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Integrated Remote Sensing and GIS for Calculating Shoreline Change in Rokan Estuary

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Abstract

This paper presents an application of satellite remote sensing techniques to detect and to analyze the spatial changes as well as quantify the shoreline change in Rokan estuary, Riau Province, Indonesia. Coastal zone of Rokan estuary, a place through which Rokan River flows into Malacca Strait is dynamically changed because of the hydrodynamic nature and high sediment transport in downstream of Rokan River. By integrating modern techniques of remote sensing and GIS (Geographic Information System), the rates of shoreline change would be easily and quickly determined for a regional area. Landsat satellite images were used with a combination of histogram thresholding and band ratio method for shoreline change detection for last 14 years from 2000 to 2014. The shoreline data then were adjusted for serving as an input for GIS tool to estimate the erosion and deposition rates. The statistical method called as LRR (Linear Regression Rate) in DSAS (Digital Shoreline Analysis System) was used in this study. The results of this study present shoreline changes map of Rokan estuary for last 14 years. Quantitatively, the shoreline of Rokan estuary is dynamically changed over a time because accretion rate is very high. The accretion rates in Halang, Barkey, and Serusai Island within 14 years are 67 m/yr, 53 m/yr, and 114 m/yr respectively.This occurs because of the hydrodynamic nature and high sediment transport in downstream of Rokan River.

Keywords: remote sensing, GIS, shoreline change, DSAS

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1. Introduction

Coastal zone and its environmental management require the information about shorelines and their changes. There are several approaches to calculate the rates of shoreline change such as numerical models and remote sensing technique. The rapid development of remote sensing and GIS technology lead to develop some applications more powerfull for shoreline change analysis. Besides some traditional computation from modeling, the integrated remote sensing and GIS also support effective results to coastal engineers and managers. By integrating modern techniques of remote sensing and GIS (Geographic Information System), the rates of shoreline change would be easily and quickly determined for a regional area. By the input data from extracted shoreline information from satellite image, GIS tool can be used to calculate long-term shoreline change rate. This approach is very effective because it would save time, costs and manpower [1].

This paper presents an application of satellite remote sensing techniques to detect and to analyze the spatial changes as well as quantify the shoreline change in Rokan estuary, Riau Province, Indonesia. Coastal zone of Rokan estuary, a place through which Rokan River flows into Malacca Strait is dynamically changed because of the hydrodynamic nature and high sediment transport in downstream of Rokan River. Currently, the use of satellite imagery dataset is very important role in providing data for analysis and monitoring of coastal areas due to the available data in long time period. Landsat TM (thematic mapper) and ETM+ (Enhanced Thematic Mapper) with 15 and 30 m spatial resolution are satellite imagery dataset that can be used for analysis and monitoring of shoreline change [2], [3], [4]. Landsat satellite images, such as Landsat 5 TM, Landsat 7 ETM+ and Landsat 8 OLI (Operational Land Imager) were used with a combination of histogram thresholding and band ratio method for shoreline change detection for last 14 years from 2000 to 2014. Image processing applied in this study included geometric rectification; atmospheric correction; on-screen shoreline digitizing for tracking the shoreline position of Rokan estuary.

With historical shoreline data input, the erosion and deposition rates can be estimated by ovelaying using GIS tool. The rate of shoreline change can be calculated by DSAS (Digital Shoreline Analysis System), an extension for ArcGIS. DSAS is a digital shoreline analysis tool that can be used to compute rate-of-change statistics for a time series of historical shoreline data which is developed by United States Geological Survey (USGS) [5]. The statistical methods called as LRR (Linear Regression Rate) in DSAS was used in this study. The LRR method can be determined by fitting a least squares regression line to all shoreline points for a particular transects. However, the LRR method is easy to employ and based on accepted statistical concepts with acceptable accuracy [6-8].

2. The Nature Condition of Rokan Estuary

The study area is located in Rokan Hilir Regency which is stretched from 1°14′0″ N, 100°17′0″ E to 2°45′0″ N, 101°21′0″ E as shown in Figure 1. Rokan River is one of four major rivers in Riau Province, Indonesia, which its length is about 400 kilometers. The river sourced from the Barisan Mountains in the west, and drained northeast-ward along Rokan Hulu Regency and Rokan Hilir Regency with estuarine located near the port town of Bagansiapiapi draining the water to Malacca Strait. The shoreline of Rokan estuary is dynamically changed over a time because of the hydrodynamic nature and high sediment transport in downstream of Rokan River. There are several islands that formed as a result of this process, and from time to time growing. Rahmansyah [9] investigated the rate of sediment transport in around Rokan estuary, and reported that the supply of suspended solids entering through either sequentially streamflow into the ebb tide and at low tide to high tide for Rokan estuary are 329,079.770 gr/sec and 297,900.580 gr/sec respectively.

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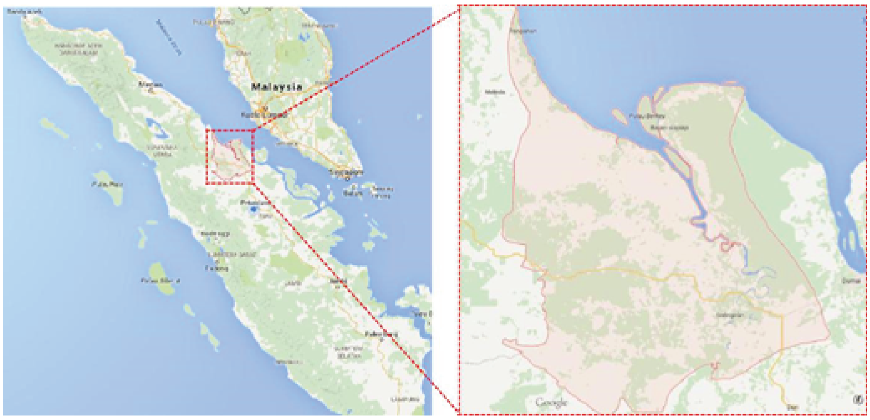

Figure 1: The Study Area.

Aquisition date	Satelit	Sensor	Resolution
10/04/2000	Landsat 5	TM	30 m
29/08/2002	Landsat 7	TM	30 m
03/08/2004	Landsat 7	ETM+	15 m, 30 m
11/11/2007	Landsat 7	ETM+	15 m, 30 m
17/06/2009	Landsat 7	ETM+	15 m, 30 m
22/05/2011	Landsat 7	ETM+	15 m, 30 m
23/03/2014	Landsat 8	OLI	15 m, 30 m

Table 1: List of Landsat scenes used for Rokan estuary study

3. Methodology

3.1. Data

Satellite data used in this study consisted of 7 years of data records, such as Landsat TM 2000, Landsat TM 2002, Landsat ETM+ 2004, Landsat ETM + 2007, Landsat ETM + 2009, Landsat ETM + 2011, and Landsat-8 OLI / TIRS 2014. Landsat TM has a resolution of 30 m, while the Landsat ETM+ and Landsat-8 OLI band 8 have a resolution of 15 m. Path and Row position is on the Path 127 and Row 29 or UTM 40N. Specifications of those satellite data are presented in Table 1. Selection of the data was based on availability and quality of the satellite data

3.2. Remote Sensing

Analysis and interpretation of Landsat data consists of cropping the image, image enhancement, geometric correction, digitization, and overlapping. Cropping the image was made to take the focus area of research to save storage in a computer memory. Image enhancement was the combination of bands needed to make clearer the boundary between land and water that will ease the process of digitization coastline. For Landsat TM and ETM+, the combination of histogram threshold and band ratio

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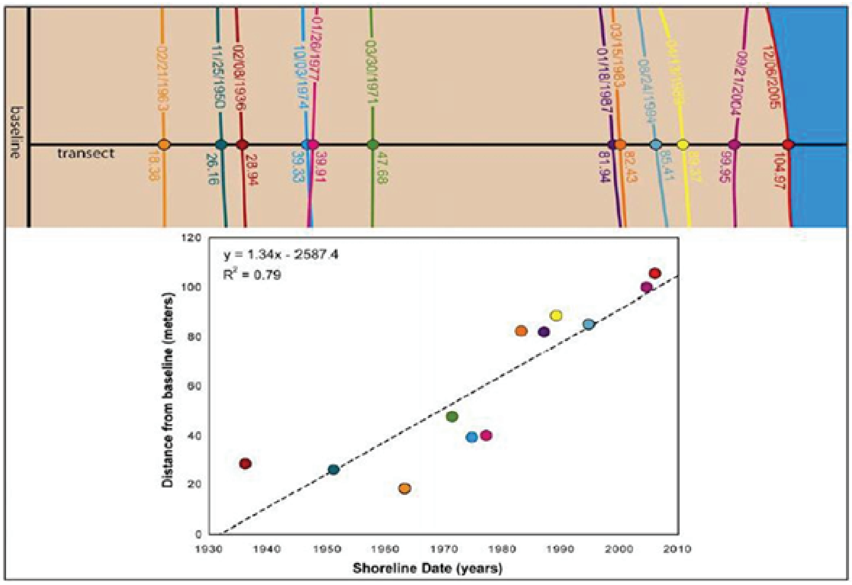

Figure 2: The method of LRR calculation (Source: Thieler, 2009).

techniques is proposed by using band 2, 4, and 5 to separate water and land directly [3]. Other approach is to use single band thresholds such as band 5 or band 7 of Landsat TM and ETM+ to extract water-land interface because they are useful in clear water conditions [10]. The Landsat image data were obtained in GeoTiff format which have been corrected so that the geometric correction was omitted. After classification, raster images would be converted to vector images. The final step is to export into shapefile format for processing in GIS tool.

3.3. GIS

Statistical analysis based on GIS was performed to determine the level of shoreline change or the rate of coastal erosion. This was done by using the software DSAS (Digital Shoreline Analysis System), an extension for ArcGIS. Shoreline analysis using DSAS consists of three main stages, such as : to set up baseline parallel to the shoreline as the reference line, to choose parameter for transects perpendicular to the baseline that divides coastline in sections, and to calcule the rate of change each section. Linear Regression Rates (LRR) method, a statistical method is chosen to present the computational results. The LRR can be determined by fitting a least squares regression line to all shoreline points for a particular transect as shown in Figure 2 [5]. The regression line is placed so that the sum of the squared residuals (determined by squaring the offset distance of each data point from the regression line and adding the squared residuals together) is minimized.

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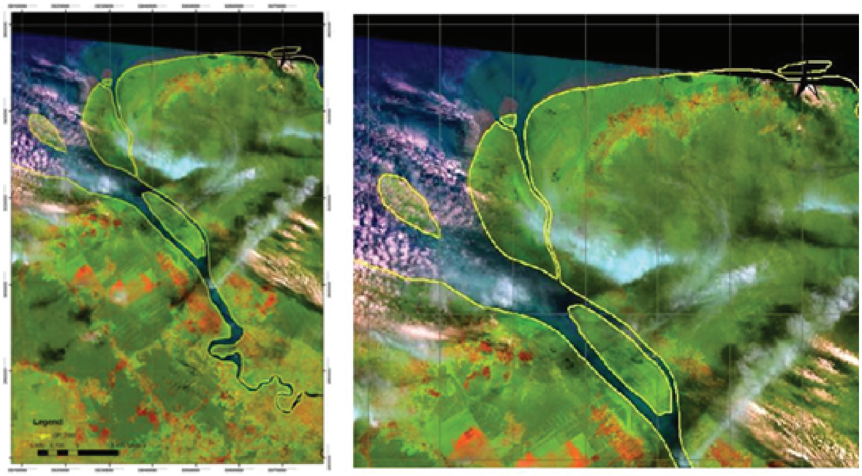

Figure 3: Shoreline extracted from Landsat-7 2002 with composite band 542.

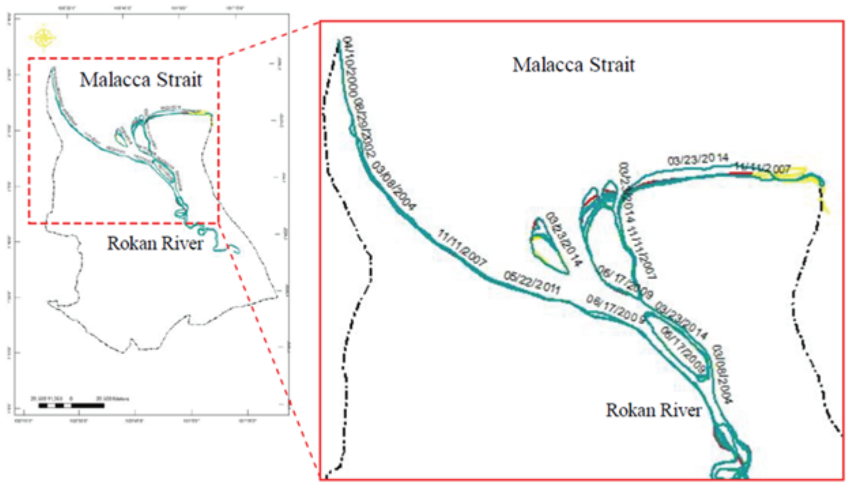

Figure 4: Shoreline extracted from Landsat 2000 ~ 2014.

4. Result and Discussion

4.1. Extracting Shoreline

The image processing, such as cropping, enhancement, and correction were applied for 7 years of Landsat data records. Fig. 3 shows an example result of the image processing for Landsat-7 2002. By using combination of bands 542, the boundary between land and water become clearer that make easier to digitize the shoreline. By image processing and digitizing, the historical shorelines data of Rokan estuary for the last 14 years can be extracted from Landsat. The extracted shoreline data are shown in Fig. 4. From the extracted shoreline data, the historical of shoreline change can be analyzed by overlaying process. Identification of coastal abrasion and coastal accretion during 14 years, from 2000 to 2014 can be carried out by overlaying the oldest and the newest shorelines, and the result is shown in Fig. 5.

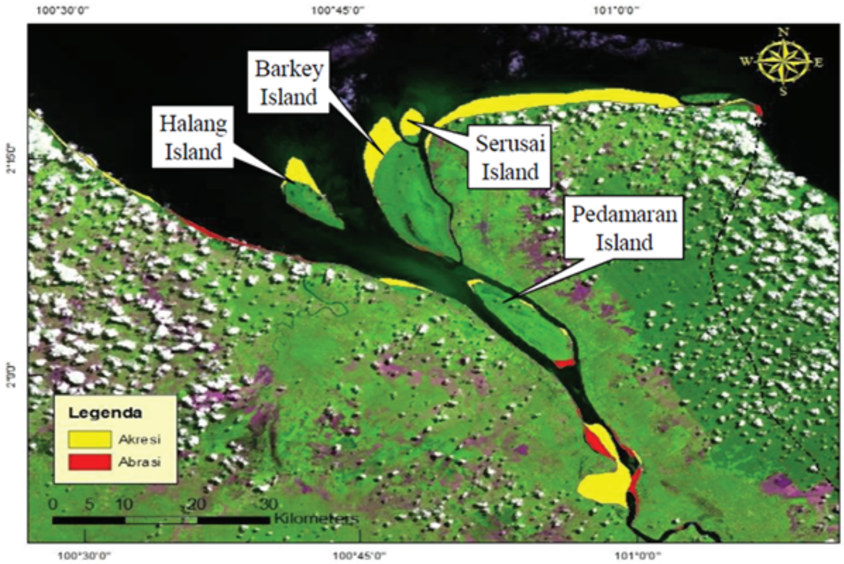

Figure 5: Abrasion and accretion area of Rokan estuary during 2000 ~ 2014.

As shown in Fig.5, accretion phenomena are very high in Rokan estuary which are dominanly occur in North area. On the other hand, abrasion phenomena are very low. This occurs because the sediment transport in Rokan river is very high which is about 297,900 gr/sec to 329,079 gr/sec [9]. There are three islands in downstream area namely Halang, Barkey, and Serusai Island which the accretion rate is very high, and an island in upstream area, Pedamaran Island which the accretion rate is relatively low. Over all, the abrasion rate in Rokan estuary is relatively low, and the accretion rate is very high as shown in Fig. 6. Historically, accretion occurrence from 2000 to 2007 was not too high, but starting from 2007, the accretion rate was gradually increased. The maximum accretion rate occurred during last 3 years from 2011 to 2014. Those phenomena occur probably caused by the activity or land use change in Rokan watershed that is need to be studied further. However, the abrasion rate in Rokan estuary was very small from 2000 to 2011. It was little bit increased from 2011 to 2014.

4.2. Shoreline Change Analysis

Multiple shoreline positions along with fictitious baseline are the basic requirement for analyzing the shoreline. Long-term rates of change were calculated for entire study areas at each transect for 14 years i.e. 2000 to 2014 using LRR method considering 7 datasets. The study area was divided into five zones for handling the data and visualization of the results at appropriate level. Fig. 7 shows an example result of the shoreline change analysis for Zone-2 which is located in Pedamaran Island. There are 157 transects established in this zone with 250 meter interval. The figure shows the rate of shoreline change in each transect number. It can be seen that the positive and negative rates of change show the beach accretion and beach abrasion correspondingly. As a result, abrasion occurs in Area-1 and accretion in Area-2, Area-3, and Area-4. The average rate of shoreline change within 14 years from 2000 to 2014 in Area-1, Area-2,

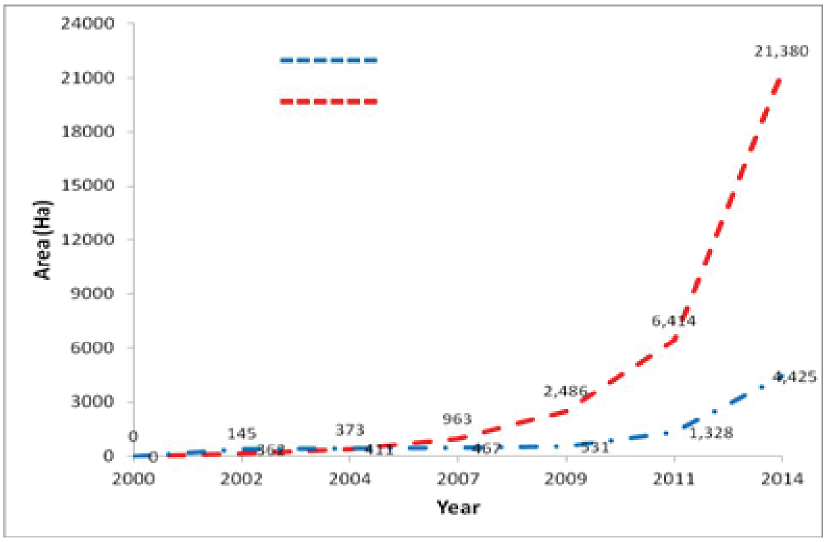

Figure 6: Rate of abrasion and acresion of Rokan estuary during 2000 ~ 2014.

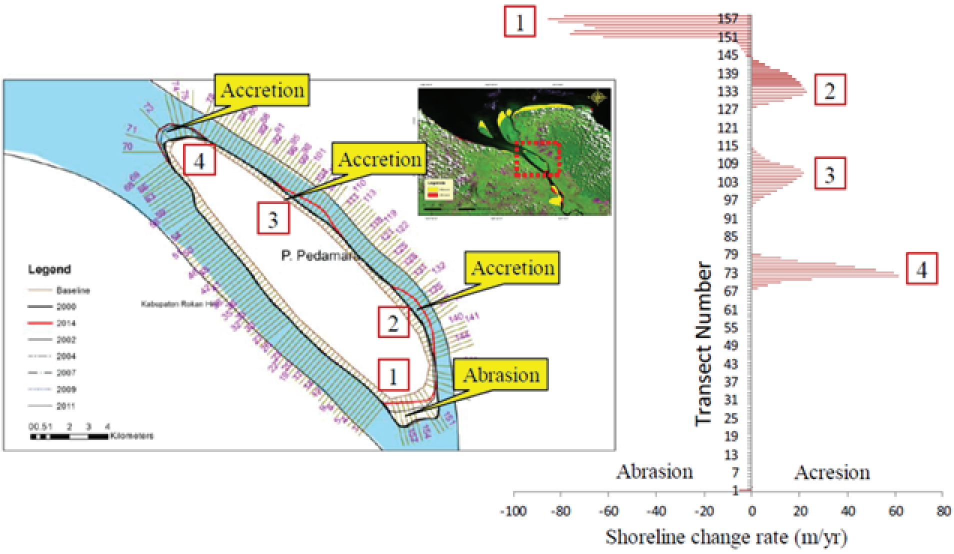

Figure 7: Shoreline change rate of Pedamaran Island (Zone-2), Rokan estuary during 2000 ~ 2014.

Area-3, and Area-4 are -44 m/yr, 13 m/yr, 10 m/yr, and 28 m/yr respectively. These phenomena indicate that Pedamaran Island is dynamically changed within this period. The upstream area of river flow tends to occur abrasion, while the downstream area occur accretion.

The shoreline change phenomena in Pendamaran Island also occur in the three other islands, namely Halang, Barkey, and Serusai Island. The shoreline change phenomena in Halang, Barkey, and Serusai Island, which are located in downstream area little bit different with that of in Pedamaran Island. As shown in Fig. 8, the rate of shoreline change in downstream islands is higher than that of in upstream island. The rate of accretion in downstream islands is very high, such as 67 m/yr, 53 m/yr, and 114 m/yr for Halang, Barkey, and Serusai Island respectively. However, the rate of abrasion is

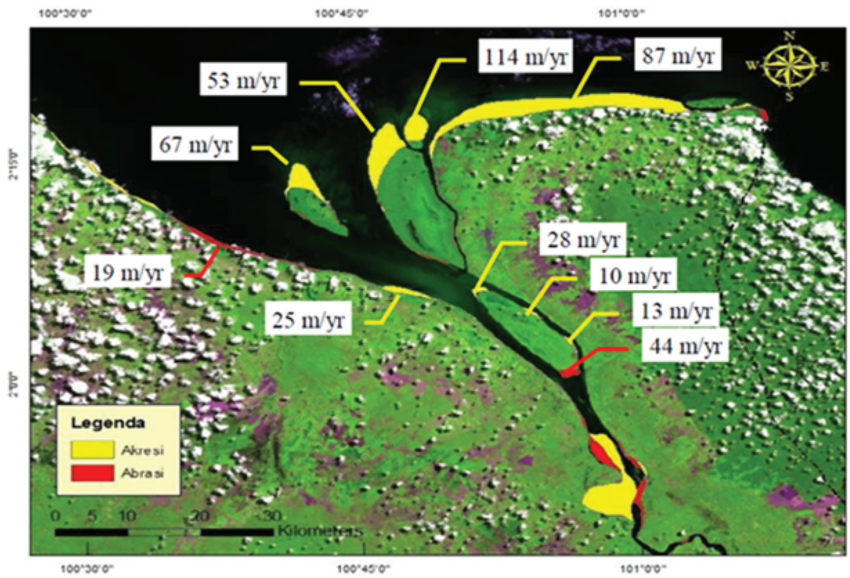

Figure 8: Shoreline change rate each lcation in Rokan estuary during 2000 ~ 2014.

very small. These phenomena make those three downstream islands become wider over a time.

5. Conclusion

The integration between remote sensing and GIS technology is very useful because it can be used to overview the long-term shoreline changes in the concerned area quickly. The paper showed that Rokan estuary shoreline could be determined rapidly by the improved band ratio. The shoreline change rates could be calculated by statistical method which was built in the extension of GIS tool. Quantitatively, the shoreline of Rokan estuary is dynamically changed over a time because accretion rate is very high. The accretion rate in Halang, Barkey, and Serusai Island within 14 years from 2000 to 2014 is 67 m/yr, 53 m/yr, and 114 m/yr respectively.This occurs because of the hydrodynamic nature and high sediment transport in downstream of Rokan River.

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