Spatio-temporal shoreline changes analysis based on Landsat satellite images in Lahewa Beach of North Nias due to tectonics 2005

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Abstract. The issue of accretion and erosion is one of the most comprehensive challenges in coastal morphology area. North Nias Regency is one part of Nias Island, located in the Megathrust Zone, which unfolds on Indo-Australian and Eurasian Plate subduction zones having a potential to interfere with the coastal region. Therefore, in order to detect the morphological shoreline changes, a time-efficient method of remote sensing is required. The purpose of this research is to detect the horizontal deformation of shoreline in the coastal area of North Nias Regency. This study uses Landsat 5 (TM), Landsat 7 (ETM+) and Landsat 8 (OLI) data. Also, the satellite imagery is utilized which consists of multitemporal data of pre-seismic (2000, 2003, and 2006), co-seismic (2005 and 2006), and post-seismic (2006, 2011, 2018). Furthermore, mapping and DSAS (Digital Shoreline Analysis System) methods are used. Mapping is done by digitizing the shoreline changes that occur by using the Landsat tools. On the other hand, the DSAS analysis is used to calculate and classify the area of erosion and accretion along the coast. The transect is given various colors to distinguish the shoreline alteration differences. The results show that maximum (accretion) and minimum (erosion) EPR values earned in every period in respective order are: pre-seismic with 43.540 m/yr and 80.810 m/yr, co-seismic with 600.840 m/yr and -10.590 m/yr, and post-seismic with 3.420 m/yr and -47.020 m/yr.

1. Introduction
The coastal area is an area that unceasingly exposed to the influence of natural changes and human activities. It has a shoreline that is changing over time as its dynamic condition is. On 28th March 2005, there was a great tectonic earthquake with 8.7 Mw power which caused a vertical and a horizontal shoreline alteration in this area [1]. Horizontally, the beach is characterized by the movement of the shoreline. Erosion and accretion processes can affect daily aspects of human life indirectly such as interfering with infrastructures, cultivations, tourism, and natural resources [2]. Nowadays, the community and the government of North Nias Regency exploit some of its areas as tourism places by building surrounding huts, inns, and infrastructures. These changes will bring an impact on coastal vulnerability to society and ecology [3]. The rate of shoreline changes was calculated in order to design a strategy for planning dynamic conditions and preventing any hazards from the coast [4].

Therefore, in order to detect and analyze the condition of the shoreline morphology, a time-efficient method is required. Historically, the GIS (Geographic Information Systems) and remote sensing
applications can be used effectively for detecting the area condition and estimating occurring changes [5-7]. The quantitative and qualitative evaluation of spatial and temporal shoreline changes are solved by using satellite imagery, aerial photographs, and other methods [8]. In this study, we focused on discussing shoreline changes in its lateral way within pre-seismic, co-seismic, and post-seismic periods.

Lahewa Beach is located in the north of Nias coast and contiguous to the Indian Ocean. The length of the Lahewa shoreline is approximately 22365.962 meters. Geographical coordinates of the Lahewa unfold between N 01° 25' 30" E 97 06' 40" and N 01° 24' 11" E 97 10' 10" (figure 1). The Geological conditions of the Lahewa coast consist of coral reefs that are visible after the tectonic activity (post-seismic period) in September 2018 (figure 2).

![Figure 1. The map of Lahewa Shoreline.](image1)

![Figure 2. Lahewa coast condition in the post-earthquake period (Aerial photograph, September 2018).](image2)
2. Methodology

First, Lahewa Beach was divided into three time periods, which are the period of the year 2000 - 2005 (pre-seismic), the period of the year 2005 - 2006 (co-seismic), and the period of the year 2006 - 2018 (post-seismic). Furthermore, shoreline changes were investigated by using satellite imagery data by Landsat USGS with every photograph having a resolution of 30 meters. The captured Landsat data consist of the sensor of Landsat 4-5 TM (Thematic Mapper), Landsat 7 ETM + (Enhanced Thematic Mapper Plus), and Landsat 8 OLI (Operational Land Imager) (the details can be seen in table 1). All of the data are available on the USGS website (earthexplorer.usgs.gov). This study used the DSAS (Digital Shoreline Analysis System) method which is an add-in toolbox in the Esri ArcGIS software [9]. DSAS is a tool to analyze the shoreline deformation based on satellite imagery [10].

Table 1. Description of the data.

| Satellite     | Date of Acquisition | Sensor  | Resolution |
|---------------|---------------------|---------|------------|
| Landsat 4-5   | 13 March 2005       | TM      | 30 m       |
|               | 29 December 2006    | TM      | 30 m       |
|               | 10 February 2011    | TM      | 30 m       |
| Landsat 7     | 19 May 2003         | ETM +   | 30 m       |
|               | 13 July 2000        | ETM +   | 30 m       |
| Landsat 8     | 04 May 2018         | OLI     | 30 m       |

First, satellite imageries were downloaded from the USGS website. Then, the imageries were extracted by using reflections from several bands obtained. After that, digitizing was conducted by using Landsat tools called Tasseled Cap. This feature generates brightness, greeners, and wetness data. The data format was produced in tiff. Furthermore, tiff data were set as the reference for the digitization process. Each shoreline layer was obtained from different acquisition dates in order to indicate the status of difference [11].

Baseline and shoreline were generated with some basic attribute field. Depending on the shoreline that has been merged, the baseline was stretched along 150 meters from the nearest shoreline. This distance was chosen for the reference to draw the transect lines from the baseline [12]. The formed transect line is a line that perpendicular to the baseline with a specified transect distance [13].

2.1. Classification of erosion and accretion

After the transect line was generated by using the DSAS method, then the transect was calculated by using the equation of EPR (End Point rate) and LRR (Linear Regression Rate) values. The DSAS technique can be used to generate the statistic for several conditions using EPR and LRR [10]. The EPR equation applied in DSAS can be seen in equation (1) as follows:

\[ \text{EPR} = \frac{\text{NSM}}{\text{Time between earliest and recent of shoreline}} \]  

The Net Shoreline Movement (NSM) is the distance between the earliest and recent of shoreline in the formed transect in meters [2]. The EPR value is determined by dividing the distance value of the shoreline change (NSM) with the time between the beginning and the end of the year. The LRR is the value produced from a combination of several shorelines and calculated to find the regression equation that fits our data. The linear regression is easily affected by outlier effects disregarding the rate of other statistics [2]. The rate of EPR and LRR Data can be classified as erosion and accretion according to the level of shoreline changes per year [12]. The changes in Lahewa Beach North Nias were categorized into 7 shoreline classifications as in table 2.
Table 2. Shoreline classification.

| No. | Shoreline Classification       | Rate of Shoreline Change (m/y) |
|-----|--------------------------------|---------------------------------|
| 1.  | Very High Erosion             | >-s                             |
| 2.  | High Erosion                  | >-s/2 to <-s                    |
| 3.  | Moderate Erosion              | >-s/2 to <0                     |
| 4.  | Stable                        | 0                               |
| 5.  | Moderate Accretion            | >0 to <-s/2                     |
| 6.  | High Accretion                | >s/2 to <s                      |
| 7.  | Very High Accretion           | >s                              |

3. Results and discussion

Along the Lahewa coast, transect lines were drawn with the gap of 100 meters between the initial transect to the other neighboring transects. Every period was constructed in different transects according to the length of the transect line. This is because the shoreline changes rate had a different rate in each period. Erosion and accretion were found in several periods along the shoreline of Lahewa Beach, Northern Nias.

3.1. Pre-seismic period

Figure 3 shows the level of erosion and accretion that occurred in the pre-seismic period of 2000 – 2005 which are shown as transect lines. Among the 96 transects, the erosion process was occurred in 55 transects (57%). On the other hand, the accretion process happened in 41 transects (43%). The length of the transect is 650 meters long. The tendency of the accretion process is significant in several areas that adjacent to the hill or inland covers as in the east. The erosion process can be seen at the northern shoreline area on the satellite imagery of July 13th, 2000. The maximum and minimum shoreline changes on the EPR is 43.540 m/year and -80.810 m/year in respective order (figure 4).

![Figure 3](image-url)  
*Figure 3. Classification map of erosion and accretion along the shoreline in 2000, 2003, and 2005.*
Figure 4. Shoreline changes the rate of Northern Nias in 2000 – 2005.

3.2. Co-seismic period
The shoreline changes rate shown in figure 5 was the most significant which is occurred in the period 2005 – 2006. In this classification, the value was very high, peaking at 600,840 m/yr representing the accretion process on the west coast side. Moreover, in this period, tectonic activity was recorded with notable indications of deformation at several points with the length of the transect reaching 1,300 meters.

Figure 5. Classification map of erosion and accretion along the shoreline in 2005 – 2006.

The shoreline conditions indicate the tendency of the accretion process to form rapidly and expanding perpendicularly to the shoreline after the tectonic activity. The rate of land loss can only be observed in the southeast area with a minimum value of -10,590 m/yr (figure 6). The satellite imagery was received
from the period of co-seismic on March 13, 2005. In this picture, the accretion process was still not apparent.

![Figure 6. Shoreline changes the rate of Northern Nias in 2005 – 2006.](image)

### 3.3. Post-seismic period

![Figure 7. Classification map of erosion and accretion along the shoreline in 2006, 2011, and 2018.](image)

The level of erosion and accretion processes were combined in the period 2006 - 2018 (figure 7) where the changes that occurred are insignificant. After the accretion process, the shoreline had been expanded to hundreds of meters. Also, in this period, the erosion process is unimportant. From the satellite imagery data on December 29, 2006, it can be seen that the significant changes are occurring in the previous period after a year the area being terraformed by a fairly-strong tectonic activity. The lowest rate which
represents the erosion process in the co-seismic period is $\pm 47,020$ m/yr and the highest rate is $3,420$ m/yr (figure 8). The length of the transect in the post-seismic period is a thousand meters. During this period, the erosion process was more dominant compared to its counterpart.

**Figure 8.** Rate of shoreline changes of North Nias in 2006 – 2018.

| Year          | EPR                      | LRR                      |
|---------------|--------------------------|--------------------------|
| **Total of**  | **Pre-seismic** | **Co-seismic** | **Post-seismic** | **Northern** | **Total of** | **Pre-seismic** | **Co-seismic** | **Post-seismic** | **Northern** | **Transect** | **Erosion** | **Accretion** | **Erosion** | **Accretion** | **Erosion** | **Accretion** | **Erosion** | **Accretion** | **Erosion** | **Accretion** | **Erosion** | **Accretion** | **Erosion** | **Accretion** |
| Transect      | Average shoreline changes (m/yr) | -1,496 | 172,718 | -0.959 | 56,90053 |
|               | Minimum shoreline changes (m/yr) | -80,810 | -10,590 | -47,020 | -44,223 |
|               | Maximum shoreline changes (m/yr) | 43,540 | 600,840 | 3,420 | 214,417 |
|               | Standard deviation (m/yr) | 12,787 | 179,261 | 5,429 | 65,826 |
|               | Total transect of erosions | 55 | 7 | 44 | 35 |
|               | Total transect of accretions | 41 | 80 | 52 | 57 |
|               | Average shoreline changes (m/yr) | -1,058 | - | -0.964 | -1,230 |
|               | Minimum shoreline changes (m/yr) | -75,060 | - | -50,120 | -65,465 |
|               | Maximum shoreline changes (m/yr) | 38,990 | - | 5,520 | 24,53 |
|               | Standard deviation (m/yr) | 12,2082 | - | 5,721 | 8,964 |
|               | Total transect of erosions | 55 | - | 46 | 33 |
|               | Total transect of accretions | 41 | - | 50 | 45 |

The value presented in table 3 came from the statistical analysis of shoreline rate changes of Lahewa, Northern Nias. Negative values indicate the erosion that happened and positive values indicate the accretion that occurred. The highest EPR and LRR values are in the period 2005 – 2006 which are occurred after the tectonic-earthquake activity. Total transects of accretion reached 80 out of 87 total transects. It is also influenced by vertical land movements after the earthquake. The highest value of
standard deviation in the EPR came from the period between before and after the tectonic earthquake of the co-seismic period (2000 – 2006). Both conditions between pre-seismic and post-seismic periods are stable where the difference in the rate of erosion and accretion processes is relatively minimal.

4. Conclusion
DSAS and remote sensing methods are capable of detecting horizontal shoreline changes by determining the level of erosion and accretion. Shoreline change is a problem that has to be considered extensively. This is simply because a coastal area is a place where the community daily activities took part; it revolving in activities such as local economies, infrastructure developments, and tourist attractions.

From the DSAS result, every period on Lahewa Beach has a different pace in terms of altering the shoreline. The results showed that the rate of shoreline deformation was greater in the co-seismic period (2005 - 2006) compared to the others. In addition, tectonic activity in the co-seismic period of 2005-2006 brought significant changes to the shoreline. The shoreline position that changes before and after the earthquake made the rate of the changes even smaller. The maximum value of EPR is 600,840 m/yr coming from the co-seismic period and the minimum is coming from the post-seismic period with the rate of -80,810 m/yr. Furthermore, using satellite imagery will provide more accurate data for every time period. Further coastal area management by the government and community is needed to bolster a better regional and municipal development in Lahewa Beach. It is also mandatory for future disaster mitigation and resilience in the area.

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