The impact of mandalika tourism area development on the Kuta village, centre Lombok, Indonesia based on tsunami hazard analysis point of view

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Abstract. West Nusa Tenggara was ever hit by an earthquake and tsunami on August 19th, 1977. This earthquake and tsunami made an impact on the area of Kuta Village Central Lombok, which is under the Mandalika Tourism Area (MTA) development now. This research conducted the assessment of the MTA development impact on the Kuta Village based on the tsunami hazard analysis point of view. This research applies the bathymetric data, the before development topography, and the after development topography to make the simulation of tsunami waves run-up. The analysis of tsunami waves run-up used four-wave height scenarios, i.e. 3.5 meters of before development and 3.5 meters, 5 meters, 7 meters of after development. The result of the tsunami simulation showed differences. The tsunami inundation area in the MTA decreased by 855,617.12 m². But, the tsunami inundation area in the Kuta Village was increased by 3,278 m².

1. Introduction

The location of Mandalika Tourism Area (MTA) is in Lombok Island, Central Lombok District, West Nusa Tenggara Province, Indonesia. Its position on the southern coast is face to the subduction zone in the Indian Ocean, which is well-known for its potential risk of earthquake and tsunami. The earthquake and tsunami ever hit West Nusa Tenggara in August, 19th1977[1], [2]. The earthquake epicentre is 33 km depth and located in 11.1° S 119.0° E (off the coast of Sumba Island) with magnitude Mw 8.3. The earthquake generated a tsunami, which reaches to Lombok and Sumbawa Island [3]. One location in Lombok Island is Kuta area in Center Lombok District which is now becoming the MTA. Figure 1 shows the location of study.

The MTA is included in the special economic area. The MTA has interesting natural tourism potency, especially its coastal area with the white sandy beach. This potency becomes the base of economic development particularly for the Centre Lombok District and the West Nusa Tenggara Province in general. The Indonesia Tourism Development Corporation (ITDC) as the development management company has planned the infrastructure development for supporting the tourism economy area. The ITDC executed some development such as land reclamations for preparing the access road and the hotel construction. The half part of MTA, particularly the west area, has been reclaimed until
elevation about + 4 meters above Mean Sea Level (MSL). The landscape of the west area already changed a lot.

The aim of this research is identifying the impact of MTA development on the tsunami inundation area. The numerical model simulated the propagation of tsunami wave and its inundation on the coastal area. The tsunami inundation area on the MTA and the Kuta Village was analyzed before and after development. The assessment criterium is how large of tsunami inundation area.

![Figure 1. The location of MTA [4]](image)

2. Methodology

The research utilized the topographic and bathymetric data from the General Bathymetric Chart of the Oceans (GEBCO). Additionally, the direct measurement data from the ITDC were also applied to increase the accuracy of the simulation result. The modelling of the tsunami inundation also requires the MTA Master Plan data of overall development area. It consists of [4]:

- a. The lot MTA data based on Detail Engineering Design (DED) Master Plan
- b. The infrastructure data include the Road Owned Area (ROW) 90, 60, 45, 30 and 15 meters, utilities and landscape.
- c. The data of buildings (hotels, villas, residential and other supporting buildings)

Figure 2 shows a) the land and sea contour condition and b) the development plan of MTA.

The simulation of tsunami propagation and inundation employed the Cornell Multigrid Coupled Tsunami Model (COMCOT) Version 1.6, which was developed by Professor Phillip L-F Liu from the Cornell University [5]. The COMCOT use the shallow water equation, which is the water depth is smaller than the wavelength. The COMCOT is able to simulate the run-up and run-down waves (inundation) in coastal areas. The shallow water equation is presented as follows:

\[
\frac{\partial \eta}{\partial t} + \left( \frac{\partial P}{\partial x} + \frac{\partial Q}{\partial y} \right) = 0
\]

(1)

\[
\frac{\partial P}{\partial t} + \frac{\partial}{\partial x} \left( \frac{P^2}{H} \right) + \frac{\partial}{\partial y} \left( \frac{PQ}{H} \right) + gH \frac{\partial \eta}{\partial x} + F_x - fQ = 0
\]

(2)

\[
\frac{\partial Q}{\partial t} + \frac{\partial}{\partial x} \left( \frac{PQ}{H} \right) + \frac{\partial}{\partial y} \left( \frac{Q^2}{H} \right) + gH \frac{\partial \eta}{\partial y} + F_y + fP = 0
\]

(3)

where:
- \( H \) = water surface elevation (m)
- \( P \) = volume flux in x direction (m²/sec)
- \( Q \) = volume flux in y direction (m²/sec)
- \( H \) = total water depth (\( \eta + h \), in meter)
- \( h \) = water depth (m)
In this study, the COMCOT Version 1.6 used the parameters as follows:
1. The grid spacing of the simulation area is 10 meters.
2. The calculation time step is 0.01 seconds.
3. The total duration of the simulation is 1,800 seconds (30 minutes).
4. The time interval of the simulation results is every 60 seconds.

Figure 2. (a) The initial contour map and (b) the development plan of MTA [4]

This research used four (4) scenarios, i.e. 3.5 meters tsunami wave height before the MTA development and 3.5 meters, 5 meters, 7 meters in the situation after the MTA development. The initial tsunami wave height refers to Kusuma’s research about the 1977 Sumba Earthquake and Tsunami [6]. Figure 3 shows the simulation results of Kusuma’s research in 18 minutes after the start of the tsunami. That result becomes the initial tsunami input in this study.

Figure 3. The simulation of tsunami wave propagation after 18 minutes
3. Results and discussion

Figure 4 and Figure 5 shows the result of the tsunami wave simulation and the maximum tsunami inundation area on the Kuta before the MTA development. The initial tsunami wave height is 3.5 meters.

![Figure 4](image1.png)

**Figure 4.** The simulation result of tsunami wave propagation before the MTA development with 3.5 meters wave height

![Figure 5](image2.png)

**Figure 5.** The simulation results of maximum tsunami run-up and inundation before the MTA development with 3.5 meters wave height

Figure 6 and Figure 7 shows the result of the tsunami wave simulation and the maximum tsunami inundation area on the Kuta after the MTA development.

![Figure 6](image3.png)

**Figure 6.** The simulation result of tsunami wave propagation after the MTA development with 3.5 meters wave height

![Figure 7](image4.png)
Table 1 presents the results of all scenarios in the MTA area as below:

### Table 1. Recapitulation of tsunami inundation area in the MTA

| Wave Scenario | Inundation Area (m²) | Total (m²) |
|---------------|----------------------|------------|
|               | 0.1-1.0 m | 1.0-1.5 m | 1.5-2.0 m | 2.0-4.0 m | > 4.0 m |          |
| Before Development – Hs 3.5 m | 2,149,028.07 | 383,380.87 | 88,379.37 | 24,593.93 | - | 2,645,382.24 |
| After Development – Hs 3.5 m  | 1,577,308.53 | 136,740.02 | 53,124.66 | 22,550.76 | 41.15 | 1,789,765.12 |
| After Development – Hs 5 m | 1,303,315.31 | 476,120.29 | 327,905.00 | 427,589.75 | 1,066.69 | 2,535,997.04 |
| After Development – Hs 7 m | 1,116,178.39 | 606,455.13 | 487,885.00 | 944,110.95 | 119,396.37 | 3,274,025.83 |

The area of the tsunami inundation occurring in the MTA are presented as follows:

1. The minimum inundation area occurs at a simulated wave height of 3.5 meters under a development condition. The extent of the inundation is 1,789,765.12 m² (31.70%).
2. The maximum inundation area occurs at a simulated wave height of 7 meters under the development condition. The extent of the inundation is 3,274,025.83 m² (40.93%).

Table 2 presents the results of all scenarios in the Kuta Village area. The area of the tsunami inundation that occurred in the Kuta Village is described as follows:

1. The minimum tsunami inundation occurs in the 3.5-meter wave simulation before the MTA development with an area of 256,516.74 m².
2. The total area of the enormous tsunami inundation on the Kuta Village was 665,748.44 m² which was occurred at 7 meters wave height after the MTA development.

### Table 2. Recapitulation of tsunami inundation area in the Kuta Village

| Wave Scenario | Inundation Area (m²) | Total (m²) |
|---------------|----------------------|------------|
|               | 0.1-1.0 m | 1.0-1.5 m | 1.5-2.0 m | 2.0-4.0 m | > 4.0 m |          |
| Before Development – Hs 3.5 m | 256,516.74 | - | - | - | - | 256,516.74 |
| After Development – Hs 3.5 m  | 251,182.39 | 8,612.35 | - | - | - | 259,794.74 |
| After Development – Hs 5 m | 232,893.87 | 177,911.20 | 130,198.13 | 26,450.82 | - | 516,311.48 |
| After Development – Hs 7 m | 352,384.56 | 172,759.68 | 68,570.09 | 72,034.11 | - | 665,748.44 |
Figure 8 presents the inundation area of the tsunami on the MTA and Kuta Village area. The figure shows that the inundation area of MTA is decreasing about $855,617.12 \text{ m}^2$ due to MTA development. The +4 meter elevation of reclamation reduces the low level of MTA area. But, the impact for the Kuta Village is the opposite. The inundation area on the Kuta Village is increasing after the MTA development about $3,278 \text{ m}^2$. Even the total increasing area is relatively small; there is addition $8,612 \text{ m}^2$ area of 1.0-1.5 m water depth. This impact should be anticipated with the proper disaster mitigation action.

4. Conclusion

Based on the results of the tsunami simulation analysis, it can be concluded as follows:

1. The impact of the MTA development on the MTA area itself is that there is a decreasing of tsunami inundation area about $855,617.12 \text{ m}^2$.

2. On the contrary, the tsunami inundation area in the Kuta Village is increasing about $3,278 \text{ m}^2$ due to the MTA development. Even though this number is small, there is an increasing area of 1.0-1.5 m water depth. It should be considered in the preparation of disaster mitigation plan.

Reference

[1] S. Nakamura, 1979. “On statistics of tsunamis in Indonesia,” Japanese J. Southeast Asian Stud., 16, no. 4, pp. 664–674.

[2] K. Kato and Y. Tsuji, 1995. “Tsunami of the Sumba earthquake of August 19th, 1977,” J. Nat. disaster Sci., 17, no. 2, pp. 87–100.

[3] E. Pradjoko, T. Kusuma, O. Setyandito, A. Suroso, and B. Harianto, 2015. “The Tsunami Run-up Assessment of 1977 Sumba Earthquake in Kuta, Center of Lombok, Indonesia,” Procedia Earth Planet. Sci. DOI: 10.1016/j.proeps.2015.07.079.

[4] Bita Enarcon J.V. Egis International Indonesia, 2015. “Detail plan masterplan mandalika resort - lombok,”

[5] X. Wang and P. L. F. Liu, 2006. “COMCOT User Manual-Version 1.6., School of Civil and Environmental Engineering, Cornell University, Ithaca, NY 14853, USA.”

[6] T. Kusuma, 2014. “Planning of tsunami prone map in coastal area of kuta lombok tengah,” University of Mataram.

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