A decade of mangrove recovery at affected area by the 2004 tsunami along coast of Banda Aceh city

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Abstract. Banda Aceh (BA) is the capital of Aceh Province, Indonesia. It was the most affected areas by the 2004 tsunami. Before the natural catastrophe, most of the BA mangroves disturbed by human activities and remaining mangroves were fragmented and had a low density of trees. Therefore, the objectives of this study were to calculate the impact of the tsunami on mangrove and subsequently to evaluate the mangrove recovery based on spatial and temporal analysis and ground truthing method within the period 11 years in intertidal areas of BA. Three regions of BA coastal areas were selected, namely Kuala Cangkoy, Gampong Jawa and Lambada coasts. Before the tsunami, the mangrove forests in BA were only 13.6\% of BA coastlands and fragmented. Approximately 48.9\% of the mangroves have destroyed due to the tsunami. The BA mangroves at 5 and 11 years after tsunami were 66.5\% and 81.3\% relative to the data before tsunami, respectively. It means that the BA is very vulnerable due to the future tsunami occur. Therefore, the mangrove restoration in BA needs to be improved and maintain based on green belt concept for coastal protection as well as productivity of estuarine ecosystem.

1. Introduction
The 26 December 2004 giant earthquake triggered the Indian Ocean tsunami that caused human loss and hardship along Indian Ocean coast. Combination of natural catastrophes destroyed the coastal vegetation and resources. Athukorala and Resosudarmo [1] stated that the tsunami on 26 December 2004 was one of the destructive natural catastrophes in the world history. Apparently, the most affected areas were Aceh in Northern Sumatra, Indonesia.

On the other hand, the good stand of mangrove forests provide shore protections, including from tsunamis and storms [2-4]. Therefore, the mangrove forests are key to manage and conserve in term of sustainable development and also as part of natural hazard mitigation. The mangrove ecosystem has been degrading over time [5-7], including in Banda Aceh (BA) as the capital of Aceh Province [3, 8-9]. Based on the high-resolution satellite images from CRISP NUS [9] indicated the undisturbed forests, both mangrove and littoral forests, as a buffer zone (green belt) along the seacoast and waterways of BA are absent. It means that coastal land areas are open and expose to the sea or without buffer zone and green belt. Therefore, when tsunami and storm strike it directly hit the adjacent land area without hindrance.

Onrizal and Mansor [3] informed that Northern Sumatra coastal studies increased after the 2004 tsunami; however, most of them are about coastal deformation due to the natural catastrophes.
Subsequently, some articles are about coastal vegetation and resource destructions by tsunami [10-11]. Mangrove species recovery was reported for Aceh Singkil [12], and for Aceh and Peninsular Malaysia [13]. However, the mangrove forests recovery at affected area in BA both spatial and temporal is not monitored and published. Hence, this study aims to calculate the impact of tsunami on mangrove and to evaluate the mangrove recovery based on spatial and temporal analysis and ground truthing method until 11 years in intertidal areas of BA.

2. Materials and methods

2.1. Study site
Mangrove forests damage due to the tsunami and their recovery in BA coasts were quantified using a time series of imagery and truthing ground data. The imagery of GoogleTM Earth from a half-year or more before, and up to 11 years after the tsunami (Table 1) used for map generation. In the pre-processing phase, the datasets were crop to include only the areas of interest (Table 1, Figure 1).

2.2. Methods
The series of land cover line of mangroves were digitized at a scale of 1:2000 and represent the coastal vegetation type transition on the coast for four dates at all sites (Table 1). It provided the smoothes on-screen resolution to mark off the mangroves, visually. Once digitized, the mangrove cover for the different dates overlapped in the ArcGIS 10.1 software and patterns of coastal vegetation change at each location examined.

Table 1. Study site, acquisition date, and area of imagery used in spatiotemporal analysis

| Site          | Acquisition* | Area of interest                                      |
|---------------|--------------|-------------------------------------------------------|
| Kuala Cangkoy (A) | 6/23/2004 1/28/2005 6/16/2009 12/25/2015 | 5°32'38.93" – 5°33'42.01" N; 95°16'1.32" – 95°17'17.68" E |
| Gampong Jawa (B) | 6/23/2004 1/28/2005 6/16/2009 12/25/2015 | 5°34'6.03" – 5°35'2.79" N; 95°17'42.74" – 95°19'17.34" E |
| Lambada (C)    | 5/14/2002 5/19/2005 2/10/2009 12/25/2015 | 5°36'58.01" – 5°38'27.46" N; 95°23'9.25" – 95°24'25.88" E |

Note: * BT = before tsunami, AT1 = immediately after tsunami, AT2 = five years after tsunami; AT3 = 11 years after tsunami.

Figure 1. Study site of recovery status of BA mangroves after the 2004 tsunami at Kuala Cangkoi (A), Gampong Jawa (B) and Lambada (C)
The training polygons of mangrove were digitized on-screen based on terrain knowledge acquired during ground checking and distributed throughout the study areas. The pixels in the polygons that selected as representative of mangroves plotted in spectral space, and a visual check made. Accuracy assessment for the mangrove maps from the studied site based on each 30-ground checking points recorded during three times field survey (Jan. - Feb. 2005, Dec. 2009 – Jan. 2010 and Aug. - Nov. 2016).

3. Results
Before the 2004 tsunami, the remaining mangroves in BA were mostly fragmented (Figure 2). Based spatial analysis, the portion of mangrove forests relative to total coastlands in all study sites was only 13.6% with the distribution was from 4.5% to 26.2% relative to total of coastland (Table 2). Most of the mangroves converted to aquaculture ponds before the natural catastrophes.

Table 2 and Figure 2 show damage and recovery statistics of mangroves in BA coast both spatial and temporal. Most of remaining mangroves, except in Gampong Jawa (Site B), severely damaged due to the giant tsunami. Approximately 48.9% of the remaining mangroves in all site destroyed due to the tsunami. All mangroves destroyed in Kuala Cangkoy (Site A). The second largest of mangrove loss due to the tsunami occurred in Lambada (Site C), i.e. 45.1%. On the other hand, the mangrove damaged in Gampong Jawa (Site B) was only 27.6%.

The recovery level of BA mangrove 5 and 11 years after the tsunami was 64.3 and 79.8% relative to mangrove areas before the tsunami. The highest of mangrove recovery was found in Site C (111.5%), followed by Site B (100.2%). On the other hand, the mangrove recovery in Site A was only 19.7% at 11 years after the 2004 tsunami. The recovered mangrove areas are lower than mangrove areas before the tsunami.

![Figure 2](image.png)

**Figure 2.** Serial map of mangrove cover (green color) before the 2004 tsunami (BT) to 2015 showing impact and recovery of mangroves due to the tsunami in study sites along Banda Aceh coast. Before the tsunami, mangroves fragmented in small paths, and most of the mangroves were converted, mainly to aquaculture ponds. Therefore, the green belt is absent, and as a result, when the 2004 tsunami occurs it directly hit the land area without hindrance.
Table 2. Areas of mangroves before and after the 2004 tsunami in Banda Aceh coasts

| Site              | Total of Coastland (ha) | Mangrove Area (ha) | Mangrove Relative to BT (%) |
|-------------------|-------------------------|--------------------|-----------------------------|
|                   | BT  | AT₁ | AT₂ | AT₃ | AT₁ | AT₂ | AT₃ |
| Kuala Cangkoy (A) | 243.4 | 27.5 | 0.0 | 0.2 | 5.4 | 0.0 | 0.9 | 19.7 |
| Gampong Jawa (B)  | 259.1 | 67.9 | 49.2 | 54.3 | 68.0 | 72.4 | 80.0 | 100.2 |
| Lambada (C)       | 301.2 | 13.7 | 7.5 | 18.0 | 15.2 | 54.9 | 131.8 | 111.5 |
| Total             | 803.7 | 109.1 | 56.7 | 72.6 | 88.7 | 52.0 | 66.5 | 81.3 |

Note: * BT = before tsunami, AT₁ = immediately after tsunami, AT₂ = five years after tsunami, AT₃ = 11 years after tsunami

4. Discussion
Evidently, the good stand of mangroves can protect coastal resources from tsunami [2-3, 14-15]. However, based on this spatial analysis, before the tsunami, most of BA mangroves were gone, and the remaining mangroves were fragmented. Fragmented mangroves did not provide sufficient protection [14], and sometimes it has increased the risk [16]. Therefore, without good stand of mangroves and present of fragmented mangroves caused severely devastated in BA due to the tsunami. When the tsunami occurs, it directly hit BA without protection and presenting of fragmented mangroves before the tsunami caused increasing the hazard.

This study shows that the usefulness of free high-resolution image of GoogleTM Earth to monitor the mangrove recovery both spatial and temporal after the tsunami. GoogleTM Earth provides a lot of serial imagery of BA both before and after the tsunami. Therefore, it allows users to calculate the damage and recovery of the mangrove without purchasing expensive high-resolution imagery.

Until a decade after the 2004 tsunami, the recovery of BA mangroves is still lower than before the tsunami and the recovered mangroves are still in scattered small patches, or many gaps occurred (Figure 2). Indonesian government created national task force, namely Aceh-Nias Rehabilitation and Reconstruction Body (BRR Aceh-Nias) and supported by international agencies and local institutions in period 2005-2009 to do recovery and reconstruction, including mangroves at affected area by the natural catastrophes, however, they could not recover mangroves of BA is likely before the tsunami. In the other word, the remaining mangrove of BA before the tsunami is far from enough as the green belt to protect the city from the tsunami [14, 17]. According to the condition, BA is relatively more vulnerable to the future tsunami.

5. Conclusions
Free high-resolution image from GoogleTM Earth is usefulness to monitor of the mangrove damage and recovery after the tsunami disaster. Based on the analyses both spatial and temporal, the recovered mangrove in the city coast at a decade after tsunami is still lower than before the 2004 tsunami.

More mangrove restoration activities and their integration with traditional coastal management institutions need to implement properly as part of the coastal protection, and disaster risk reduction [18-20]. The mangrove restoration is also to support the healthy estuarine ecosystem for fishery production as the main livelihood of the coastal community [21-24], regional economy [14, 25-27] and climate change mitigation [24, 28-29]. Subsequently, the spatiotemporal mangrove recovery needs to monitor [30] and map [5-7, 31-32] as well as social recovery [33] based on adequate technique, including remote sensing approach. Finally, the healthy mangroves with their ecological and socio-economical values as part of sustainable development goals need to promote.

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