Evaluation of shoreline change using multitemporal satellite images

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Abstract. Coastal areas are vulnerable to change because, in this region, many human activities and natural influences change. These activities can result in changes in the existing coastline. Moreover, the city of Surabaya has a reasonably long coastline. This study calculated the speed of shoreline change using remote sensing technology of SPOT 6 and SPOT 7 high-resolution satellite imagery from 2015 to 2019. Calculation of shoreline change speed is assisted by the application of the Digital Shoreline Analysis System (DSAS) using several methods, namely Shoreline Change Envelope (SCE), Net Shoreline Movement (NSM), End Point Rate (EPR), and Linear Regression Rate (LRR). Based on data processing and analysis, the longest coastline of Surabaya City was found in 2015 with a length of 69.605 km, and the shortest coastline was in 2019 with a length of 65.759 km. The maximum speed of Surabaya shoreline changes can be identified by using the SCE method (956.590 m), the NSM method (+584.722 m), the EPR (+148.725 m per year), and the LRR (+154.386 m per year). Also, an analysis of land area changes during the 2015-2019 period resulted in the Kalisari Village experiencing the most significant accretion of 358073.62 m², while in Keputih Village abrasion of 30189.72 m².

1. Introduction
Shoreline has a significant role in coastal management, coastal engineers, and coastal researchers to manage the coastal and marine areas in the city, provinces, or countries. For practical purposes, the shoreline is defined as the intersection between land and water surfaces, and it depends on the temporal and spatial scale. It is being considered to use a range of shoreline indicators, such as mean sea level, high water level, low water level, and other types of higher or lower water levels [1]. Coastal areas have considerable development potential because ecosystems support them with high biological productivity, such as coral reefs, mangroves, estuaries, seagrass, and so on [2]. Coastal areas also provide environmental services that are of relatively high economic value. Therefore, coastal zones often experience changes in function, region supposed to be a conservation area or coastal protection forests. Water catchment areas and habitats of mangrove forests have been turned into residential, warehousing, industrial, region large-scale housing, and other functions [1].

Multispectral and multitemporal satellite images from a low, medium, and high resolution such as Landsat, SPOT, Quickbird, World View, and other satellite images can detect shoreline changes. Some researchers such [3][4][5] and [6], used Landsat Satellite image (Landsat MSS, Landsat 5 TM, Landsat 7 and Landsat 8 OLI) with spatial resolution 60 m (MSS) and 30 m (5 TM, 7 TM, and 8 OLI) to detect shoreline change in East Java [3], Demak [4], Cisadane Watershed [5] and Kendal Coastline [6]. All of them also used the Digital Shoreline Analysis System to analyze the change of shoreline in some location areas. Surabaya city, one of the biggest cities in Indonesia, is a coastal area that has a coastal line from northern to the eastern part. Surabaya's coastal zone, especially in the East Surabaya, is reclaimed much influenced by several factors, including results from landfill for various purposes (residential areas, factories, businesses, etc.), and is caused by the sedimentation of the estuary lead the emergence of the mainland. The impact of the reclamation on both landfill and natural sedimentation positively affects the shoreline. This research will determine the changes in coastline and the speed of shoreline changes.
that occur quickly and accurately using high resolution satellite imagery. The drawbacks of low or medium spatial resolution are Landsat TM 6, TM 7 dan 8 OLI can only identify shoreline changed more than 30 m, and Landsat MSS can identify more than 60 m of shoreline changes. Information on shoreline changes is essential in various coastal studies [7], such as coastal area management plans, disaster mitigation, abrasion-accretion studies, morphodynamic beach analysis, and modeling.

2. Method

The research location is the city of Surabaya, geographically located at 112 ° 36' - 112 ° 54' East and 7 ° 9' - 7 ° 21' South. Surabaya is the second biggest city in Indonesia after Jakarta. It has a coastline from the northwest (borders with Gresik) to the east to the south (borders with Sidoarjo) with 65 km length approximately. In this study, we use a high satellite resolution image (SPOT 6 and SPOT 7) from 2015 to 2019.

Figure 1. Research location Surabaya Coastline from the north to the east.

Geometric correction aims to correct geometric errors that occur in satellite images. Because of the Pandemic Covid19, the geometric correction method to correct all of the images is an image to image registration with one image as a reference image, ie. SPOT image in 2015. This method used nine Ground Control Points (9 GCPs) as common points in the same points for all images to rectify all of the images. This geometric correction process will produce images with the same map properties, scale, and projection [8]. The value can see the quality of image geometric correction of the Root Mean Square Error (RMSE), defined by the equation:

\[
RMSE = \sqrt{\frac{\sum_{i=1}^{n} ((x'_i-x_i)^2 + (y'_i-y_i)^2)}{n}}
\]  

where \((x'_i, y'_i), (x, y)\) and \(n\) successively the coordinates of the transformation, the coordinates of the control point, and the number of GCP.

This geometric correction results are then carried out to test the accuracy by using the ICP point. In this study, 20 ICP points were used, where these ICP points were common points sought from the five satellite images. The next step is the coastline digitizing based on direct interpretation using NDWI (Normalized Difference Water Index). NDWI uses the principle of dominance from water areas because the green wave spectrum in the range (1.55-1.75 µm) maximizes the reflectance of water by the recorded object, and defined by equation [10]:
where GREEN and NIR respectively the green channel reflectance value and the near-infrared reflectance value.

After the digitizing process, calculating the shoreline change speed used the Digital Shoreline Analysis System (DSAS). This process needs baselines and shorelines. The baseline results from the buffer process of the existing coastline, and this buffering process is 150 m inshore. Shoreline change velocity needs a transect with an interval of 100 m along the existing coastline is used. The direction of the transect itself extends from the baseline towards the sea to the outer coastline. The DSAS uses a point as a measurement reference generated from intersections between the transect lines created by the user and coastlines based on time [11].

The speed of shoreline changes can be described with many various methods such as the Shoreline Change Envelope (SCE), the Net Shoreline Movement (NSM), the End Point Rate (EPR), and the Linear Regression Rate (LRR). The SCE measures the total change in coastline considering all available coastline positions and reports on their distance, without reference to a specific date, and the EPR calculates the speed of shoreline change by dividing the distance between the longest coastline and the most recent coastline by time (Figure 2) [11].

![Figure 2. EPR and SCE description [11]](image)

The NSM measures the distance of coastline change between the longest coastline and the newest coastline. The LRR measures based on a statistical analysis of the rate of change using linear regression can be determined using the least-square regression line for all points of shoreline intersection with transect (Figure 3) [11]. The process of calculating land area changes is classified into two, namely accretion and abrasion in every village in the coastal area of Surabaya. The accretion condition is that the shoreline experiences an increase in area, and the abrasion condition is that the shoreline has a broad reduction.

![Figure 3. NSM and LRR description [11]](image)

3. Results and discussion

3.1 Geometric Correction

An Image to image registration performed geometric correction to correct the satellite image from the error position. Following the five satellite images' appearance obtained, GCP's common points are used as common points for transformation parameters in the image to image registration process. In this case,
the number of GCPs is nine points, and the number of ICPs is twenty points, and Figure 4 shows the number and the distribution of GCPs and ICPs in the area of study.

![GCPs and ICPs distribution](image)

**Figure 4.** GCPs (red dot) and ICPs (green dot) distribution

RMS error value is an indication of the accuracy of the image registration. The geometric correction process gives the residual coordinates of the satellite imagery. This geometric correction process shows that the smallest RMS error is 2018 images with 0.68 pixels, and the most significant RMS error is 2017 images with 0.84 pixels. However, all of the RMS errors for all images are lower than one pixel. The pixel coordinates of the rectification results are not exactly 100% following the coordinates supposed to be in the field to calculate errors. In this study, the immense ICP RMSE value in 2017 was 1.410 m, and the smallest in 2018 was 1.164 m.

### 3.2 Shoreline Changes

It was digitizing of five corrected images identified five shorelines from 2015 to 2019. It shows that the longest coastline was in 2015 with a length of 69,605 km, while the shortest coastline was 2019 with 65,759 km (Figure 5 (a)). So, the Surabaya coastline has been changed for four years. The SCE method shows that the furthest distance between the deepest coastline and the outermost coastline was 956.590 m in Kalisari, Mulyorejo District, and the shortest distance coastline outer coastline was 0.059 m in Tanjung Perak, north Surabaya. Also, the average distance produced was 38.412 m (Figure 5 (b)). The distance between the oldest coastline (2019) to the youngest coastline (2015) can be shown by the NSM method. The furthest was +584.722 m, the shortest was -62.73 m, and the average distance was +26.236 m. Where a positive sign means that the coastline has a process of adding to the sea (accretion), while a negative sign means the coastline has a process of reduction towards the land (abrasion) (Figure 5 (c)). The speed of shoreline change (the EPR) is the distance NSM divide by four years. In this case, the speed of change in the Surabaya coastline was +148.725 m per year (maximum), -15.966 m per year (minimum), and 6.674 m per year (average) (Figure 5 (d)). The LRR method shows that the shoreline changes each year, such as a maximum of +154.386 m, a minimum of -17.895 m, and the average shoreline change +6.642 m (Figure 5 (e)).
Figure 5. The speed of shoreline changes in Surabaya Coastline

In the port area of Tanjung Perak Surabaya (Figure 6), northern Surabaya, for four years, there has been no change in the coastline. This case is due to the existing port's condition in a built area with fixed and unchanged embankments or piers.

Figure 6. Tanjung Perak Port SPOT imageries Coastline from 2015 to 2019
In the mangrove area, east of Surabaya, (Figure 8) in Kalisari, Mulyorejo District, there has been a significant change in the coastline from 2015 to 2019. This change is due to the rapid addition of mangrove land that leads toward the sea (Figure 9).

On the other hand, in Keputih Village, Sukolilo District, there has been a reduction in mangrove land, which may have been caused by tree cutting, aberration, waves, or other activities. So that the coastline turns outward towards the mainland (Figure 10).
3.3 Change in Land Area

For four years, from 2015 to 2019, the coastal area of Surabaya has changed, namely sedimentation (increasing land area) and erosion (reducing land area) (Table 4). Almost all areas on the Surabaya, the coastline, occurs sedimentation. The largest sedimentation occurs in Kalisari Village, Mulyorejo District covering 358073.62 m² (35.81 Ha). The smallest sedimentation in Kedung Cowek, Kenjeran District, covering an area of 992.24 m² (0.099 Ha). There is only one sub-district that experienced erosion, namely Keputih Village, Sukolilo District, reducing 30189.72 m².

| Village       | Sub-district | Area (m²)  |
|---------------|--------------|------------|
| Romokalisari  | Benowo       | 53683.68   |
| Tambakoswilangun | Benowo     | 19612.42   |
| Tambaklangon  | Asemrowo     | 75826.18   |
| Greges        | Asemrowo     | 16162.32   |
| Kalianak      | Asemrowo     | 21393.25   |
| Morokrembangan| Krembangan   | 12367.40   |
| Perak Barat   | Krembangan   | 19449.10   |
| Perak Utara   | Pabeancantikan | 11999.32 |
| Ujung         | Semampir     | 10142.40   |
| Bulak Banteng | Kenjeran     | 8014.60    |
| Tambakwedi    | Kenjeran     | 32781.96   |
| Kedung Cowek  | Kenjeran     | 992.24     |
| Kenjeran      | Kenjeran     | 16862.13   |
| Sukolilo      | Kenjeran     | 49868.48   |
| Dukuh Sutorejo| Mulyorejo    | 107005.47  |
| Kalisari      | Mulyorejo    | 358073.62  |
| Keputih       | Sukolilo     | -30189.72  |
| Wonorejo      | Rungkut      | 12160.54   |
| Medokanayu    | Rungkut      | 31731.70   |
| Gunung Anyar Tambak | Gununganyar | 53683.68 |

Table 1. Changes in the coastal area of Surabaya city in 2015-2019

Figure 10. The Coastline changes in Keputih, Sukolilo District (left: image 2015) and right (image 2019)
4. Conclusion
The Surabaya shoreline has been changed from 69.605 km in 2015 to 65.759 km in 2019, using SPOT 6 and 7 images. The maximum speed of Surabaya shoreline changes can be identified by using the SCE method (956.590 m), the NSM method (+584.722 m), the EPR (+148.725 m per year), and the LRR (+154.386 m per year). Changes in the land area during the period 2015-2019, namely in the Kulisari Village, experienced accretion of 358073.62 m², while in Keputih Village experienced an abrasion of 30189.72 m².

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