Assessment of mangrove forest damage and its recovery in Banda Aceh city post-tsunami disaster

M Affan1*, N Fadli2, J Jufriadi1, N Nazaruddin1, H Sofyan1, N Nizamuddin1, M Marzuki and D Sapha3
1 Faculty of Mathematics and Natural Science, Syiah Kuala University, Banda Aceh, Indonesia
2 Faculty of Marine and Fisheries, Syiah Kuala University, Banda Aceh, Indonesia
3 Faculty of Economics and Business, Syiah Kuala University, Banda Aceh, Indonesia
*E-Mail: muzailin@unsyiah.ac.id

Abstract. The Indian Ocean Tsunami on 26th December 2004, had caused devastation on land and coastal ecosystems. One of the worst affected ecosystems is the mangrove forest. Many areas of mangrove forest have been destroyed, and it may pose a long-term impact for the region, both in terms of forest and biodiversity conservation and in terms of the ability of the ecosystem to support the livelihoods of the coastal communities. The tragedy of tsunami has requested the rationale for conserving and sustainably managing natural ecosystems among the researchers and scientific community. The research was carried out to make a post-tsunami damage assessment and recovery of mangrove forest in Banda Aceh city area. Several high-resolution satellite imageries data have been effectively used to detect, assess and monitor the changes of mangrove forests in the pre and post-tsunami period using multi-temporal optical satellite data. An on-screen visual interpretation was made to identify the heterogeneous patches for the preliminary classification of fieldwork. A supervised classification was performed to obtain the pre and post Tsunami assessment maps. Accuracy assessment of the classified maps was performed on pixel-level using ground truth. The result highlighted the changes in the spatial extent of the mangrove forests in the study area as a result of Tsunami disaster. The latest condition of the mangrove forest recovery is about 90.3% of the total damage area.

1. Introduction
Geographically, Banda Aceh city is located on 05°16'15"–05°36'16 N and 95°16'15"–95°22'35" E. The city consisted of 9 districts and 90 villages [1]. On 26 December 2004, Banda Aceh was hit by the Indian Ocean Tsunami damaged nearly 75% of the city, measuring 9 m high and reaching as far as 5 km inland [2-5]. The population in Banda Aceh was reduced from 263,669 to 192,194 inhabitants due to this tragedy. The casualties (dead and missing) reached 71,475 on 12 April 2005, and 65,500 persons had to be relocated in resettlement houses[2, 6]. Moreover, the tsunami washed away thousands of buildings and most of the urban infrastructure e.g. roads, electricity and water supply and telecommunication networks [7]. Furthermore, the tsunami also damaged almost the entire coastal ecosystems of this city including the mangrove forest [8-11]. Many mangrove areas have been destroyed, and it may pose a long-term impact for the region, both in terms of forest and biodiversity conservation and in terms of the ability of the ecosystem to support the livelihoods of the coastal communities. The updated information of the mangrove condition including the total coverage in an area is one of the important information needed to develop mangrove conservation management strategies. A well manage mangrove ecosystem might provide essential ecology and economic
services for coastal communities [12]. Nevertheless, limited information of the mangrove condition in Banda Aceh is available among others studies done by [13] and [14].

Remote sensing is one of the technologies to capture objects without direct contact and covered a wide area of target. Recently, remote sensing is become commonly used in the assessment the spatial and temporal changes of coastal vegetation globally such as: [15]used remote sensing technique for the evaluation of mangrove and salt marsh area in the northeastern coast of Florida, USA;[16] utilized satellite imagery to mapping estuarine vegetation in Europe; [17] and [18]also used remote sensing technique to assess the mangrove ecosystem health and the mangrove area changes in India. Hence, this research was carried out to make a post-tsunami damage assessment and recovery of mangrove forest in Banda Aceh city area utilizing remote sensing technique.

2. Materials and Method

2.1 Study Area

The study area of this research is mangrove area located in the coastal area of Banda Aceh city, Aceh province. The area is approximately 1748,98 ha, consist of 13 villages in 4 sub-districts of the coastal area affected by the tsunami disaster in 2004 (Figure 1 and Figure 2).

![Figure 1. Study Area Banda Aceh](image1.jpg)

![Figure 2. Satellite Image of the study area](image2.jpg)

2.2 Data analysis

The data used in this study are several high-resolution satellite images, e.g. IKONOS, Quickbird and Pleiades satellite images. The data processing was done using ArcGIS software. Mangrove forest identification was carried out by on-screen digitizing and supervised classification for six multi-temporal satellite imageries of year 2004, 2005, 2009, 2013, 2015 and 2018 as described in Table 1.

| No | Satellite Image | Date     |
|----|----------------|----------|
| 1  | IKONOS         | 23 Jun   |
| 2  | IKONOS         | 29 Jan   |
| 3  | Quickbird      | 23 Feb   |
| 4  | Quickbird      | 11 Oct   |
| 5  | Pleiades       | 23 Jun   |
| 6  | Pleiades       | 18 Jan   |
3. Results and Discussion

The 2004 tsunami disaster caused significant damage to the mangrove forest in the coastal area of Banda Aceh city. The research result shows that the mangrove area before the tsunami was 84.32 ha (Table 2). The tsunami disaster caused damage to the mangrove areas in the city of Banda Aceh reaching 66.24 Ha or 79%. The recovery program of mangrove forest in Banda Aceh was conducted by the government, local and international organizations, as well as the local community, had resulted in the extension of mangrove forest in Banda Aceh. The greatest change in the mangrove area occurred from 2009 to 2013 about 37.09 Ha. After 14 years of recovery, it reached 76.15 Ha mangrove area or 90.30% compared to the condition before the tsunami (Figure 3).

| No | Date  | Area (ha) |
|----|-------|-----------|
| 1  | 2004  | 84.32     |
| 2  | 2005  | 18.08     |
| 3  | 2009  | 29.21     |
| 4  | 2013  | 66.30     |
| 5  | 2015  | 68.18     |
| 6  | 2018  | 76.15     |

Several factors were hypothesized to be responsible for the mangrove area extension in Banda Aceh such as the coastal topography, tides, climate, soil type and also nutrients. [15] also found significant effects of precipitation, temperature, seasonality, and time on mangrove and saltmarsh areal extent in the northeastern coast of Florida, USA. The results of this study also comparable with the result from [14]. They found that the mangrove in Banda Aceh were five times fold higher than before tsunami. Furthermore, the replanting program initiated by the community and government also accelerates the mangrove recovery in Banda Aceh in addition to natural mangrove reproduction.
4. Conclusions
Recovery of mangrove areas in Banda Aceh city after tsunami disaster is about 90.3% or 76.15 Ha from 84.32 Ha before the tsunami. The recovery process of mangroves in Banda Aceh needs another 2-3 years to recover fully. For further research, it is recommended to use more updated and temporal satellite images as well as fieldwork to identify the mangrove tree conditions.

Acknowledgments
Author thanks the member of GIS and Remote Sensing division of Integrated Laboratory, Syiah Kuala University.

References
[1] BPS 2013 *Banda Aceh dalam Angka 2013* (Banda Aceh)
[2] JICA 2005 The Urgent Rehabilitation and Reconstruction Plan for Banda Aceh City. (Jakarta: JICA) p 262
[3] Prasetya G, Black K, de Lange W, Borrojo J and Healy T 2012 Debris dispersal modeling for the great Sumatra Tsunamis on Banda Aceh and surrounding waters *Nat Hazards* **60** 1167-88
[4] Borrojo J C 2005 Field Data and Satellite Imagery of Tsunami Effects in Banda Aceh *Science* **308** 1596
[5] Prasetya G, Borrojo J, Lange W, Black K and Healy T 2011 Modeling of inundation dynamics on Banda Aceh, Indonesia during the great Sumatra tsunami December 26, 2004 *Nat Hazards* **58** 1029-55
[6] JICA 2012 Ulee Lheu community on reconstruction process from tsunami damage. (Jakarta, Indonesia p 45
[7] Matsumaru R, Nagami K and Takeya K 2012 Reconstruction of the Aceh Region following the 2004 Indian Ocean tsunami disaster: A transportation perspective *IATSS Research* **36** 11-9
[8] Athukorala P-c and Resosudarmo B P 2005 The Indian Ocean Tsunami: Economic Impact, Disaster Management, and Lessons *Asian Economic Papers* **4** 1-39
[9] Steinberg F 2007 Housing reconstruction and rehabilitation in Aceh and Nias, Indonesia—Rebuilding lives *Habitat International* **31** 150-66
[10] Srinivas H and Nakagawa Y 2008 Environmental implications for disaster preparedness: Lessons Learnt from the Indian Ocean Tsunami *Journal of Environmental Management* **89** 4-13
[11] Griffin C, Ellis D, Beavis S and Zoleta-Nantes D 2013 Coastal resources, livelihoods and the 2004 Indian Ocean tsunami in Aceh, Indonesia *Ocean & Coastal Management* **71** 176-86
[12] Feller I C, Friess D A, Krauss K W and Lewis R R 2017 The state of the world’s mangroves in the 21st century under climate change *Hydrobiologia* **803** 1-12
[13] Onrizal O and Mansor M 2016 Status of coastal forests of the Northern Sumatra in 2004’s tsunami catastrophe *Biodiversitas Journal of Biological Diversity* **17**
[14] Onrizal and Mansor M 2018 A decade of mangrove recovery at affected area by the 2004 tsunami along coast of Banda Aceh city *IOP Conference Series: Earth and Environmental Science* **126** 012121
[15] Rodriguez W, Feller I C and Cavanaugh K C 2016 Spatio-temporal changes of a mangrove–saltmarsh ecotone in the northeastern coast of Florida, USA *Global Ecology and Conservation* **7** 245-61
[16] Calleja F, Ondiviela B, Galván C, Recio M and Juanes J A 2019 Mapping estuarine vegetation using satellite imagery: The case of the invasive species Baccharis halimifolia at a Natura 2000 site *Continental Shelf Research* **174** 35-47
[17] Shrestha S, Miranda I, Kumar A, Pardo M L E, Dahal S, Rashid T, Remillard C and Mishra D R 2019 Identifying and forecasting potential biophysical risk areas within a tropical mangrove ecosystem using multi-sensor data *International Journal of Applied Earth Observation and Geoinformation* **74** 281-94
[18] Jayanthi M, Thirumurthy S, Nagaraj G, Muralidhar M and Ravichandran P 2018 Spatial and temporal changes in mangrove cover across the protected and unprotected forests of India *Estuarine, Coastal and Shelf Science* **213** 81-91