

INVESTIGATION OF TSUNAMI IMPACTED AREA FROM ANAK KRAKATOA VOLCANIC ERUPTION

Agus Dwi Wicaksono and *Fadly Usman

Department of Urban and Regional Planning, Faculty of Engineering, Brawijaya University, Indonesia

*Corresponding Author, Received: 05 Aug. 2019, Revised: 24 Jan. 2020, Accepted: 13 March 2020

ABSTRACT: The eruption of Anak Krakatoa Volcano is assumed to be the cause to generate tsunami wave; it can also be assumed that the wave source is only about 50.3 km from the coast. The interesting point is that the propagation of the tsunami wave was not caused by an earthquake but rather by volcanic material from Anak Krakatoa Volcano which slid into the sea. An investigation was conducted using spatial analysis of coastal areas around Tanjung Lesung, Banten with GIS analysis. While the propagation of tsunami waves was calculated from Anak Krakatoa Volcano that was projected towards Tanjung Lesung, Banten. These analyses were done to obtain assumptions of the wave velocity and propagation time from the center of the wave to the coastal area. The primary purpose of this study is to investigate the effectiveness of the vegetation belts as tsunami mitigation. This study used a 2D numerical simulation wave based on a VOF method. The numerical simulation calculated the interaction between the bore wave propagation and the vegetation belts. Numerical analysis was done to estimate the altitude and velocity of tsunami waves toward the coastal area of Tanjung Lesung. By comparing the results of the spatial and numerical analysis, the delineation of the tsunami-affected area on 31 December 2018 can be determined.

Keywords: *Anak Krakatoa, Tsunami, Vegetation belts, Numerical simulation, GIS Analysis*

1. INTRODUCTION

The tsunami that hit South Lampung and Banten Province on December 31, 2018, is an unusual phenomenon in the case of a tsunami disaster. The tsunami happened without any earthquake, taking the coastal residents by surprise.

In general, tsunamis that hit coastal areas begin with an earthquake with a fairly shallow epicenter point. The official state institution that provides early warning of potential tsunamis in Indonesia is the Meteorology, Climatology and Geophysics Agency (BMKG), which, at the time of the tsunami in Banten and South Lampung, did not even record earthquakes with specific strengths before the tsunami.

According to several past research reports, tsunamis caused by volcanoes are quite rare. The eruption of Krakatoa Volcano in 1883 was the only series of eruptions that had enough data for detailed studies of tsunamis. Historical records estimated the tsunami to originate from a volcanic eruption, at a distance along the coastline to a tide gauge calculating 15 minutes of travel time to the coast, or equivalent to the range of a tsunami wave in the observed interval time against the distance of Krakatoa Volcano towards the shore [1].

More in-depth studies need to be conducted to determine the relationship between the Anak Krakatoa eruption and tsunami wave propagation. The mechanism of tsunamis triggered by a volcanic eruption is slightly different from the tsunami triggered by an earthquake.

In this study, a spatial analysis was carried out using ArcGIS to delineate the impacted topographic areas in the coastal area of Tanjung Lesung, Banten. Field observations were done with the help of aerial photographs using unnamed aerial vehicle (UAV) or drones. The numerical analysis is also used in this study, which is useful to determine the height and velocity of the tsunami waves range entering the land.

2. LITERATURE REVIEW

Numerical simulations on waves are often used in several studies, and in this research, it was conducted to verify and compare the results of the tsunami with several scenarios such as wave height, earthquake center, topography, etc. [2].

A satisfactory correlation was reached between the results of the explosion and the deposits caused by the eruption, as was geologically determined to be close to the eruption source. Thus, to determine the tsunamigenic potential of a certain volcano, a specified index can be estimated to be in specific planes to calculate the tsunami amplitude, and therefore can also serve as a basis for tsunami risk contingency plan [1].

Volcanic tsunamis are rare compared to seismic tsunamis. Volcanic tsunamis are characterized by short to medium wavelengths, and their effects are often limited. By considering the diversity of source mechanisms, the prevention of volcanic tsunamis through monitoring is very challenging and must be combined with the preparedness policies of

potentially affected communities. In the case of hazard evaluation and warning, the worst case scenario is from tsunamis caused by activity or instability of submarine volcanoes, most of which are not monitored [3].

The profile of the simulated waves from the tsunami caused by volcano avalanche (Fogo, Cape Verde) can reach 50-100m. The comparison of two tested avalanche scenarios (massive or retrogressive) based on the numerical simulation results shows that the failure mechanism of landslide material can be simulated to determine the impact based on waves and rise of seawater [4].

The eruption of the Krakatoa Volcano in 1883 showed that the velocity of a pyroclastic flow was 15 minutes faster than a tsunami wave. While the pyroclastic flow that hit the coastal area, which is as far as 60 km from the center of the explosion, have killed around 1,000 people [1, 5].

As the tsunami waves have occurred, all the available data for the assumptions of wave propagation velocity and wave height in coastal areas use numerical simulations and GIS-based spatial analysis.

Previous research has shown that the use of numerical simulations can help researchers to calculate wave velocities as well as wave heights at predetermined measurement points [6-9]. While the use of satellite imagery or aerial photo processing to identify tsunami risk have been conducted by previous researchers with a variety of variables [10, 11].

The reality faced by developing countries, like Indonesia, is the absence of a good early warning system which is closely related to information on tsunami risks which should be widely accessible to the community. Like Japan with the Japan Meteorological Agency (JMA) is being the official state institution that provides reliable information and is easily accessible to all communities [12].

This study shows the trigger for the tsunami wave was the activity of Anak Krakatoa Volcano. If a straight line projected from Anak Krakatoa Volcano to Tanjung Lesung, Banten, the distance would be around 50 km. Another preliminary data for numerical simulation is the velocity of the tsunami wave, knowing the depth of the Sunda Strait being about 100m can determine the assumed tsunami wave velocity before it hit the coastal area in Tanjung Lesung, Banten, Indonesia. This study will use CADMAS Surf/2D software with measurement parameters such as wave velocity and inundation height. The results of the numerical simulation can also show how big the horizontal force is when compared between wave height and wave velocity.

Tsunami risk can be defined as a mathematical calculation by entering the relevant variables and the vulnerability of the tsunami or the tsunami

hazard, so it can be assessed using spatial multi-criteria [10]. Physical vulnerability parameters such as topographic data, distribution of settlements, etc. are then analyzed and evaluated where all the parameters in tsunami vulnerability and the tsunami risk assessment are analyzed through the overlaying technique for each attribute in the geospatial analysis [10, 11].



Fig.1 Tsunami affected areas in Banyuasih Village, Pandeglang, Banten, Indonesia

The ability of the tsunami wave height to propagate to a higher location is also limited. Thus, topographic data in spatial analysis becomes very important, and the range of the waves will also be limited by how much volume of seawater enters the land. Thus, analysis needs to be done simultaneously, namely (1) analysis based on tsunami events, (2) numerical analysis to determine the water level height (inundation depth), and (3) spatial analysis to determine the estimated inundation based on the results of the previous analysis.

One variable can be found in the tsunami-affected area in Tanjung Lesung, Banten which is a terrestrial area. There is a great deal of vegetation distribution that can hinder tsunami waves to go further inland. Field observations show that shrub vegetation dominates the tsunami-affected area, but other vegetations can be significant barriers to withstand tsunami waves, thus decreasing the hydraulic force and the destructive force will also decrease dramatically.

The distribution of vegetation at the research location as shown in Figure 1 above is drawn the spacing between vegetations and residential area. Two regions contrast, namely in areas with dense vegetation cover and coastal areas with low-density vegetation cover. Based on the aerial photos in Figure 1, it can be assumed that the tsunami waves were dampened. Thus the destructive force was also significantly decreased. The aerial photo above will be analyzed based on topography and land cover. Thus the initial assumption that tsunami waves slow

down after being blocked by vegetation belts can be scientifically proven both by using spatial analysis and numerical simulation.

3. METHOD

This research uses two technical approaches to analyze the propagation of tsunami waves from Anak Krakatoa Volcano to Tanjung Lesung, Banten, namely by conducting numerical analysis using CADMAS Surf / 2D software. This software can calculate the wave velocity and altitude at the measured points previously set in the simulation, enabling the assumption of initial behavior of the tsunami waves that hit Tanjung Lesung.

The other technical approach is a spatial analysis based on terrestrial area and topographic data in the research location. The data related to the maximum height, farthest wave range and information about other affected areas are used when calculating wave propagation in numerical analysis and also as preliminary data in the spatial analysis to determine the delineation of the affected area.

Many past studies have developed a numerical analysis method to analyze the behavior of tsunami waves to study the impact of the tsunami disaster and further understand the geophysical phenomena in the tsunami. Such a method has also been applied to generate tsunami waves on a computer layer which are then observed based on the measurement points previously set in the numerical analysis [13-15].

$$\frac{\partial \gamma_x u}{\partial x} + \frac{\partial \gamma_z w}{\partial z} = S_p \quad (1)$$

$$\lambda_v \frac{\partial u}{\partial t} + \frac{\partial \lambda_x u u}{\partial x} + \frac{\partial \lambda_z w u}{\partial z} = -\frac{\gamma_v}{\rho} \frac{\partial p}{\partial x} + \frac{\partial}{\partial x} \left\{ \gamma_x v_e \left(2 \frac{\partial u}{\partial x} \right) \right\} + \frac{\partial}{\partial x} \left\{ \gamma_x v_e \left(\frac{\partial u}{\partial z} + \frac{\partial w}{\partial x} \right) \right\} - D_x u + S_u - R_x \quad (2)$$

$$\lambda_v \frac{\partial w}{\partial t} + \frac{\partial \lambda_x u w}{\partial x} + \frac{\partial \lambda_z w w}{\partial z} = -\frac{\gamma_v}{\rho} \frac{\partial p}{\partial z} + \frac{\partial}{\partial z} \left\{ \gamma_z v_e \left(2 \frac{\partial w}{\partial z} \right) \right\} + \frac{\partial}{\partial z} \left\{ \gamma_z v_e \left(\frac{\partial w}{\partial x} + \frac{\partial u}{\partial z} \right) \right\} - D_z w + S_w - R_z - \gamma_v g \quad (3)$$

$$\gamma_v \frac{\partial F}{\partial t} + \frac{\partial \gamma_x u F}{\partial x} + \frac{\partial \gamma_z w F}{\partial z} = S_F \quad (4)$$

To estimate the tsunami wave propagation, the software CADMAS-Surf/2D is used as this software can generate tsunami waves in numerical simulations. The used equation consists of the continuity equations, the Navier-Stokes equation in the directions of x, y, and z as an advection equation to trace the water level.

The last equation includes the function, $F(x, z, t)$, which is the ratio of the volume of water in each numeric cell. In the equation below, t is time, while x and z is a horizontal and vertical coordinate point.

Whereas, p means pressure. The value u and w are the components of horizontal velocity and vertical velocity, in each term.

Then ρ is fluid density, ν is the sum of molecular kinematic viscosity and eddy kinematic viscosity, g is the gravitational acceleration. Whereas γ_v is porosity, γ_x , and γ_z are components of air porosity, S_F , S_u , and S_w are sources of wave generation, D_x , and D_z are coefficients for the sponge layer, and R_x , and R_z is a resistance component because of porosity on the x and z -axes [2, 16].

To perform a numerical simulation using CADMAS-Surf 2D, continuous time is needed based on water level elevation and fluid velocity at the initial boundary of a particular channel, to produce waves with profiles like tsunamis. This study initially assumes a bore wave profile in offshore areas, with the bore wave velocity obtained through the following equation [17].

$$U = \frac{C\zeta}{H} = \zeta \sqrt{\frac{g(H+h)}{2H(H-\eta\zeta)}} \quad (5)$$

In this equation, U means the velocity of the average water depth and g means the acceleration of gravity. $H = h + \zeta$ means the total depth of datum and ζ also means the height of the temporal bore. η is the coefficient obtained from the ratio between the initial water depth in the total depth propagation area and is specified as 1.03 in this study. The bore wave propagation and velocity in this study are set according to the experimental study by Wijatmiko [18]. To Consider the vegetation area in numerical simulation, the porosity of vegetation belts area is set as 0.97 according to the experimental study by Harada [19] and Suzuki [20].

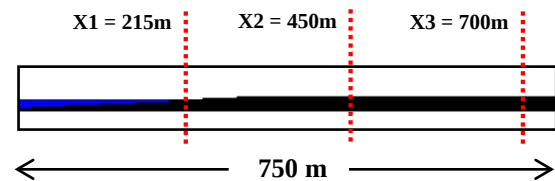


Figure 2. The used flume for numerical simulations with CADMAS Surf

Figure 2 above shows the wave channel scheme for numerical simulation in this study. The flume has a length of 750m and a height of 35m. The offshore wave depth is maintained as 10m. The beach slope is 1/25. While the grid size for numerical simulations in the x and z directions is set at $\Delta x = 0.25m$, $\Delta y = 0.25m$ and $\Delta z = 0.25m$, respectively

The measuring point in the simulation is $X1 = 215m$, $X2 = 450m$ and $X3 = 700m$. Figure 3 below shows the researcher's assumption in calculating

the tsunami travel time from the landslide point of volcanic material until it reaches Tanjung Lesung, Banten.

Equation (6) helps determine that the velocity of a tsunami wave is 33.3 m/s or equivalent to 108 km/hr, making the arrival time of the tsunami wave to be about 30 minutes after a volcanic eruption. This is because the distance between the location of Anak Krakatoa Volcano is approximately 50.3 km and the Sunda Strait sea depth is 100m.

$$v = \sqrt{gh} \quad (6)$$

The shallow water wave equation (equation 6) can help estimate the travel time of the wave from the earthquake point to the location of the plan. In this equation, v is the velocity (m/s), g is gravity (m / s^2) while h is the depth of the sea in the Sunda Strait (m). However, considering that the depth of the sea gets shallower as it gets closer to land, the wave velocity will also ultimately be slower. Thus, the travel time of the waves from Anak Krakatoa Volcano to Tanjung Lesung is about 45-60 minutes after the eruption of Anak Krakatoa Volcano.

In this study, the spatial analysis uses ArcGIS 10.3 software where the software has a feature to display terrestrial area at the research location. The relationship between remote sensing techniques and GIS needs to be studied more deeply, which will play an important role in mapping the zones of tsunami-affected areas based on aerial photographs and topographic data.

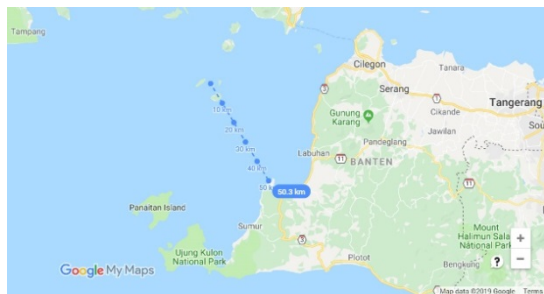


Figure 3. The distance from Anak Krakatoa Volcano to the tsunami-affected area

Identification of tsunami-affected areas can be made mainly by comparison of satellite remote sensing data and topographic analysis. In this case, the use of GIS technology is used to display the boundaries of the affected area using existing attributes. However, maps affected by the tsunami must be validated by conducting ground checks in the field [21]. When the before and after the tsunami conditions are known, several analyses can be done, such as tsunami range, distribution of residential areas, number of directly affected housing units, other assets and property affected by the tsunami, and other natural features that are directly affected

by tsunamis such as rivers, forests, rice fields, fields, and so on.

As for estimating slopes and 3D shapes from the research location, Global Mapper 16 is used to calculate the tsunami range based on land height data from the sea surface. There are two comparison maps, which are images from aerial photographs and based on BingMap or GoogleMaps database while other comparative data series are based on the available data on GoogleMaps features and aerial photography results using DJI Mavic Pro drones.

4. RESULTS AND DISCUSSION

As previously described, the research was conducted based on the tsunami data in Tanjung Lesung, Banten. Figure 4 below is the difference between Banyuasih Village, Cigeulis District and Pandeglang District which is some of the villages affected by the tsunami around Tanjung Lesung Beach, Banten. There is a contrast condition between the affected and non-affected areas. The field information stated that the wave height is only about 50cm with a limited wave range reaching the highway. The initial assumptions are that coastal vegetations can reduce the wave velocity and local roads that divide the village also stop the wave velocity whereas the vegetations after the local road dampen the effect of the tsunami wave.

To assess the existence and function of vegetation belts as a natural damper tsunami wave, some numerical simulation scenario are conducted.



Figure 4. Before and after conditions of Banyuasih Village, Cigeulis, Pandeglang, Banten Province

Figure 4 clearly shows the contrast of the west and east side of Banyuasih Village. The west side of Banyuasih Village is clean as the remnants and debris of the tsunami rubbish were cleared by the villagers, while the east side of Banyuasih village was still lush with plants with very high plant density. Based on observations in the field, the planted trees planted are coconut (*Cocos Nucifera* sp), with a spacing of about 3m.



Figure 5. Green belts and land cover

To perform numerical simulations using CADMAS/Surf software, several scenarios were made based on the topographic conditions in the field. Figure 5 above is a pre-tsunami terrestrial area at the research location. Based on Figure 5, a water flume plan is made with several obstacles in the form of vegetation belts which are then set in numerical simulations. Figure 6 is a section of Banyuasih village, Pandeglang, Banten. The image shows that the road is in the middle of the village and the road divides the village into two parts, namely the west and east. The west side and the east side of the village have coconut groves, and this coconut garden is assumed to provide a dampening effect thus preventing houses on the east side from being damaged by the tsunami on 31 December 2018.

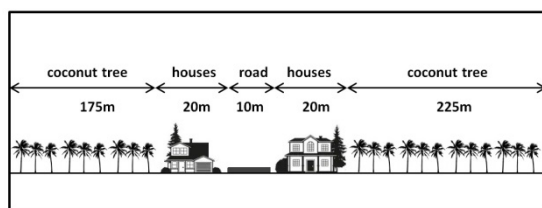


Figure 6. Section of Banyuasih village

Based on the physical conditions in Figure 6, a scheme is made which is then used in numerical simulations to measure wave velocity and altitude at several measurement points.

Figure 7 above is a screenshot of numerical simulation results using CADMAS/Surf. On the side of the coastal area (on the side of the beach) vegetations with spacing of 2.5m were planted. The arrangement of vegetation belts is also placed after

a local road that divides Banyuasih Village, Pandeglang, Banten (see Figure 5).

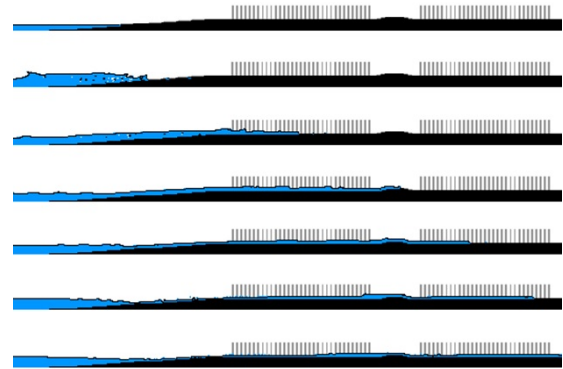


Figure 7. Screenshot of the numerical simulation

While figure 8 below is shown the result of water level (inundation depth) on several measurement points, namely at points 215m, 450m, and 700m. These results show that initially, the tsunami wave came with a height of about 1.20m and then dropped to around 0.5 meters. After passing through the coconut groves as vegetation belts in Banyuasih Village, Pandeglang and passing through the local roads in the village, the inundation height became only 0.20 meters.

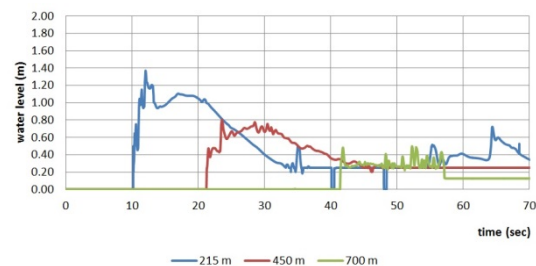


Figure 8. Water level in measurement points

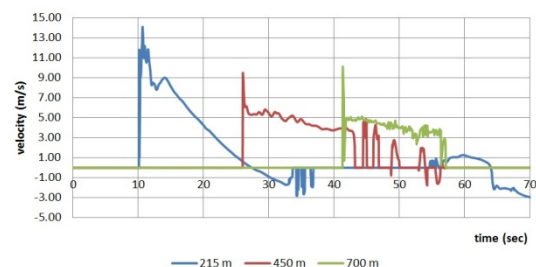


Figure 9. Velocity in measurement points

Similar to the results of the water level measurement, the results of the tsunami wave velocity measurement also showed a significant decrease. At the beginning of the measurement, the wave velocity is 9.00 - 11.00 m/s but after passing the first belts vegetation, the velocity of the tsunami wave drops to around 5.00 m/s, and after passing the

second vegetation belts, the wave velocity again drops to 3.00 m/s or equivalent to 10.8 km/hr.

Table 1 below is the result of a numerical simulation at several measurement points. The three measurement points show the water level and velocity of the tsunami waves that came crashing into Banyuasih Village, Pandeglang

Table 1. Measurement points and the results

Point	water level (m)	velocity (m/s)
215 m	1.00 - 1.20	9.00 - 11.00
450 m	0.50 - 0.75	3.50 - 5.00
700 m	0.20 - 0.35	3.00 - 4.00

Table 1 and Figures 7-9 shows that vegetation belts provide a dampening effect to segmentize the tsunami waves, such as the first vegetation segment in the Banyuasih Village, then a local road that also dampened the wave velocity, and the third segment is a denser vegetation belts from coconut groves on the west side of the Village. The phenomenon of vegetation belts as a tsunami dampener can be seen clearly in this study. With the planting density of each tree and the thickness of the vegetation belts, the dampening effect becomes more optimal.

5. CONCLUSION

The results conclude the following. Assuming that the source of the tsunami was the eruption of Anak Krakatoa Volcano, the velocity of the tsunami from the center of the eruption was around 108 km/h with a travel time of about 45-60 minutes to land.

The average wave height in the coastal area is around 1.00 meters with a wave velocity of approximately 10 m/s. After hitting the coastal area and coconut trees, there was a significant slowdown to approximately 0.60 m for wave height and 5 m/s for velocity.

The thicker the vegetation belts, the greater the dampening effect, it can be seen from the measurement results at point X3 which is 700m from the lip of the flume. The wave height is only around 3.00 m with the wave velocity dropping to around 3.00 m/s or equivalent to 10.8 km/hr. There needs to be a national scale recommendation for reforestation to be conducted as a natural mitigation to reduce tsunami energy, and consequently also have an economic value such as coconut trees (*Cocos Nucifera* sp).

This research uses a numerical simulation method that requires a lot of cell in grids. This method requires a number of grids of simulation in computation analysis. This condition gives an impact on the limited area that is used as a model in numerical simulations.

6. ACKNOWLEDGMENTS

The author would like to express his greatest gratitude towards Institution of Research and Community Service (LPPM) through the Earth and Disaster Research Center, Brawijaya University for funding this research.

7. REFERENCES

- [1] Latter J.H, Tsunamis of volcanic origin: Summary of causes, with particular reference to Krakatoa, 1883, Bulletin Volcanologique, Vol. 44, Issue 3, 1981, pp. 467–490.
- [2] Fadly U. and Murakami K., Study on reducing tsunami inundation energy by the modification of topography based on local wisdom, Journal of Japan Society of Civil Engineers, Ser. B3 (Ocean Engineering), Vol 68, No. 2, 2012, pp. I_66-I_72
- [3] Raphaël P., Source mechanisms of volcanic tsunamis, Philosophical Transaction, The Royal Society Publishing, Vol 373, Issue 2053, 2015, pp. 1-15.
- [4] Paris R, Giachetti T, Chevalier J, Guillou H, Frank N., Tsunami deposits in Santiago Island Cape Verde archipelago as possible evidence of a massive flank failure of Fogo volcano. Sedimentary Geol. Vol 239, 2011, pp. 129–145.
- [5] Carey S, Sigurdsson H, Mandeville C, Bronto S. Volcanic hazards from pyroclastic flow discharge into the sea: examples from the 1883 eruption of Krakatoa, Indonesia. Geol. Soc. Amer. Spec. Publ. Vol. 345, 2000, pp. 1–14.
- [6] Fadly U., and Rahim S.E., Investigate the Effectiveness of Seawall Construction using CADMAS Surf 2D, MATEC Web of Conferences 97, Vol. 1065, 2017, pp. 1-8.
- [7] Yati Muliati, Ricky Lukman Tawekal, Andojo Wurjanto1, Jaya Kelvin, and Widodo Setiyo Pranowo, Application of Swan Model for Hindcasting Wave Height in Jepara Coastal Waters, Nort Java, Indonesia., International Journal of GEOMATE., Vol.15, Issue 48, 2018., pp.114-120
- [8] Cho M., Shin S., Yoon H., and Daniel T. C., Numerical Simulation of Tsunami Force Acting on Vertical Walls. Journal of Coastal Research: Special - The 2nd International Water Safety Symposium., 2017, pp. 289 – 293.
- [9] Charles L.M., Numerical Simulation of Tsunamis, Journal of Physical Oceanography, Vol 4, Issue 79, pp. 74-82
- [10] Integrated Satellite Remote Sensing and Geospatial Analysis for Tsunami Risk Assessment, Int. Journal of GEOMATE, Vol.14, Issue 44, 2018, pp. 96-101.
- [11] Estimation Method of Amount of Tsunami Disaster Wastes during the 2011 off the Pacific

- Coast of Tohoku Earthquake, *Int. Journal of GEOMATE, Geotech.*, Vol.4, No.1 (Sl. No. 7), 2013, pp. 456-461.
- [12] Kurahashi S., and Koike N., Tsunami Generator Warning System Using Earthquake Early Warning, *Int. J. of GEOMATE, Geotech.*, Vol. 9, No. 2 (Sl. No. 18), 2015, pp. 1472-1476
- [13] Imamura F., Latief H. and Puspito N.T., Tsunami catalog and zoning in Indonesia, *Journal of Natural Disaster*, Vol. 22(1), 2000, pp. 25-43.
- [14] Usman F., Murakami K. and Basuki E.K., Study on Reducing Tsunami Inundation Energy by the Modification of Topography based on Local Wisdom, *Procedia Environmental Sciences*, Vol. 20, 2014, pp. 642-650.
- [15] Usman F., Murakami K. and Bisri M., Investigation of Landslide affected area using UAV and GIS in Banaran Village, Ponorogo, Indonesia., *Disaster Advances*, Vol 11 (6), 2018, pp. 30-34.
- [16] The Study Group for the Development of CADMAS-SURF. CADMAS-SURF User's manual, 2003., pp 519.
- [17] Fukui Y., Hidehiko S., Nakamura M., and Sasaki Y., Study on Tsunami, *Annual Journal of Coastal Engineering in Japan*, Volume 9, 1962, pp. 44-49.
- [18] Wijatmiko I. and Murakami K, Numerical Simulation of Tsunami Bore Pressure on Cylindrical Structure, *Annual Journal of Civil Engineering in the Ocean, JSCE*, Volume 26, 2010, pp. 273-278.
- [19] Kenji H., Fumihiko I., Experimental Study on the Effect of Reducing Tsunami by the Coastal Permeable Structures, *Proceeding of The Twelfth International Offshore and Polar Engineering Conference, ISOPE*, 2002., pp. 652-658.
- [20] Tomohiro S., Numerical Analysis of Bulk Coefficient in Dense Vegetation By Immersed Boundary Method, *Proceedings of the International Conference on Coastal Engineering*, No 32, Shanghai, China, 2010
- [21] Pareta K. and Pareta U., Landslide Modeling and Susceptibility Mapping of Giri River Watershed, Himachal Pradesh (India)., *International Journal of Science and Technology.*, Vol 1 No. 2, 2012., pp.91-104.

Copyright © Int. J. of GEOMATE. All rights reserved, including the making of copies unless permission is obtained from the copyright proprietors.
