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A decade process of coastal land use changes in Peukan Bada-Aceh after the 2004 Indian Ocean Tsunami

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Abstract. Sudden environmental changes due to the impacts of the 2004 tsunami demolished a vast area of land around Peukan Bada of Aceh Besar. There were paddy fields and ponds as major livelihoods supports for coastal communities around this area. However, the tsunami waves demolished all the paddy fields and ponds around this sub-district. Since the 2004, a number of interventions were made to recovery the paddy fields and ponds. This study was aimed at monitoring the land use changes, in term of paddy fields and ponds, during 12-year of recovery process. Geographic Information System tools were used to map every 100 meter of interval in this area to observe the recovery process of the two land use types. After 12-year of the recovery process, total areas successfully being recovered in Peukan Bada were about 80% and only 19% for paddy fields and ponds, respectively. Some reasons were behind these changes. Two of the most frequent reasons are the changes of job types of the residents and the low productivity of the tsunami affected ponds/paddy fields.

1. Introduction
Most of coastal communities in Indonesia are situated in difficult situation. One of them is the stark evidence showing that the coastal areas are prone to a number of coastal hazards. About 80% of coastal areas in Indonesia are prone to tsunami. The 2004 Indian Ocean tsunami has proven the power of the disaster to eliminate several decades’ development process made in the affected area. Some of the most destroyed land use types were agricultural land and brackish water ponds. In some area in Aceh coast, paddy fields were situated closely to the sea and were planted at low-lying area. Furthermore, ponds were major economic driven for coastal communities for years. These were also the situation in Peukan Bada, a sub-district of Aceh Besar, located at the western coast of Banda Aceh.
In Aceh and many parts in Indonesia, brackish water ponds are used as aquaculture activities that have significant contributions to people economic and livelihoods of coastal communities [1]. Most of the pond’s farmers were small-scale farmers where their ponds area are less than 2 ha. The 2004 tsunami caused a serious disruption to their livelihood. In total, there were about 20,000 ha of ponds and 70,000 of agricultural land destroyed by the 2004 tsunami. In the first second year after the tsunami, BRR Aceh Nias managed to recover about 6,800 ha of ponds and 50,000 of agricultural land in Aceh and Nias [5].

The 2004 Indian Ocean Tsunami has caused a severe erosion at coastal areas in Aceh and Nias Island of Indonesia. One of the most stricken area was Peukan Bada Sub-District of Aceh Besar. The coastal area of Peukan Bada receded to about 200 m from its initial coastline position [2]. One study proven that large shear stress generated by the waves transported the sediment to areas around foothill of the location and to the northern offshore part of Peukan Bada, which is estimated about 2.5 km from the coastline. The impacts of the 2004 tsunami on the land use area was severe. Interestingly, the return of the land use types in this area is seen to gain some momentum following the coastal morphology changes.

Notwithstanding with the rehabilitation and reconstruction process after the tsunami, studies on the recovery of the coastal areas are still limited. This study was aimed at observing the land use recovery after the 2004 Indian Ocean tsunami at the affected area that was accompanied by the coastal morphological changes followed after the 2004 tsunami. Northern coast of Peukan Bada of Aceh Besar District was selected as the study area. The coastal area was totally demolished by the 2004 tsunami. The area is situated between a headland named Ujong Pancu at the western edge of the area and a hill side of Bukit Barisan Mountain at the southern limit of the area. Before the 2004 tsunami this area was largely known for its vast mangrove forest area and aquaculture land use, such as ponds.

### 2. Study area

Northern Peukan Bada sub-district is situated between a steep hilly side of Bukit Barisan Mountains at the west, The Ulee Lheue Bay at the north, and Banda Aceh at the eastern part of the sub-district. Figure 1 shows the study area. The sub-district is divided into 26 villages, with total population 17,000 people in 2014 [3]. Before the 2004 Indian Ocean tsunami, the study area was sparsely used for settlement around the Ulee Lheue Bay, but it was known for massive mangrove areas and aquaculture such as ponds [4]. The maximum tsunami wave height around this area was about 9.0 m [2].

![Figure 1. The Peukan Bada Coast as the study area.](image-url)
3. Methods

We employed Geographical Information System (GIS) method by digitizing types of land use, i.e. ponds and paddy fields. The images were captured in 2003 (before the tsunami), 2005 (just two months after the 2004 tsunami), 2007, 2009, 2011, 2013, 2014, and 2015. The source of the images were obtained from various sources, i.e. IKONOS (for the condition in 2003 and in 2005), Quick Bird (for condition in 2007), and the rest of the data were retrieved from Google Earth. Each of the land use were measured the distance to the coastline. Accumulation of the digitized land use types were plotted against the distance to the coastline. We also conducted a preliminary interview to local community to identify the factors that drove the changes of the land use during the recovery process. Similar methods employed in this research were applied by other researchers previously [7, 8].

4. Results

There were many interventions made to the recovery process around Peukan Bada. Although the recovery process was not performed through the introduction of hard structures, the development of new land barriers helped some land-use types around Peukan Bada to be recovered. For a simplicity, in this paper we only show four digitized images taken in 2003, 2005, 2007, and 2015. Figure 2(a) shows the land-use types condition in 2003, Figure 2(b) shows the condition in 2005. Condition in 2007 and 2015 are shown in Figures 3(a) and 3(b), respectively.

![Figure 2. (a) Land-use types before tsunami digitized based on 2003 condition and (b) after tsunami, digitized based on 2005 condition.](image)

![Figure 3. (a) Land-use types based on 2007 condition and (b) recently land use changes digitized based on 2015 condition.](image)
4.1. Paddy Fields

Before tsunami, paddy fields in this area were about 189 ha. Mainly the paddy fields used dryland farming system. Due to the 2004 tsunami, the paddy fields were totally destroyed. The ill function paddy fields after the 2004 tsunami were caused by the length of the time the agricultural land inundated by salt water, the thickness of tsunami deposit in the paddy fields, damaged irrigation system that could dilute the salt contamination, and low precipitation rates after the tsunami [9]. In 2015, the recovery of the paddy fields reached about 151 ha or about 80% compared to the situation before the tsunami. Recovery of the paddy fields was done by several measures depending on the level of the damages. For thin tsunami deposit, lower than 20 cm, run-off process generated by precipitation is sufficient to deplete the salt contamination and neutralize the sea-sand into original soil. However, tsunami deposit thicker than 20 cm required mechanical removal of the sea-sand to make the paddy field cultivable again. In another area, a bunding technology has proven effective to reduce the salinity level and was also successful to recover the agronomic productivity from the tsunami-affected paddy field [10]. However, the mechanical methods were not performed in this study area according to our interview process. Considering the thicknesses of tsunami deposit at several places were thick, therefore some of paddy fields failed to be recovered. In 2007, a small retention basin (embung) construction named Embung Lambadeuk was started. The basin is expected to irrigate the paddy field around this area [11]. Figure 4 shows the recovery of the paddy field in the study area from spatio-temporal analysis.

![Figure 4. Recovery process of paddy field area in Peukan Bada from 2005 until 2015.](image)

4.2. Ponds

This area had about 149 Ha of ponds before the 2004 tsunami. The tsunami waves damaged all of the ponds. The damages at ponds were mainly caused by the collapse of pond’s dykes, sedimentation, and severe erosion. Rehabilitation of ponds were performed in the first four years after tsunami by International Donors and later continued by Marine and Fishery Department/DKP [5]. Until 2015, the recovery of ponds reached only about 28 ha or about 19% of total ponds area before the 2004 tsunami. According to the interviews made at former ponds farmers, they revealed that during the first two years after the tsunami, they had to look for another type of job. Some of them became construction workers or fishermen with their own boat or employed at some one’s fishing boat. Another reasons for
the low rate of the ponds recovery was the unsuccessful recovery of the ponds’ area with minimum facilities provided. There was a conflicting report regarding the ownership of the lands near the coastline. This also hampered process of constructing facilities to rebuild the ponds. Furthermore, most of non-productive ponds are located near the coastline where the fresh water inputs is limited and no canal to discharge the fresh water to maintain the brackish water environment suitable for ponds. One study revealed that the salinity level around this area was above 25ppt [6]. This is beyond of the brackish water salinity environment, which is between 0.5ppt-17.0ppt. Figure 5 shows the return of the ponds area until 2015. Figure 6 shows an aerial image of Gampong (village) Lambadeuk coast in Peukan Bada. In the figure, a large area of non-productive ponds can be seen, close to the settlement in the village.

![Figure 5](image1.png)

**Figure 5.** Recovery of ponds in Peukan Bada compared to ponds area before the tsunami (black-solid line).

![Figure 6](image2.png)

**Figure 6.** An aerial image of non-productive ponds around Gampong Lambadeuk in Peukan Bada, captured by drone in November 2016.
The non-productive ponds, as shown in Figure 6, are now being left by local communities. There is no significant economic activities done to reactivate the ponds. Some Non Governmental Organisations are trying to replant mangroves (Rhizopora Sp.) in the area. However, due to limited knowledge on the ecological situation post the tsunami, many of the replanted mangroves did not grow properly.

5. Conclusions

This research concludes that the recovery of paddy field areas in Peukan Bada and Ponds, both did not reach a complete recovery process. About 80% of the paddy fields were recovered and productive. However, only about 19% of ponds were successfully being recovered. A low percentage of the ponds recovery was driven by several reasons, i.e. the change of the job of the pond’s farmers, the unavailability facility to cater fresh water to recreate brackish water environment, and the severe level of damages due to the 2004 Indian Ocean Tsunami. A promising return of the paddy field productivity in this area was due to a new irrigation system from the Lambadeuk basin, introduced to maximize water supply to the paddy fields. A further recovery process of ponds in this area requires more attention to construct canal to cater fresh water to the ponds area. This will enable to re-create a brackish water environment to rerun the ponds productively.

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