds to the maximum potential for earthquake magnitude in the Sunda Strait segment. The length and width of the rupture is greater than the magnitude of M_w 8, which is 299 km and 112 km, respectively. Dislocation and deformation are also greater, giving rise to higher tsunami waves (Figure 6 and Figure 7). Water level profiles due to tsunami waves on two numerical gauges are shown in Figure 7. One of the numerical gauges is located on the southern coast of Ujung Kulon peninsula, the other on southern tip of Panaitan Island. From this profile, it can be seen the maximum wave height and the arrival time of the tsunami. In this case, the tsunami came sooner on Panaitan Island than in Ujung Kulon peninsula, each 14 minutes and 17 minutes from the time the earthquake occurred. The amplitude and wave height in Ujung Kulon Peninsula is significant, 7.4 m and 12.9 m respectively. It is greater than in Panaitan Island, reaching 5.6 m and 8.4 m for amplitude and height of tsunami wave respectively. The tsunami wave heights for M_w 8.0 were lower than M_w 8.7. They were 4.5 m and 5.2 m for Ujung Kulon Peninsula and Panaitan Island respectively, which were not significant different in both location. These wave amplitudes, wave heights and arrival times can be different if we simulate with different parameters. It is possible to obtain a higher wave height. Therefore, it is necessary to simulate various scenarios. A probability tsunami hazard assessment (PTHA) may be done for this region. Since PTHA includes intensive simulation work, for efficiency, the study area can be expanded, for example by including the entire Sunda Strait area.

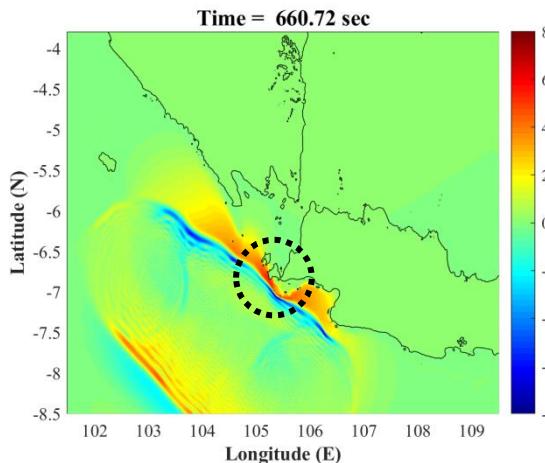


Figure 6 Tsunami waves generated by the Mw 8.7 earthquake seen higher than the magnitude of Mw 8. Black-dots circle is UKNP

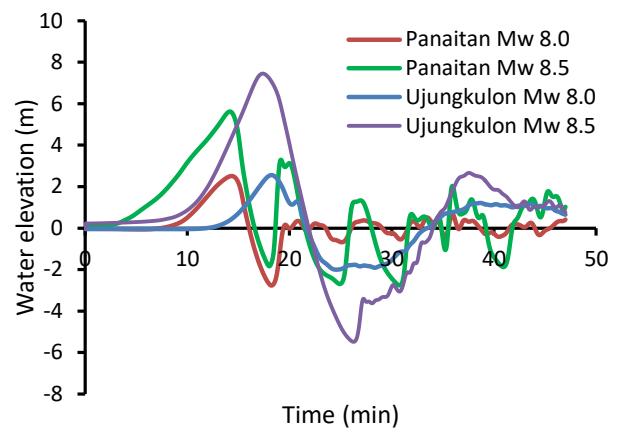


Figure 7 The height of the tsunami on Panaitan Island and Ujung Kulon due to the Mw 8.0 and Mw 8.7 earthquakes

From the simulation results it can be seen that the UKNP area has a risk of tsunami hazard. Likewise, the results of the field survey by Widiyanto et al. illustrate that part of the forest in Ujung Kulon National Park was destroyed by the tsunami in December 2018 [6]. Fortunately, the last population of Javan rhinos escaped extinction. This suggests that providing a second habitat outside the Ujung Kulon peninsula for the Javan rhino is very urgent. Research on the suitability of the release location has been investigated, for example by Ramono et al. who conducted a field survey and proposed relocation sites on Java, namely on Mount Honje, Mount Halimun, Masigit Kareumbi and Leuweung Sancang [15]. Therefore, it is time for the authorities to adopt policies to accelerate the realization of the second habitat of Javan rhinos.

4. Conclusion

The simulation results show that the UKNP area has a potential tsunami event with a significant height reaching nearly 13 m with a relatively short tsunami arrival time around 15 minutes. Mitigation needs to be done to save the Javan rhino habitat. Relocation of populations to second habitats located in areas farther from the coast is urgent.

This simulation only uses earthquakes with magnitudes of M_w 8 and M_w 8.7. The simulation needs to be extended for earthquakes with the same magnitude but different parameters causing the seabed deformation. Likewise, it can be continued for other magnitudes or worse scenarios need to be simulated also to find out the worst impact on UKNP. If deemed necessary, the simulation can be reproduced with the magnitude of other earthquakes to form a tsunami hazard probability for UKNP that extends to the Sunda Strait or the West Coast of Lampung which also has a UNESCO heritage national park namely the Bukit Barisan Selatan National Park. Another future work needs to be conducted will be tsunami simulation and analysis related to Mount Anak Krakatau, both due to the landslide cliffs and eruptions that directly change the sea surface.

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