Monitoring long-term shoreline changes along the coast of Semarang

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Abstract: Shoreline is defined as the intersection of land and water which provides economic and social security to coastal communities. Semarang is having approximately 20 km shorelines. It faces multiple threats as a result of for instance urban development, industrialization, land reclamation, land subsidence and erosion. In the present study, an attempt was made to monitor the accretion and erosion processes from multi-temporal images from 1988 up to 2017. Fuzzy approach and OTSU method were made to extract the shoreline and DSAS (Digital Shoreline Analysis System) was used to analyse the changes and estimated the shoreline change rate. From change detection results, a general trend of continuous changes of shoreline can be detected representing a vulnerable shoreline affected by human activities. The results of this study can be used to prioritize action and to develop a suitable adaptation measure.

1. Introduction
Shoreline as the intersection of water and land is a dynamic environment. The change of shoreline positions may be effected by waves, winds and tides which are categorized as natural components. Furthermore, sediment transport processes, changes in water level and geomorphologic characteristics erode shoreline and cause the change of shoreline positions as well. Man-made processes that trigger beach erosion are for instance offshore dredging, structure constructions, beach mining, and dams development [1].

Shoreline position changes over time. Therefore, monitoring shoreline should consider temporal and spatial aspects [2]. The selected time scale will depend upon the objective of the research. In addition, monitoring of shoreline position is important in planning and integrated coastal zone management (ICZM). Shoreline change is one of environmental indicators which influences economic development and management [3]. Coastal erosion poses threat to coastal population and coastal environment. It defines as a long term process of sediment removal leading to shoreline retreat to landward direction [4]. It is the loss of land due to natural processes or human interference. The objective of the study is to investigate long-term shoreline changes in the northern coastal area of Semarang by means of remote sensing and GIS as a tool to indicate areas with a high risk to coastal erosion.

2. Study area
Semarang based on its elevation can be defined as the lower part (elevation <15 m) and the upper part with elevation >100 m (see figure 1). The study site has an area of almost 246 km² and more than 1 millions inhabitants [5]. For the last 30 years, hundreds of hectares of low-lying areas consist of swamps
and rice fields have been urbanized which have brought pressure and changed coastal areas into industrial and settlement areas.

![Figure 1](image1.png)

Figure 1. Study site was located in the coastal area of Semarang City SRTM is used to visualize the area. The location of villages was mentioned in the text.

![Figure 2](image2.png)

Figure 2. Local newspaper extract on the rob occurrences in May 25th, 2018 [6].

Semarang as the capital city of Central Java Province faces a serious problem regarding coastal flooding and erosion. The flood and erosion leads to changes of shoreline in the area. Flood risk has become a major problem since the colonial era (1900s) [7]. However, the threat has been aggravated after the enormous reclamation [8, 9]. Flood risk in Semarang municipality is caused not only by the lack of urban drainage system to support water discharge particularly during the rainy season, but also affected by high sea tides. Tidal floods called rob often threaten the city since the mid-1980s due to industrialization and the rapid growth of population. Moreover, the increase activities in the industrial zones accelerate the urbanization in Semarang and increase the number of settlements and expanding the urban area. The construction of urban areas increases runoff by reducing the capacity of ground to absorb rainfall. Because of this process, part of the northern coastal area of Semarang municipality has experienced growth of coastal inundation since almost three decades. Flood risk also makes people more vulnerable and threatens economic assets. Three types of floods have occurred in Semarang including: 1) tidal floods occurred periodically in line with tide cycles; 2) local flooding caused by rainfall; and 3)
river flooding caused by water overflow from the hinterland. The risk is aggravated by the monthly high tides. The phenomena can occur even there is no rain and getting worse during the rainy season (see figure 2).  

Figure 3. The maps of tidal floods risk in Semarang municipality (modified from Miladan [9]).

3. Methodology

3.1. Satellite Image and Data Pre-processing

Ten images consisting of Landsat and ASTER were used to monitor the changes of shoreline in the study area as can be seen in table 1. Seven images were captured during the low tides with little variation in water level. Three images in 1994, 2000, and 2009 were recorded at the high tides. Histogram minimum method was applied to eliminate the effect of path radiance [10]. Landsat 8 OLI/TIRS of 27 August 2013 was rectified using a 2013 Pleiades image. This Landsat image was used as the base image for georeferencing purposes. In this study, other images were geo-rectified with more than 70 GCPs (ground control points). Root mean square error (RMSE) values were <0.5 pixels.

| No. | Acquisition Date | Sensors | Tide Level (m) | Reference Data               |
|-----|------------------|---------|----------------|------------------------------|
| 1   | 23 Sep 1988      | TM      | -0.03          | Landsat TM, 23 Sep 1988      |
| 2   | 31 Aug 1991      | TM      | 0.01           | Landsat TM, 31 Aug 1991      |
| 3   | 08 Sep 1994      | TM      | 0.19           | Landsat TM, 08 Sep 1994      |
| 4   | 15 Aug 1997      | TM      | 0.05           | Landsat TM, 15 Aug 1997      |
| 5   | 06 Jul 2000      | TM      | 0.19           | ASTER, 16 Feb 2001           |
| 6   | 20 May 2003      | ETM+    | 0.01           | ASTER, 26 Feb 2002           |
| 7   | 12 May 2006      | ASTER   | 0.08           | ASTER, 12 May 2006           |
| 8   | 07 Jul 2009      | ASTER   | 0.3            | ASTER, 07 Jul 2009           |
| 9   | 27 Aug 2013      | OLI/TIRS| -0.09          | Image via Google, 31 Dec 2013|
| 10  | 19 Jun 2017      | OLI/TIRS| 0.04           | Sentinel-2, 28 Jun 2017      |

Landsat 8 OLI/TIRS of 27 August 2013 was used as a base image and it was rectified by using 2013 Pleiades image. Afterwards, ASTER images were resampled to match Landsat image in 30 m pixel resolution. For classification, seven bands of Landsat OLI/TIRS were used, six bands of Landsat ETM+, six bands of Landsat TM, and three bands of ASTER images. The spectral band information of those images is available in table 2. For accuracy assessment purposes, several reference data from Sentinel-
2, ASTER, and Landsat were used. Their spatial resolutions were 10, 15, and 30 m for Sentinel-2, ASTER and Landsat, respectively. Those images were obtained from USGS EarthExplorer [11].

### Table 2. Information of spectral band for each image used in this study.

| Satellite         | Bands          | Wavelength (μm) |
|-------------------|----------------|-----------------|
| Landsat TM        | Blue           | 0.45–0.52       |
|                   | Green          | 0.52–0.60       |
|                   | Red            | 0.63–0.69       |
|                   | NIR            | 0.76–0.90       |
|                   | SWIR1          | 1.55–1.75       |
|                   | SWIR 2         | 2.08–2.35       |
| Landsat ETM+      | Blue           | 0.45–0.52       |
|                   | Green          | 0.52–0.60       |
|                   | Red            | 0.63–0.69       |
|                   | NIR            | 0.77–0.90       |
|                   | SWIR1          | 1.55–1.75       |
|                   | SWIR 2         | 2.09–2.35       |
| Landsat OLI/TIRS  | Coastal and Aerosol | 0.43–0.45 |
|                   | Blue           | 0.45–0.51       |
|                   | Green          | 0.53–0.59       |
|                   | Red            | 0.64–0.67       |
|                   | NIR            | 0.85–0.88       |
|                   | SWIR 1         | 1.57–1.65       |
|                   | SWIR 2         | 2.11–2.29       |
| ASTER             | VNIR band 1    | 0.52–0.60       |
|                   | VNIR band 2    | 0.63–0.69       |
|                   | VNIR band 3N   | 0.76–0.86       |

3.2. Fuzzy Classification

Shorelines was identify by performing fuzzy \( c \)-means classification or FCM to calculate the membership value of non-water and water [12, 13]. FCM is a clustering method that separates data class with fuzzy boundaries. Once the clustering process is finished, each pixel is assigned to a label to produce water membership image. A combination of infrared bands (near or short-wave infrared) is used to decide the water class. The sum of the class means of the infrared bands was estimated. Water class is defined when this value is the lowest, as follows (equation 1) [13]:

\[
W = MIN[v_{i,c_1}, v_{i,c_2}]
\]

where \( v_{i,c_1} \) is the sum of class mean of the first class, for example water, while \( v_{i,c_2} \) is the sum of class mean of the second class, for example non-water. Both are in the infrared bands. The FCM was applied by setting parameters such as level of fuzziness \((m=1.8)\) and number of classes \((c=2)\) based on study conducted by Dewi, Bijker [14].
3.3. Image Segmentation
In this study, shoreline locations were determined by performing image segmentations to create binary maps. The method developed by Otsu was applied to obtain an optimal threshold by maximizing variance between water area and land area [15]. Assuming \( d \) is the threshold varying from \( a \) to \( b \) (\(-1 \leq a \leq b \leq 1\)), the following equations calculate the optimal \( d^* \) (equation 2) [16]:

\[
\begin{align*}
\sigma^2 &= \mu_{nw}(-M)^2 + \mu_w(M_w - M)^2 \\
M &= \mu_{nw}M_{nw} + \mu_wM_w \\
\mu_{nw} + \mu_w &= 1
\end{align*}
\]

\( \mu_{nw} \) is the non-water membership and \( \mu_w \) is the water membership. \( \mu_{nw} \) and \( \mu_w \) are the average value of non-water and water pixels, respectively. \( \sigma \) is the variance between two classes (non-water and water). \( M \) is the average value of the whole membership image. Pixels with values \( \geq d^* \) was divided into water and the pixels were scored 1. If pixels were categorized as non-water, then they were scored zero. Afterwards, the border of water and non-water is considered as shoreline which is extracted from water image maps using ArcGIS software.

3.4. Accuracy Assessment
For the accuracy assessment purposes, more than 200 points were visually interpreted from reference images (as in table 1) to obtain reference points. Furthermore, error matrices were generated to assess the accuracy of image classifications indicated by a value of kappa (κ) [17] ranging from -1 to 1.

3.5. Change Detection and Shoreline Change Analysis
Post classification change detection was implemented to inform the spatial distribution of shoreline changes. Shoreline images were overlaid to measure the size of the change of shoreline. Shorelines were emphasized to indicate the process of erosion and sedimentation along the coastal area. The calculation of shoreline change area was conducted for each type of the changes.

To analyse the changes of shoreline in terms of rates of erosion and accretion including the distance of the changes, the DSAS (Digital Shoreline Analysis System) tool was used [18]. Transect lines which are perpendicular to the baselines and located across the shorelines were generated based on a certain interval. Due to large changes of shoreline in the study area, various transects were generated ranging from 1000 up to 2500 m with interval 50 m of successive transects. Change statistics rates were calculated by using the transects [19]. The change statistics measured using DSAS tools consist of net shoreline movement (NSM), end point rate (EPR) and shoreline change envelope (SCE). The distance between the oldest and the youngest shorelines was calculated by NSM. This NSM represents the total distance between both shorelines. If this distance is divided by the number of years passed between the two shorelines, the result is the EPR. Meanwhile, the SCE reports the distance in meter between the farthest and the closest shorelines representing the overall change of the movement of shoreline for all positions. In this study, change of all shorelines for three decades data was analysed simultaneously to estimate the end point rate (EPR). The rate of changes was calculated based on the 378 transects that have been developed. These 378 transects were oriented straight to the baseline at 50 m spacing.

4. Results and Discussion
Fuzzy c-means classification classified pixels into cluster by allowing partial membership. Shorelines were then developed by applying Otsu method as an image segmentation method. Figure 4 shows the shoreline resulted by applying this method. In some places, shorelines move to seaward direction (advance) while in other places, shorelines move to landward directions (retreat). Table 3 shows kappa values of the classified shorelines in the accuracy assessment processes. Kappa values range from 0.76 up to 0.93.
The shoreline change rates computed at 378 transects with 50 m spacing along the 120 km stretch of shoreline. The results are presented in figure 5. The change rate is presented in meter/year (m/yr) in positive and negative values. The positive values convey deposition of sediments or reclamation activities to provide space for housing or industrial purposes. The negative values represent erosions. For this long term analysis, the lowest EPR value was -40.3 m/yr implying erosion occurred at Tugu sub-district in the west part of the area (transect ID=27). Meanwhile, the highest EPR was 57.4 m/yr representing accretion/reclamation occurred at Genuk sub-district in the eastern part of the study area (transect ID=403). In average, the long term rates were 5.3 m/yr for the entire study area showed a general trend of shoreline movement to seaward direction due to land reclamation.

![Figure 4. Shorelines resulted by applying FCM classification and OTSU method for image segmentation. Four shorelines are presented from 1988, 1997, 2006 and 2017 implying the advance and retreat of shoreline locations](image)

**Table 3.** The accuracy assessment results of shorelines developed using OTSU method

| Acquisition Date | Kappa (μ) | Acquisition Date | Kappa (μ) |
|------------------|----------|------------------|----------|
| 23 Sep 1988      | 0.76     | 20 May 2003      | 0.89     |
| 31 Aug 1991      | 0.78     | 12 May 2006      | 0.82     |
| 08 Sep 1994      | 0.84     | 07 Jul 2009      | 0.74     |
| 15 Aug 1997      | 0.93     | 27 Aug 2013      | 0.77     |
| 06 Jul 2000      | 0.78     | 19 Jun 2017      | 0.83     |

![Figure 5. Long term shorelines change rates (1988-2017) at 378 transects along the entire study area](image)

Shoreline change rates in the short term were computed separately (1988-1994, 1994-2000, 2000-2003, and 2003-2017). By doing so, the erosion or sedimentation between these individual periods was estimated. For the determination of the period from 1988-1994, the EPR average is 13.5 m/yr and the
accretion/reclamation and erosion are 31.6 and -25.9 m/yr, respectively (see table 4). During this period, a forward movement of shorelines were detected more dominant than a retreat movement or erosion.

**Table 4.** EPR rates estimated separately for four periods using DSAS analysis of shoreline in the study area

| Change period  | Sedimentation (m/yr) | Erosion (m/yr) | Average (m/yr) |
|----------------|----------------------|---------------|----------------|
|                | Min  | Max  | Average | Min  | Max  | Average |
| 1988-1994      | 0.0  | 252.2| 31.6    | -145.0| -0.1 | -25.9  | 13.5 |
| 1994-2000      | 0.0  | 240.2| 48.1    | -194.9| -0.1 | -53.3  | -16.2|
| 2000-2006      | 0.5  | 238.7| 36.8    | -212.1| -0.9 | -19.9  | 17.5 |
| 2006-2017      | 0.3  | 132.0| 24.3    | -130.2| -0.2 | -29.1  | -4.3 |

The second set during the period 1994-2000, the shoreline in the study area exhibits accretion/reclamation for 48.1 m/yr and erosion for -53.3 m/yr. In overall, the average of EPR value for this period was -16.2 m/yr implying that erosion was dominant (see figure 6). In between 2000-2003, accretion/reclamation was more dominant than erosion. The accretion/reclamation was displayed with average EPR value of 36.8 m/yr while erosion was -19.9 m/yr. The average of EPR value in overall was 17.5 m/yr. The last set during the period 2006-2017 has the average of EPR value around -4.3 m/yr implying accretion was less powerful than erosion. The average of EPR value for accretion/reclamation and erosion are 24.3 and -29.1 m/yr, respectively (see table 4).

![Figure 6](image_url)  
*Figure 6. The rate of shoreline change in a short term along the entire area estimated separately for four time periods.*

5. **Conclusion**

Information regarding shoreline change is very important in understanding shoreline positions in the future and in creating management policies in the coastal area. Monitoring of shoreline change for three decades in this area has revealed that shoreline is generally advancing. Meanwhile, the short term change trends exhibit advancing in the first and third periods, and retreating in the second and fourth periods. The advancing of shoreline was due to a massive reclamation activity in Semarang as the capital city of Central Java. This reclamation has a long history dated back in 1980s [9]. It occurred on a large scale due to a high demand for space for housing and other economic activities. Land reclamation was carried out starting from 1979 to develop real estates such as Tanah Mas, Puri Anjasmoro and Semarang Indah in 1985, and Marina in 2004 [8]. National harbour and airport were also developed and extended through coastal reclamation since 1980s and 1990s, respectively [9, 20].

Reclamation of land expands the space which is available for industrial and economic activities; however, reclamation has negative impacts on environment. Urban constructions increase the surface
runoff and prevent the ground in absorbing rainfall. These cause floods, land subsidence and erosion to the related area and its surrounding.

Therefore, coastal communities need to be educated considering the effect of land reclamation and other activities on shoreline changes. Furthermore, spatial data acquisition which is conducted regularly at the coastal area is important for further research in particular on shoreline changes. In this case, policy on coastal management regarding human intervention to coastal systems is mandatory.

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