The study of SSC patterns on coastline changes in Socah Gulf using Landsat imagery and in-situ data

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Abstract. Socah as an economical buffer in Surabaya Metropolitan Area becomes one of important sub-districts in Bangkalan. As a shallow coast, this area is predicted to have significant coastline changes and a unique sedimentation pattern. This research aimed to analyze the sedimentation pattern and coastline changes in Socah. The 30 m of Landsat imagery was used in this research to observe sedimentation pattern that is represented by a suspended sediment concentration (SSC) trend from 2013, 2015, and 2018. Landsat images were also used to monitor the coastline changes in Socah starting from 1994 to 2018. From the sea color analysis, SSC values in rainy season are higher than those in dry season. The difference of SSC average between two seasons, in three stations, is 127 mg/L. SSC values in 2018 is also higher than those in previous years, with difference up to 94,17 mg/L in dry seasons and 357,67 mg/L in rainy seasons. Based on coastal changes calculation in the MHWL position from 1994 to 2018, the coastline changes in Socah reaches +5.325 m at a rate of about 0.26 m/yr. Coastline changes in Socah cause the area increase in 2018 up to 3.534 ha or 0.06% bigger than that in 1994. Those changes are dominated by accretion in Junganyar, Buluh, and Penarjuh Villages.

1. Introduction
Socah Gulf is a part of Socah Sub-district that is located in the west coast of Bangkalan district. This gulf is located on the West Surabaya Shipping Lane (Alur Pelayaran Barat Surabaya - APBS) whose traffic volume in 2005 amounted to 29,558 ships, and is predicted to double by 2030 [1]. Socah was once recommended as a general cargo port in the JICA port study [2] to support Perak port in Surabaya.

As westernmost coast, Socah waters have been affected by current from the Madura straits [3]. The dynamic process of the beach stability (back and forth) every year is affected by sediment movement near the beach area [4] such as littoral drift from oceanographic parameters including current and tide. The continuous interaction between them and the bottom of waters causes the morphology of coastal region to become very dynamic [5]. The longshore currents in shallow waters flow parallel to the
coastline and generally downwind [6]. Longshore sediment transport caused by current along the beach is often sufficient to erode the bottom of waters [7]. In the shallow beach with slope < 2%, the dominant sediment transport is suspended with fine texture based on Wentworth scale [8]. Periodical monitoring of the coastline changes is necessary to observe the dynamic of coastal conditions such as accretion and abrasion due to these parameters.

There are many methods to monitor coastline changes such as field surveying to determine coastline and its coordinates. However, it is often difficult to implement due to the high cost and the number of efforts that must be done. Increased optical image of remote sensing might be used as an alternative tool in monitoring coastline changes by interpreting objects on the surface of the earth recorded from satellite sensors. There are also some studies that provide coastal observation using moderate resolution and Landsat images which can be obtained free of charge [9], [10]. Landsat imagery has various bands with various wavelengths. This research utilized the multi-temporal resolution from Landsat images to analyze the suspended sediment concentration pattern (SSC) from 2013 to 2018, and to monitor the coastline changes in Socah from 1994 to 2018. This research studied the SSC patterns towards coastal changes in Socah waters with Landsat free images. Some in-situ data in 2019 were used to validate the SSC values that were extracted from Landsat data.

2. Research methodology

2.1. Characteristic location of Socah Sub-District

As stated before, Socah sub-district is a coastal area located in the westernmost of Bangkalan district. From Figure 1, it is illustrated that Socah has four coastal villages. They are Penarjuh, Dakiring, Junganyar and Buluh village. Socah Gulf is located in Jungayar village and the river which empties into this gulf is the Gladakpanjang river.

Socah has a declivous coast. It is indicated by the average of 0.640 % slope gradient in its bathymetric profile. Figure 2 describes the Socah coastal profile taken from LPI 1:50000 as bathymetric map issued by BIG.

![Figure 1. Study location.](image)

2.2. Data and tools

This research employed a free remote sensing satellite known as Landsat imagery. Landsat has several missions, starting from Landsat 4-5 ETM until Landsat 8 OLI. These Landsat satellite images have 30 meter spatial resolution [11]. Landsat has not only various spectral bands but also sufficient temporal resolution to monitor coastal changes and SSC pattern periodically. This study tried to explore NIR band of Landsat imagery. Firstly, NIR band was used to extract SSC value. Furthermore, NIR was combined with SWIR and red band as RGB band combination to detect the edge of land. Then, the edge was separated with visual interpretation.
This research used three L1T Landsat images for coastline delineation purpose, dated 28 July 2013, 16 June 2015, and 10 July 2018 while to examine SSC pattern, couple data in rainy and dry seasons were used, dated 28 July and 1 November 2013, 16 June and 23 November 2015, 10 July and 30 October 2018. Those data were chosen in path/row 118/065 with cloudless sky condition. In the same day with in-situ data collection, Landsat images on 24 April 2019 were used to validate the SSC data from Landsat.

Arcgis 10.3 was the most used software in this research, not only for on-screen digitizing but also for image processing. However, additional modeling software was also used to get the current flow model around the Socah Gulf at the time of image acquisition.

2.3. **Research flowchart**

The step of this research is illustrated in Figure 2 below. There are 6 main components: (i) pre-processing, (ii) SSC data extraction, (iii) SSC data validation, (iv) coastline extraction, (v) transect analysis, (vi) tidal current modeling.

![Figure 2. Research flowchart.](image)

2.4. **SSC data extraction**

The color of water in Near Infrared’s wavelength (NIR) will be darker than others. It is because water absorbs energy as much as 90 % of the total energy received [12]. Water reflects electromagnetic energy in the visible range and casts back a little in NIR range. All energies higher than 1,200 nm will be absorbed [13].

This study utilized the characteristics of NIR wavelength interactions to distinguish water color from other objects. It is because infrared wavelength in optical remote sensing technology almost always separates the response between water and vegetation object [12], The focus in this research was not to retrieve new algorithm but to utilize an algorithm that was previously successfully used in Venezuela [14]. The algorithm is:

\[
SSC = 1.35512x \rho_w 5x1000 - 2.9385
\]  

Where SSC in mg/L and \( \rho_w \) in percentage.

2.5. **SSC validation techniques**

There was no permanent station in Socah so the samples were collected from the temporary station on 24 April 2019 along with the passing of Landsat 8 above Socah. There are three stations, namely station
1, 2, and 4. Station 1 is located in the Glandagpanjang river mouth and station 2 is on the outside of the river mouth, but both are located inside the Socah Gulf. Meanwhile, station 4 is located on the outside of the gulf. Unfortunately, when Landsat imagery was obtained on April 24, 2019, station 4 was covered by clouds. It makes a huge error in SSC data extraction. Therefore, station 4 was removed from validation analysis.

Samples were collected using a water sample directly from the gulf, then brought to Environmental Quality Management Laboratory to get the SSC laboratory value. The method of measuring the concentration of suspended sediments in the laboratory was the gravimetric method using 0.45µm pore-sized filter paper. Although the SSC laboratory test method looks similar to the TSS laboratory test method, this method can still be used. It is because those laboratory test shows no bias when the size of the sand material composes less than about a quarter of the sediment mass sample, and finer material sizes of 0.062 mm [15]. The SSC laboratory values were then compared with SSC values that were extracted from Landsat images as validation step.

| Number of Station | Place            | Village | SSC Laboratory Value (mg/L) | Depth of Sampling (m) | Surface Current Speed (m/s) |
|-------------------|------------------|---------|----------------------------|-----------------------|-----------------------------|
| 1                 | Socah Gulf       | Junganyar | 266.0 | 0.5 | 0.013 |
| 2                 | Socah Gulf       | Junganyar | 102.0 | 0.5 | 0.083 |

2.6. Coastline extraction
Delineating the coastline to monitor shoreline changes using Landsat imagery is vulnerable to bias because the spatial resolution that Landsat has belongs to the medium resolution image. However, Landsat imagery has advantages that other free images do not have. Geometric correction in Landsat L1T (Level 1 Terrain) image is processed by incorporating GCPs taken from The NASA Global Landsat Survey (GLS) Image Database and a DEM to provide systematic geometric and topographic accuracy [16]. “The accuracy of the GLS2000 dataset is better than 25 m (RMS) for most of the constituent scenes” [17].

A conventional method using subjective on-screen digitations was used in this research to avoid blank data caused by thick cloud above shoreline when automatic method was applied. Moreover, this method was also used to avoid error caused by the bottom of water that is exposed when the water is in low tide conditions. Because Socah Gulf is declivous and the bottom of the water is vulnerable to exposure, this research delineated shoreline in MHWL position to maintain the shoreline shapes. In terms of increasing the Landsat ability to delineate coastlines, the sharpening method and the SWIR-NIR-red band combination were used in this study.

2.7. Transect analysis
Transect analysis is an analytical method used to get the difference between two or more coastlines at the same location in different years. The transect line is basically a sampling of horizontal intersection lines that are made transversely above two or more coastlines in different periods. The principle of this method utilizes coastline morphological changes through the difference in distance that appears between the old coastline and the new one on each transect [18]. This study used Net Shoreline Movement (NSM) transect, Shoreline Change Envelope (SCE) and End Point Rate (EPR) method with 10 m transect spacing.

2.8. Tidal current modelling
Modeling software was used to model the current movement and direction around Socah Gulf that are raised by tidal. This model aims to know the oceanographic condition at the same time when the Landsat
captures sea color. This condition is important because the distribution of SSC obtained from Landsat was temporary condition when Landsat passed over Socah before they were settled. Velocity of particle deposition depends on density, particle size, water viscosity and flow velocity [6].

3. Result

3.1. SSC pattern in Socah Gulf
The value difference between SSC extracted from Landsat with the SSC from the in situ data shown in table 2 is not too large. The value difference in station 1 is relatively small with the difference under 10mg/L.

Table 2. The comparison value of SSC extracted from Landsat with the SSC from the in situ data.

| Number Of Station | Place Name       | Village | SSC Laboratory Value (mg/L) | SSC Value Extracted From Landsat (mg/L) | Difference (mg/L) |
|-------------------|------------------|---------|-----------------------------|----------------------------------------|-------------------|
| 1                 | Socah Gulf       | Socah   | 266,00                      | 272,83                                 | 6,83              |
| 2                 | Socah Gulf       | Socah   | 102,00                      | 149,40                                 | 47,4              |

This research tried to explore the pattern of SSC distribution by ocean colour interpretation after the SSC algorithm was used. Figure 3 shows that the colour of SSC pattern in rainy season is darker than that in dry season, especially in 2015 and 2018. SSC value in 2018 is higher when approaching the land. This condition is affected by the water level at the time when Landsat passed over and captured the Socah Gulf. At that moment, the water level was receding.

Figure 3. SSC distribution patterns in the Socah Gulf in 2013, 2015, and 2018.
Figure 4. The patterns of SSC value based on station number.

Figure 4 shows the value of SSC based on the station number. Those values at that point are expected to represent the SSC pattern analysis in multi time condition. In the rainy seasons, the variation of SSC value is high. The SSC value in 2013 was relatively high but decreasing in 2015. On the contrary, in 2018, the SSC value in dry seasons increased consistently. SSC value in 2013 is the smallest of all. The average of SSC value between two seasons in three stations is 127 mg/L.

3.2. Coastline delineation result

As stated before, conventional method that was applied to delineate the coastline in moderate-resolution images is vulnerable to bias. To see how good this image delineates coastlines with this method, the coastline obtained from Landsat image was then compared with reference coastline. This research assumed that coastline published by BIG, as the authorized institution in Indonesia, is the reference.

The 1994 aerial photography is the BIG coastline data source. Thus, this research used Landsat 4-5 TM in 1994 too. The comparison of the two data used 1278 samples of the transect line on the west coast of Bangkalan included Socah sub-district. The distance of the lines is assumed to be the difference between the reference coastline and the coastline obtained from Landsat image. Then from the average distance, RMSE_X and RMSE_Y can be calculated.

Table 3. The comparison between coastline from Landsat delineation and BIG coastline.

| Calculation Parameters        | Value     |
|------------------------------|-----------|
| Number of samples            | 1278 samples |
| Average transect distance    | 27,131 m  |
| Standard deviation of transects | 26,408 m |
| X-axis RMSE                  | 9,690 m   |
| Y-axis RMSE                  | 24,389 m  |

Table 3 above shows that the difference between coastlines from Landsat image is less than 30 meters. It means that the coastline deviates not exceeding its resolution.

3.3. Coastline changes and rates

Figure 5 and table 4 show the result of transect analysis and coastline changes calculation in MHWL position. From the SCE, NSM and EPR range in Figure 5, it can be seen that the coastline changes are
dominated by accretion in Junganyar, Buluh, and Penarjuh Villages with values of more than 16 m for the NSM.

Tabel 4. Coastline changes value.

| Place       | SCE (m) | NSM(m) | EPR(m/yr) |
|-------------|---------|--------|-----------|
| Socah Gulf  | 92,278  | 5,325  | 0.268     |

Figure 5. Transect analysis result.

4. Conclusion
From the result above, it can be concluded that there are coastline changes in Socah from 1994 to 2018 with accretion value of up to 5,325 m and rate of about 0.26 m/yr. Coastline changes in Socah cause the area increase in 2018 of up to 3,534 ha or 0.06% bigger than that in 1994. Those changes are dominated by accretion in Junganyar, Buluh, and Penarjuh Villages. This condition is in accordance with the tendency of suspended sediment congregate based on the location point analysis.

In order to understand the pattern of coastline changes for the future prediction purpose, not only tidal current modeling with a long period of days, but also the influence of sea level rise is needed to calculate, and the resolution of satellite imagery need to improved.

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