

Shoreline change after 12 years of tsunami in Banda Aceh, Indonesia: a multi-resolution, multi-temporal satellite data and GIS approach

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Abstract. The Indian Ocean Tsunami event on the 26 December 2004 has caused severe damage of some shorelines in Banda Aceh City, Indonesia. Tracing back the impact can be seen using remote sensing data combined with GIS. The approach is incorporated with image processing to analyze the extent of shoreline changes with multi-temporal data after 12 years of tsunami. This study demonstrates multi-resolution and multi-temporal satellite images of QuickBird and IKONOS to demarcate the shoreline of Banda Aceh shoreline from before and after tsunami. The research has demonstrated a significant change to the shoreline in the form of abrasion between 2004 and 2005 from few meters to hundred meters' change. The change between 2004 and 2011 has not returned to the previous stage of shoreline before the tsunami, considered post tsunami impact. The abrasion occurs between 18.3 to 194.93 meters. Further, the change in 2009-2011 shows slowly change of shoreline of Banda Aceh, considered without impact of tsunami e.g. abrasion caused by ocean waves that erode the coast and on specific areas accretion occurs caused by sediment carried by the river flow into the sea near the shoreline of the study area.

1. Introduction

Banda Aceh was one of the worst cities hit by tsunami on December 26, 2004. However, now Banda Aceh is totally in recovery after 12 years of rebuilt. The tsunami has affected the morphology unit, especially in the shoreline, established since Holocene period [1]. The impact of tsunami can contribute seawater submerged into the coastal plain. This can change the depositional and erosional process in the shoreline. This fact shows that the big tsunami and land subsidence effects not only occur instantaneously, but also causes morphological changes in proportion to the change, which usually occurs at a time scale of centuries to millennia.

The most powerful earthquake occurring in this area in the last 40 years was identified approximately as a 9 on the Richter scale. The earthquake caused deadly giant waves which stormed nearly a dozen countries around the world and killed ten thousand peoples [2]. The giant tsunami on 26 December 2004 has affected the shoreline along the Banda Aceh beaches, especially near the Uleulue seaport, a famous and historic seaport of Banda Aceh. The impact of the tsunami in this area



has caused the change of shoreline from few meter to hundred meters [3]. The extent of the change of the shoreline along the coastline of Banda Aceh can be traced back using remote sensing data combined with Geographical Information System (GIS). Satellite data can provide precision (cm even to mm), high spatial resolution, and wide coverage measurements of surface deformation, reducing the use of in-situ traditional techniques [4, 5]. Remote sensing data combined with GIS analysis can provide the compressive result of geomorphological change. As a GIS is regarded as a toll to collect, store, manage, manipulate, analyze and visualize geographic or spatial data, it can be regarded as a special case of information systems where the database consists of observations on features distributed spatially. Using GIS involves capturing the spatial distribution of features by means of measurement or maps [6].

Digital Globe launched the QuickBird satellite sensor in October 2001, as one of the first commercial satellites that has high image spatial resolution. It has contributed to Indonesian authority to quickly access virtually and monitor the damage caused by tsunami in 2004 by providing image of the affected area. The QuickBird had observed earth for more than a decade with a four-band multispectral spatial resolution which is about 2.4 m and 0.65 m in the panchromatic band. QuickBird has been chosen for this study because of the high spatial resolution result. In line with the QuickBird image, space imaging (now owned by GeoEye) had launched the IKONOS satellite on September 1999. IKONOS, on the other hand, has a 4-meter multi-spectral spatial resolution, possibly its panchromatic band sharpened to one meter. QuickBird and IKONOS from digital Globe have been utilized to classify the five species of saltmarsh vegetation, soil and water around Venice Lagoon, Italy and give clear and accurate result [7]. Thus, with a fine spatial resolution, these datasets would be useful result to analyze the shoreline change part of Banda Aceh coastal area.

Mapping shoreline change is important aspect for Banda Aceh as its development is in progress after it was struck by huge tsunami in 2004. The use of GIS as mapping and analysis tool for spatial data can be realised to obtain high quality of the shoreline change. The result can be used as guidelines for the local government planning in relation to shoreline policy in the future. The use of GIS to analyze for shoreline change has been implemented by Bouchahma and Wanglin in 2014 [8] at the coastal area in Djerba Island and produced a good map of coastal change in the area. The analysis of shoreline is needed not only for a good consideration of spatial and temporal analysis but also for the integration of planning in the area. Remote sensing and GIS are commonly used in coastal geomorphology since they provide a better source in studying the changes of shoreline in the long term use [9]. With the ultimate useful and high resolution, this study aims to provide multi-resolution and multi-temporal satellite image of QuickBird (by digital Globe) and IKONOS to demarcate the shoreline change in Banda Aceh shoreline before and after tsunami without considering the change of tide and sea surface during the period of acquiring and analyzing images.

2. Materials and Methods

The location of this study is along the shoreline of Banda Aceh (Figure 1). Banda Aceh is located at 95°16'27,68"-95°22'47,40" Longitude and 5°30'47,77"- 5°36'47,54" Latitude. Selected samples are located at 95°18'52.62" – 95° 21' 19.40" Longitude and 5°35'8.29" – 5°36'39.33" Latitude. The main source of image data for this study was IKONOS with the data acquired in 2004 and 2005 and QuickBird images with the data acquired in 2009 and 2011. The data were supported by Geospatial Data Centre of Aceh Province, Indonesia. Maps related to the study were collected from National Land Resources Agency of Aceh.

Due to lack of data availability consecutively years for both IKONOS and QuickBird for the years of image acquired, we used different date of acquisition for IKONOS and QuickBird as a temporal analysis and different multi-resolution images.

Due to the lack or unavailability of image data required in consecutively years from both IKONOS and QuickBird, we used different date of acquisition for IKONOS and QuickBird as a temporal analysis and different multi-resolution images. Pre-processing images of IKONOS and QuickBird were carried out.

Selection of sample area was carried out by choosing the worst area after the tsunami which has not been built up or has been being developed. Thus, we only focus on detail calculation of shoreline change for Syiah Kuala, sub-district of Banda Aceh. The other four sub-districts, such as Meuraxa, Kuta Raja and Kuta Alam, are also included for initial analysis of a shoreline change of Banda Aceh coastal area.

2.1. Image analysis, registration and shoreline digitation

Image registration, sharpening, cutting, classification and overlaying process over the area were applied. Sharpening the image, enlarging the scale of the images in order to distinguish between the sea and shoreline, and re-digitalizing through the polyline method to determine the shoreline, were carried out and overlaid images was conducted for before tsunami image e.g. 2004 image, and after tsunami images of 2005, 2009, and 2011. Shoreline digitation was carried out through the polyline method on the scale of 1:50.000 for all images. The QuickBird and IKONOS images were good enough, allowing to determine the boundaries between the sea and land. Digitizing on the base of the 1:50.000 map scale has produced clear images with new digitized boundaries of the shoreline.

2.2. Overlaying images

Overlay images were carried out to distinguish the shoreline changes of the study area among years of images acquired. The IKONOS images acquired in 2004 and 2005 were utilized to distinguish before and just after tsunami. Meanwhile QuickBird images acquired in 2009 and 2011 were also utilized to spatially analyze the change of shoreline of Banda Aceh, not only for before and after tsunami but also along the years of change since 2004, in the time of catastrophic disaster of tsunami. Overlaid maps were done to demarcate the changes of shoreline images in 2004, 2005, 2009 and 2011. On this stage, overlay was carried out over the shoreline of digitized polylines of IKONOS and QuickBird images before tsunami in 2004 to after the tsunami; for example, 2005, 2009 and 2011.

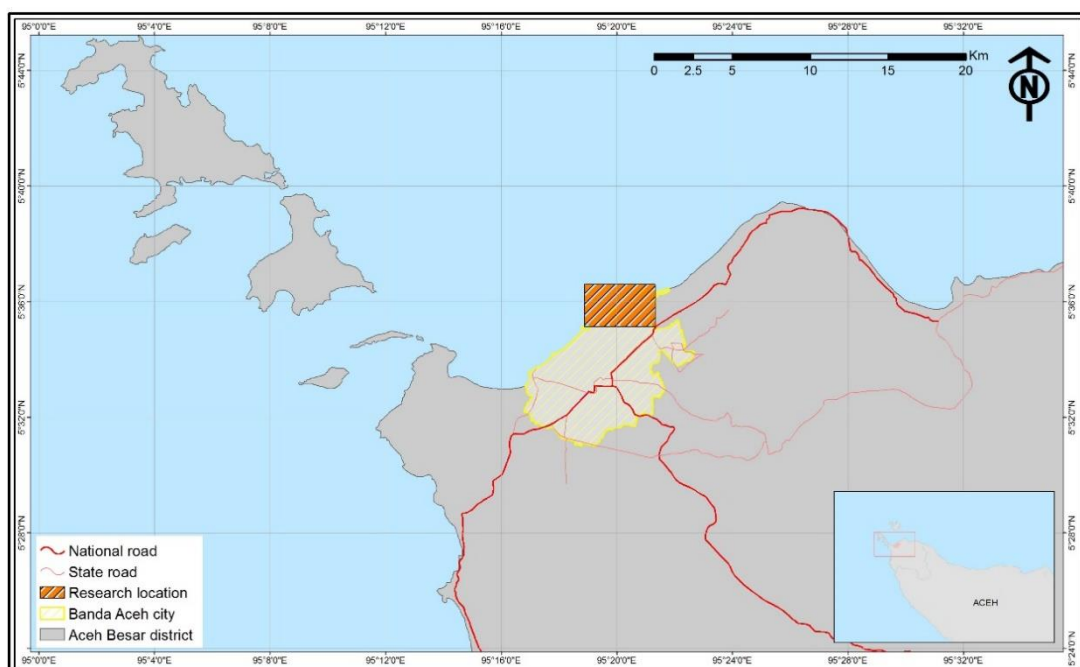


Figure 1. Map of Banda Aceh with the inset for selected sub district investigated for shoreline change analysis

3. Result and Discussion

The four sub-districts out of the nine sub-districts in Banda Aceh, i.e.: Meuraxa, Kuta Raja, Kuta Alam, and Syiah Kuala, were directly hit by tsunami in 2004 and the hitting has directly impact on shoreline change with the average change of 12.15 to 309.9 meters. The shorelines of these four sub-districts have changed after the tsunami in 2004 with various extents and sizes (figure 2), and the worst area was Syiah Kuala sub district, as sample point used for the multi-temporal and multi resolution images.

The result from IKONOS image analysis for 2004 and 2005 shows a variation of shoreline changes starting from north to south of Banda Aceh. The greatest change was at Deah Raya Village shoreline of Syiah Kuala Sub-district. QuickBird image analysis for 2009 and 2011 shows a slowly change of shoreline of Syiah Kuala sub-district. This is due to abrasion and accretion in this area. This change shows the dynamic transformation of shoreline along the coastline of Banda Aceh city after the tsunami. In the short and longtime, the changes of shoreline should be analyzed [10] and mapped as those are important for navigation safety, coastal resource management, environment maintenance, development of coastal resources, and city planning. The shoreline changes are important information for mapping and deformation of coastline.

3.1. The shoreline of Syiah Kuala before tsunami

The shoreline of Syiah Kuala sub-district before tsunami was undamaged, as shown in figure 2. It clearly indicates the shoreline of Banda Aceh before tsunami. The red line on the map indicates the shoreline of Syiah Kuala which was undamaged. While, the dotted line on the map indicates the shoreline and part of rives canal which toward to the sea.



Figure 2. Shoreline map of Syiah Kuala Sub-district, Banda Aceh before tsunami in 2004

3.2. The Shoreline after tsunami

The shoreline of Syiah Kuala after tsunami in 2004 was severe damaged where it suffered high enough coastal erosion so that the level of sea water was so big enough to immerse the land area along the shoreline of Banda Aceh. For more detail, the impact of tsunami on shoreline of Syiah Kuala sub district can be traced back as described in figure 3.



Figure 3. Syiah Kuala-sub-district map showing shoreline change for January 2005

After tsunami, the shoreline of Syiah Kuala sub district changed in certain areas, as noted with the disconnected green line in Figure 3. This change is caused by the sea flooding the land has diminished some part of the shoreline. The long term effects of tsunami on the shorelines could vary to be due to the natural erosion and the flood. However, tracing back the damage can be retrieved again as long as the image data are available.

3.3. The changes of shoreline after tsunami

The result analysis of the shoreline of Syiah Kuala area before and after tsunami based on overlaid result of image using GIS tool for 2004 and 2005 shows various changes (figure 4). Figure 4 illustrates the changes of Syiah Kuala shoreline between 2004 and 2005.



Figure 4. Map of the Syiah Kuala shoreline changes between 2004 and 2005, note: redline represent previous shoreline

The changes of shoreline at Banda Aceh between 2004 and 2005 were totally worst in which shoreline on 2005 had been disappeared caused by tsunami. On 2004 to 2005 the shoreline along Syiah Kuala had been seriously damaged (abrasion) started from the lowest level that were 12.15 meter to 309.92 meter. In certain area, the shoreline was also totally wrecked and this made flood flow into pond of residents near the area. To see the rate of shoreline changes after tsunami at Syiah Kuala subdistrict, it was conducted an analysis between 2004 and 2009 (figure 5). Figure 5 shows several changes of shoreline at Syiah Kuala with different wide of coastal owing to both abrasion and accretion. Between 2004 and 2005, we checked for nine dots as points for GPS points recorded to see the changes with the lowest (55.1 meter) and the highest (178.77 meters) changes.

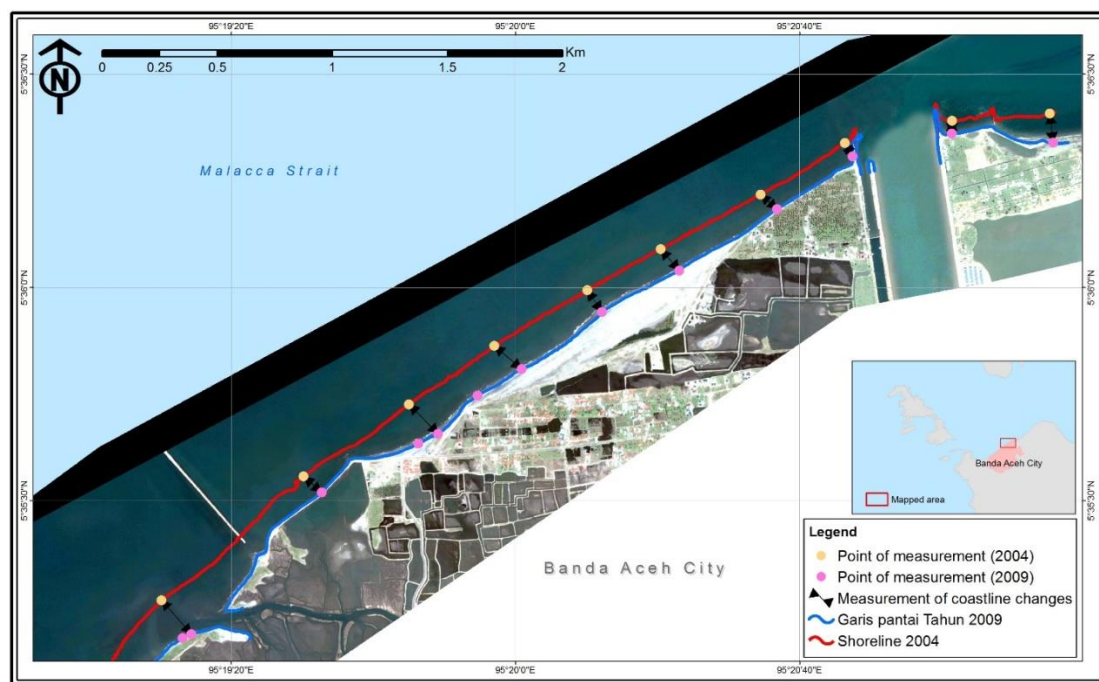


Figure 5. Map of Syiah Kuala's shoreline changes in 2004-2009

Analyzing the changes of shoreline of Syiah Kuala in the 2009 and 2011 images without considering the tsunami effects in 2004 give the assumption that the changes are not caused by tsunami, but rather the dynamic of geomorphology process in the area. The shoreline changes of Syiah Kuala shoreline between 2009 and 2011 could be due to abrasion along the shoreline area investigated. Figure 6 clearly shows the changes of shoreline. The changes occurring between 2009 and 2011 were dominated by the abrasion of sediment carried by rivers flowing into its sub-districts. The size of the abrasion was in the range of 1.08 and 32.69 meters. Meanwhile, the size of the abrasion happening only at Tibang area, a village name in Syiah Kuala sub-district, was in the range of 10.24 and 14.87 meters and this abrasion might be due to the waves and tides, as revealed by the multi-temporal image analysis.

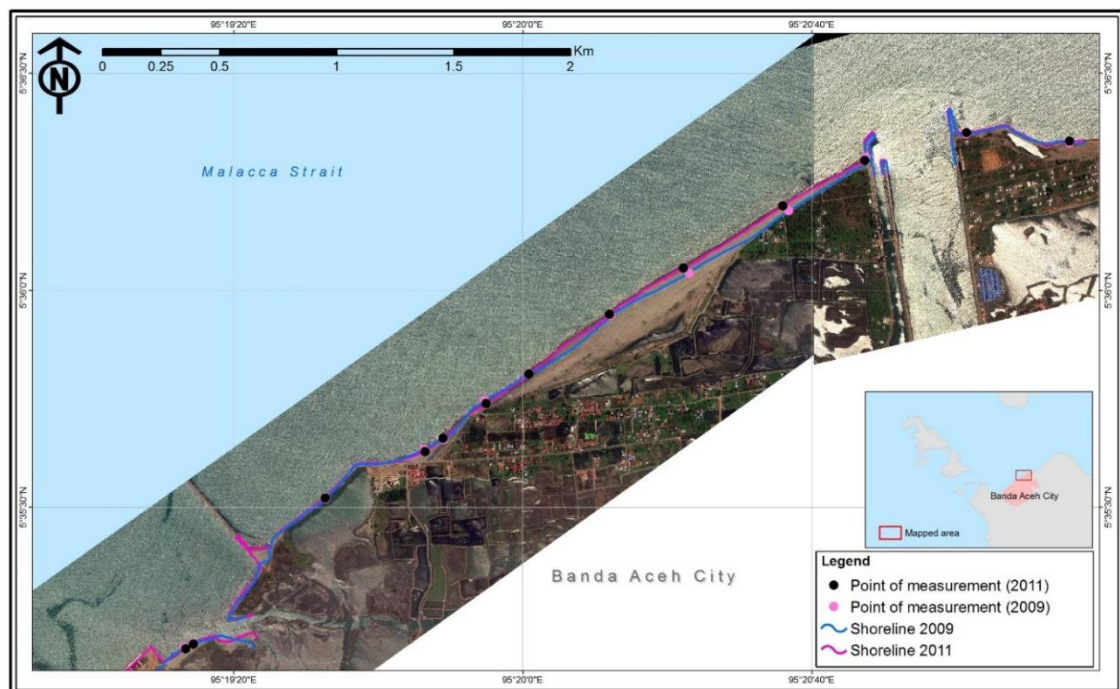


Figure 6. Map of Syiah Kuala changes on its shoreline between 2009-2011

4. Conclusions

Multi-temporal and multi resolution image analysis has been performed to demonstrate its ability to identify the extent of shoreline change in Banda Aceh, from few meters to hundreds of meter changes after 12 year of tsunami.

IKONOS images was used to show the changes of shoreline in Banda Aceh between 2004 and 2005, accounting for 12.15 to 309.92 meters from abrasion, while for accretion counting for 15.39 to 33.57 meters.

QuickBird images show an abrasion shoreline of Banda Aceh coastal area from 2004 to 2009 from 18.3 to 194.93 meters. The changes of Syiah Kuala shorelines sample point for Banda Aceh between 2009 and 2011 not only caused by tsunami, but it also could be from the abrasion and geomorphological dynamic process of this area during the period after tsunami, e.g.: from 2005 to current date.

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