Coastal Dynamic Products Monitoring: Ratioing Strength and Weakness Analysis, ENVI Based Modelling

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Abstract

Studies on coastal area changes have attracted more studies over time. Monitoring highly dynamic coastal areas is effective using raster-to-vector modeling methods. This study aimed to demonstrate the ratioing method and evaluate other image-processing in simple raster analysis methods to analyze shoreline changes as coastal dynamics products. The most commonly used methods are change detection analysis, color mapping: density slice, Region of Interest (ROI), and ratioing. However, the existing methods are distinctive in assumptions, which reflect their suitability and effectiveness as the primary method for monitoring the coastal dynamics. As part of simple raster analysis, ratioing is deemed the most accurate in determining shoreline change. It shows clear pixel values with binary codes, i.e., “0” and “1” as sea or water body, and land or non-water, respectively. The lowest initial percentage of Digital Number at the first decline of the histogram is the key to minimize the error value in band ratio. This study thereby employed it to process the Landsat 8 OLI/TIRS and Landsat 5 TM images from 2011 until 2021 and identify the coastal dynamic in Kendal Regency, Central Java Province, Indonesia. The results showed that throughout ten years’ sedimentation occurred dynamically in Kendal estuary from 0.84 km to 1.19 km, with average LRR of 6.99 m and 111.77 m for the highest rate.

1. Introduction

The shoreline changes significantly influence the human population that lives in the coastal area, which accounts for 66% globally [1]. The impact and the intensity of shoreline change varies over time and, thus, induces changes not only on the shoreline itself but also in coastal areas [2]–[6]. The intensity is determined by natural and human factors [7], whereby wind energy affecting the movement of waves and currents is the main natural agent [8]–[10]. This includes the people residing in the coastal area of the Kendal Regency in Java, Indonesia. Kendal, traversed by the North Coast Road, i.e., one of the most congested highways on Java Island, experiences the impacts of rapid urbanization because it experiences accelerated population growth year after year [11]. A rapidly growing population creates particular pressures on the coastal area [8], [12], [13]. One of the most common by-products is an increase in the inundated area due to the development of residences in coastal areas [14]. In this case, the residents extract groundwater on a massive scale, which makes that the porous materials underneath the land surface lack groundwater. The weight of the constructions on the surface and the empty porous sub-surface triggers the subsidence of land. In addition, the local government’s plan to centralize industrial activities in Kendal Regency [15] will likely affect the natural landscape of its coastal area in the future [16], because the presence of settlements and industry intensifies coastal dynamics [13]. Therefore, monitoring the coastal dynamic becomes essential to maintain and protect the environment of the coastal area [7]. This protection includes minimizing the damages and losses caused by the detrimental impacts of coastal processes.

Shoreline monitoring requires time series data with spatial features. Shoreline monitoring is an important issue because the shoreline has a significant position to determine certain boundaries in matters about the state or other legal administrative areas [17], [18]. On a smaller scale, such as Kendal Regency, the information of shoreline changes is important to know the boundary of the regional management authority (Act No. 1/2014). As the most employed technique for spatiotemporal data acquisition, remote sensing has been developed for many purposes like a technical aspect, health, and spatial planning. The diverse uses of remote sensing are due to its efficiency in digital image usage, which accelerates its application, mainly through spatial data presentation. Therefore, shoreline change monitoring, as an effort to understand the spatially and temporally diverse impacts of intensive coastal dynamics utilize the Geographic Information System (GIS) supported by remote sensing [19]–[22]. In addition, information on the effects of shoreline change on coastal resources and the livelihoods of coastal communities is provided by shoreline monitoring [23].

This study aims to determine the effectiveness of several GIS-based methods in producing vector data from raster data through simple raster analysis methods for shoreline change monitoring in Kendal Regency, Central Java Province, Indonesia. The simple raster analysis is chosen as the compilation form for comparing each of the executed analyses. Hence, this research brings several pieces of evidence from each method and reveals the best way to conduct shoreline change analysis.

2. Materials And Methods

The primary materials consisted of Landsat 5 TM and 8 OLI/TIRS images captured from 2011 until 2021 with 30m spatial resolution received from USGS (United States Geological Survey) in *EarthExplorer* [24]. The Landsat Imageries identity is shown in Table 1. This study worked on raster-to-vector data processing for mapping the shoreline change. As its simplest meaning, Raster is a matrix of cells or pixels organized into columns and rows and organized as a grid. Each cell or pixel has its purpose and representation in digital numbers (continuous). In contrast, a vector is represented as a point, multi-point, line, polyline, or polygon.

Table 1
Images used in this study and their identities

Images	Acquisition	Sensors
1	6 June 2011	TM[1]
2	12 September 2013	TM[1]
3	18 September 2014	TM[1]
4	21 November 2015	TM[1]
5	20 March 2016	TM[1]
6	16 April 2017	TM[1]
2	1 August 2021	OLI_TIRS[1]

[1] Source: metadata, information: TM abbreviation of Thematic Mapper and OLI_TIRS is an abbreviation of The Operational Land Imager and Thermal Infrared Sensor.

The selected Landsat Imageries were evaluated on cloud coverage, which influences the image quality. The Landsat Imageries were considered by their acquisition time in the same local season, i.e., dry season. Due to the Landsat descending (daytime) acquisitions run time at 10.00 and 10.25 AM local time, the Landsat Imageries were selected to have the same tide condition [25]. These data characteristics were essential to be considered because a comparative study was executed. When the data characteristics are more similar, the comparison results can be accounted for scientific purposes or policy decisions.

The data-processing methods included change detection analysis, color mapping: density slice, Region of Interest (ROI), and ratioing, as shown in Fig. 1. These four methods are parts of the image processing feature in ENVI mapping software that uses raster data as its basis processing. Mapping with a raster database is currently more accurate than with its vector counterpart, because pixel values in raster data produces a more detailed map than line or area information in vector data [26], [27]. Nevertheless, raster processing lacks layout, therefore vector processing is needed to improve the result. This study chose one of the four raster-to-vector data processing methods, namely band ratio based. This method shows its effectiveness as the simple raster analysis method, as well as its simple application and limited time consumption. The resultant data was then used as input for shoreline change analysis in a digital vector data-processing software, i.e., ArcGIS.

This study used a series of Landsat 5 TM and Landsat 8 OLI/TIRS multispectral satellite images in the period 2011–2021, with a spatial resolution of 30 meter at *path 120* and *row 65*, or at an area that covered entire Central Java and the Special Region of Yogyakarta. Landsat images are the preferred satellite images in studies on coastal dynamic-induced shoreline change [1], [7], [17], [28]–[30].

3. Results And Discussion

Change detection analysis, color mapping: density slice, Region of Interest (ROI), and ratioing are used in determining shoreline change. However, each of them has different efficiency and accuracy regarding the results of their data processing. Change detection analysis does not support the use of more than two images [31]. In addition, the temporal change of the shoreline cannot be observed clearly. When the value of single-pixel changes from one year to the following year, this method produces a new pixel whose value is the combination of the pixel values in these two consecutive years. Change detection analysis shows the pixels that changed between the observed years are colored in a specific color with a different tone. Meanwhile, color mapping: density slice and ROI prioritize pixel information by determining a specific pixel range based on the density class method. ROI determines the value of a particular pixel with the nearest neighborhood approach. The determination of pixel value and range in these two methods does not have a specific reference to the focus of the study [32], [33]. Users have to input the desired range manually for every feature, including the upper and lower limits, for the density class method [27].

Determining pixel value and range manually to identify another pixel using the nearest neighbor approach is deemed less effective and less accurate because the results solely rely on the users' subjectivity [33]. In other words, there is a potential for bias during the identification of the land-sea interface, depending on the information added to each pixel. Such bias becomes critical considering the measuring point in shoreline change analysis is obtained by identifying the land-sea interface. Based on the diverse accuracy of the methods mentioned above, this study reveals that the ratioing method is the most accurate in determining shoreline change (Fig. 2). The data-processing results show a distinct boundary between land and sea, so that shoreline change in the study area can be relatively easily identified. In addition, ratioing does not require a manual input of pixel values, which makes that this method is not only accurate, but also more objective compare to the other methods in simple raster analysis.

As a result, ratioing method (Fig. 2c) is efficient as pixel values are converted into binary codes, i.e., "0" and "1". Zero "0" is allocated to a pixel that represents sea or water body and represented in black color, while one "1" represents land or non-water that shown in white color. Figure 2a, change detection analysis, almost shew similar visualization as ratioing. But the change detection analysis will leave massive holes in several areas since its only deliver the changes for its result. The most complicated method for resulting the shoreline image is color mapping, density slice – ROI. The default training samples for ROI resulted green and red color (Fig. 2b) that could not be interpreted. The binary codes conversion in rationing is another advantage of using the ratioing method that shows it simplicity and effective understanding [34]. Figure 3 presents how binary codes of the pixel value is generated.

Behind its superiority in detecting shoreline changes, ratioing method has an issue on the user's level of attention during interactive stretching on the histogram, because the histogram range is determined manually to get an optimal contrast. However, the user's subjectivity can be minimized by observing the lowest initial percentage of Digital Number (DN) at the first decline of the histogram. The lowest initial percentage that can be observed on the bottom-right corner of the histogram threshold window is shown in Fig. 3. This is often overlooked by ratioing users, which results in increasing error the result.

The shoreline was identified using ratioing on Landsat 8 OLI/TIRS bands 5 and 2 and Landsat 5 TM bands 4 and 1. Different bands were used to avoid band generalization from declining by one level due to the addition of Landsat 8 OLI/TIRS band 1 instead of Landsat 5 TM bands 4 and 1. Landsat 8 OLI/TIRS band 5 and Landsat 5 TM band 4 are the same bands that work very well for near-infrared, i.e., suitable for interpreting a body of water. Because they have zero reflectance on water, a body of water is thereby colored black or dark in Landsat panchromatic image. Landsat 8 OLI/TIRS band 2 and Landsat 5 TM band 1 are the first bands of each band combination. They were selected because they are the only visible bands with the highest soil reflection [25].

Another method that can be used to analyze the shoreline changes is fuzzy classification. In this study, the four methods chosen are the most common ones. These methods are also the simplest methods within simple raster analysis. Fuzzy classification is not part of simple raster analysis. The reason is that the fuzzy classification method needs some classes to be built manually. Otherwise, the class boundaries are not always clear for reasons such as imprecision of thought, ambiguous categorization rules, vagueness, and ambivalence. Argues for the use of the rationing method, as the outcomes are only a single binary code "1" or "0" for non-water and water classes.

The vector data obtained from the ratioing method was analyzed using the digital shoreline analysis system (DSAS) as one of the function tools of ArcGIS. This tool creates the shoreline changes automatically, which means minimizing human error. The results show that Kendal Regency had intensive shoreline change, i.e., 0.87–1.19 km from 2011 to 2021 as the most extended change, which occurred due to sedimentation during the years of observation (Fig. 4). These findings align with previous research that used spatial and multi-temporal data analysis over 100 years [28]. This study found that the shoreline development in Semarang City, a city abutting the Kendal Regency, was mainly due to the sedimentation process. In addition, another study by Khakhim et al. (2005) [35] confirmed that the development of the coastal area in the Kendal Regency was primarily due to the sedimentation process by determining the potential sedimentation magnitude using the cell sediment approach [35].

The shoreline change in Kendal Regency throughout the year was caused by the presence of the Bodri River that supplis a copious amount of sediment (Fig. 5). These findings are in line with previous research, which states that bettering of the living conditions in the slums in Kendal Regency is particularly hard, especially for tourism purposes, because the sediment transported by the Bodri River remains in the residential area in the form of mud after floods or when high tides recedes [36]. The sedimentation impacts are experienced by the people residing along the shoreline. The impacts were confirmed during field observation as part of this research project. On this case, the sedimentation affects fishing activities, because the increased siltation in the estuary of the Bodri River prevents fishers from sailing out or anchoring their boats flexibly, both to sail and land their craft. Inundation occurrences also increase due to the high siltation rate on the river mouth.

The final ratioing results showing shoreline changes along 0.84–1.19 km right at the end of the Bodri River estuary provide another evidence that if sedimentation occurs gradually (Fig. 5), sedimentation in this area is an unsteady state of sediment budget phenomenon, where the sedimentation process is more dominant than erosion. This trend can be classified as a positive trend, implying that sediment inputs or unqualified sources occur more intensively than output [37]. This logic is taken from the formula:

$$\sum Q_{sources} - \sum Q_{sink} - \Delta V - P - R = Residual$$

1

In this equation, Q sources are sediment sources, Q sink refers to the control volume, V indicates the net volume change of one cell, and P and R, are interpreted as the total of material placed in and moved from the cell, respectively. The result, as Residual, indicates the degree to which the cell has to be balanced [38]. With the phenomenon of an unsteady state of sediment budget in this area, which is indeed a single unit of sedimentary cells [35], there is no balance between sedimentation and erosion. The sedimentation appeared with the average of linear regression rate (LRR) ca. 6.99 m/year with highest number up to 111.77 m in 2016. LRR determines the position of shoreline to the certain time measurement base on the baseline. LRR was emphasized as it reveals the R square value and other components to make a further analysis [39], [40]. These findings reveal that integrated spatial planning in Kendal Regency must be managed as the main priority to maintain the coastal area of Kendal Regency. Integrated means that the planning program involves all sectors across territories, fragmented spaces among actors, and any stakeholders to deliver the policy to be right on target [41]. In this case, emphasizing the terrestrial aspects as the sources intensive level of sedimentation is one of the proper managements regarding integrated spatial planning. Not only the management subject, but also the management steps must be well integrated and defined. In this case, this means monitoring and adhering to the most effective raster-to-vector production method to observe and act on the dynamic changes in the coastal area.

The equation of the linear regression of y = 0.0013x – 48.901 means the rate of the shoreline change in Kendal Regency reach up to 0.0013 m. Otherwise, the R^2 (coefficient determination) of the linear regression implies the LRR does not in line with the upcoming year. For instance, we cannot predict that in 2030, the shoreline will propagate the 0.0104 m toward the sea. These values indicate that the coastal dynamic of the Kendal Regency has high complexity.

5. Conclusions

Coastal area is the most dynamic place on the earth surface. Hence, it requires simple, and precise method to be more effective for following the dynamic processes within. Ratioing is the most effective method of raster-to-vector data processing for monitoring coastal dynamics compared to the other techniques in simple raster analysis. This method is less subjective than the other data-processing methods applied, namely change detection analysis, color mapping: density slice, and Region of Interest (ROI). Ratioing is the method that shows clear boundaries between water and non-water, represented as pixel values which are converted into binary codes, i.e., “0” and “1”. A series of ratioing methods showed that Kendal Regency has the most intensive coastal dynamics among the other regencies in Central Java Province. Over ten years, i.e., from 2011 until 2021, the shoreline in Kendal Regency changed as far as 0.84–1.19 km seaward.

Declarations

6. Data Availability

The data supporting this study’s findings are openly available (free access) in USGS (https://earthexplorer.usgs.gov/).

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9. Contributions

Edy Trihatmoko: design the study, and performed simple raster analysis processing; Junun Sartohadi and Muh Aris Marfai: verified and validated the processes and supported the theoretical review; Juhadi and Ananto Aji: provided a computer processing laboratory; Elok Surya Pratiwi, Chantalle Elisabeth Rietdijk, and Satya Budi Nugraha: provided general ideas and summarized the back-ground studies: Misdianto Wongsokarto, Muhammad Hafizh Annaufal, and Dwi Yulianasari: conducted field surveys, and Rini Kusumawardani: analyzed the statistical review for the models.

10. Ethics Declaration

Conflicts of Interest: The authors declare no conflict of interest.

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Figures

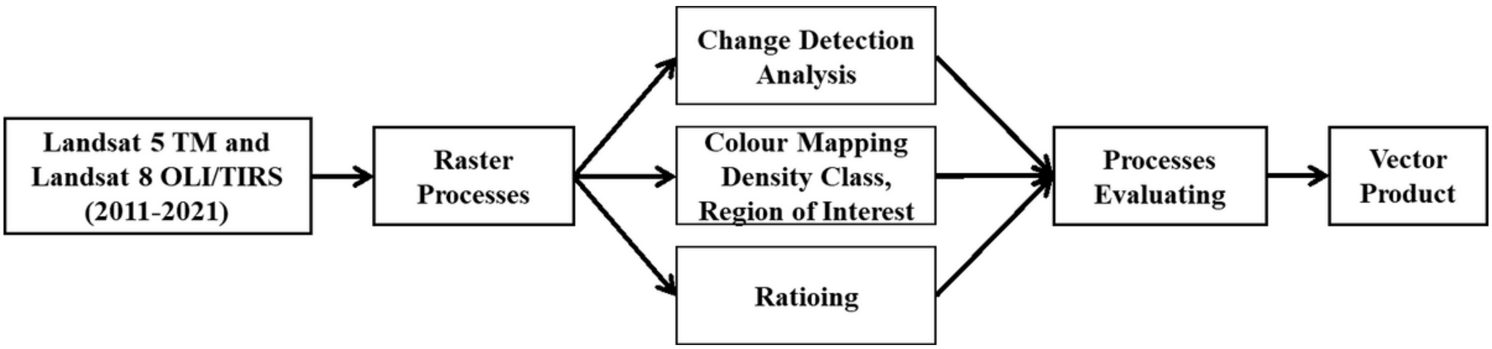

Figure 1

This is a figure. Schemes follow the same formatting.

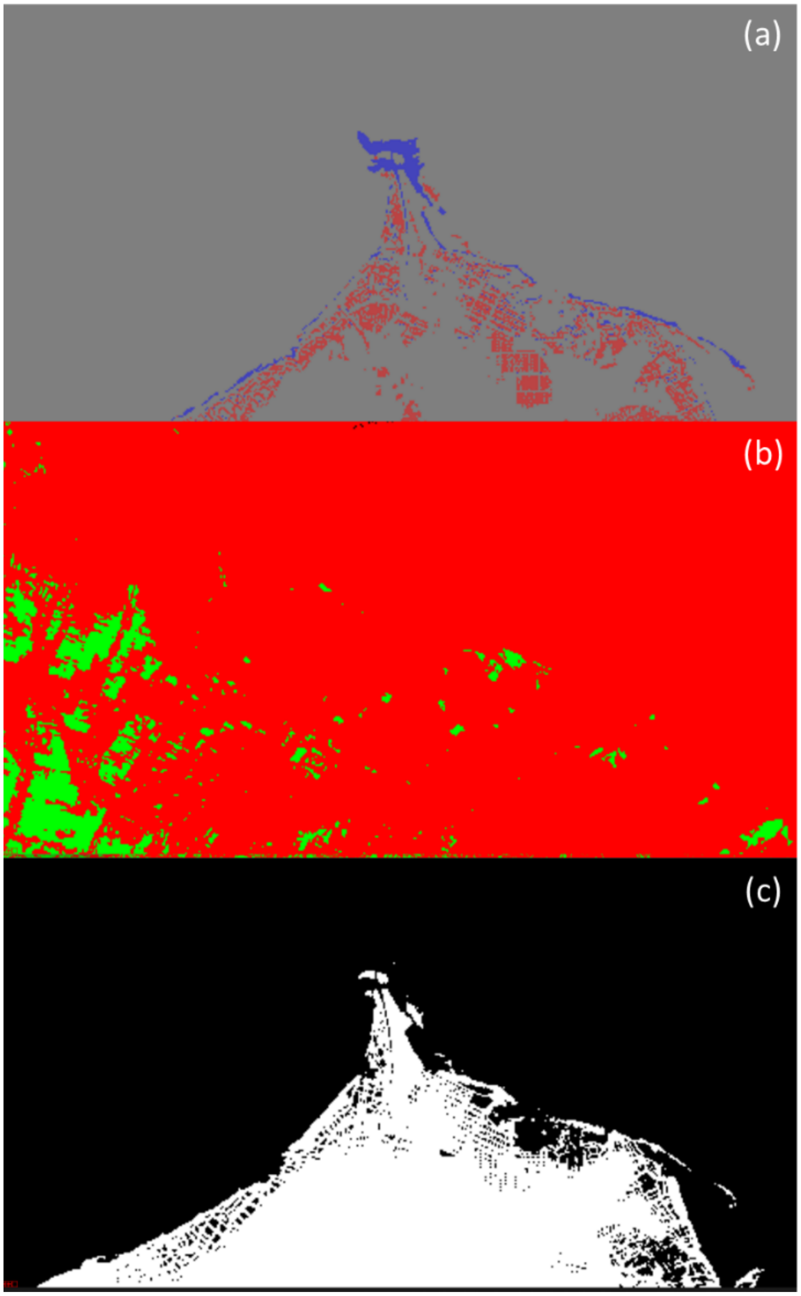

Figure 2

The result of image processing using band change detection analysis (a), color mapping (b), and ratioing (c). Blue color in change detection analysis indicates the missing area on the last period of analysis, otherwise the red color indicates the additional area on the last period of analysis. Color mapping requires advance analysis and steps to get an ideal land and water mapping, especially on the ROI determination. The result of image processing using band ratio method shows a clear boundary between sea and land.

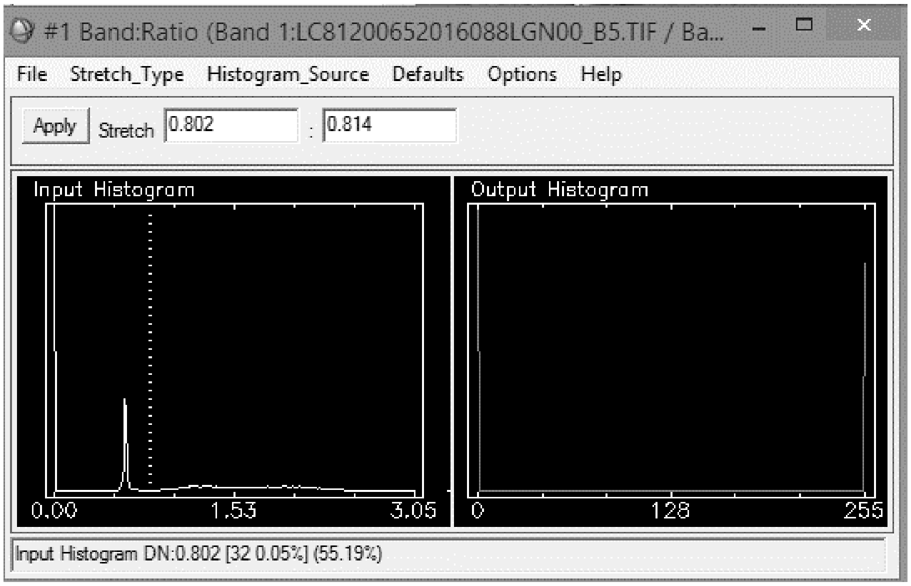

Figure 3

The process of ratioing method and its lowest value of interactive histogram for the best visualization shows the input of digital number (DN) 0.802 (32 0.05%) (55.19%) as the lowest value of the histogram's first decline.

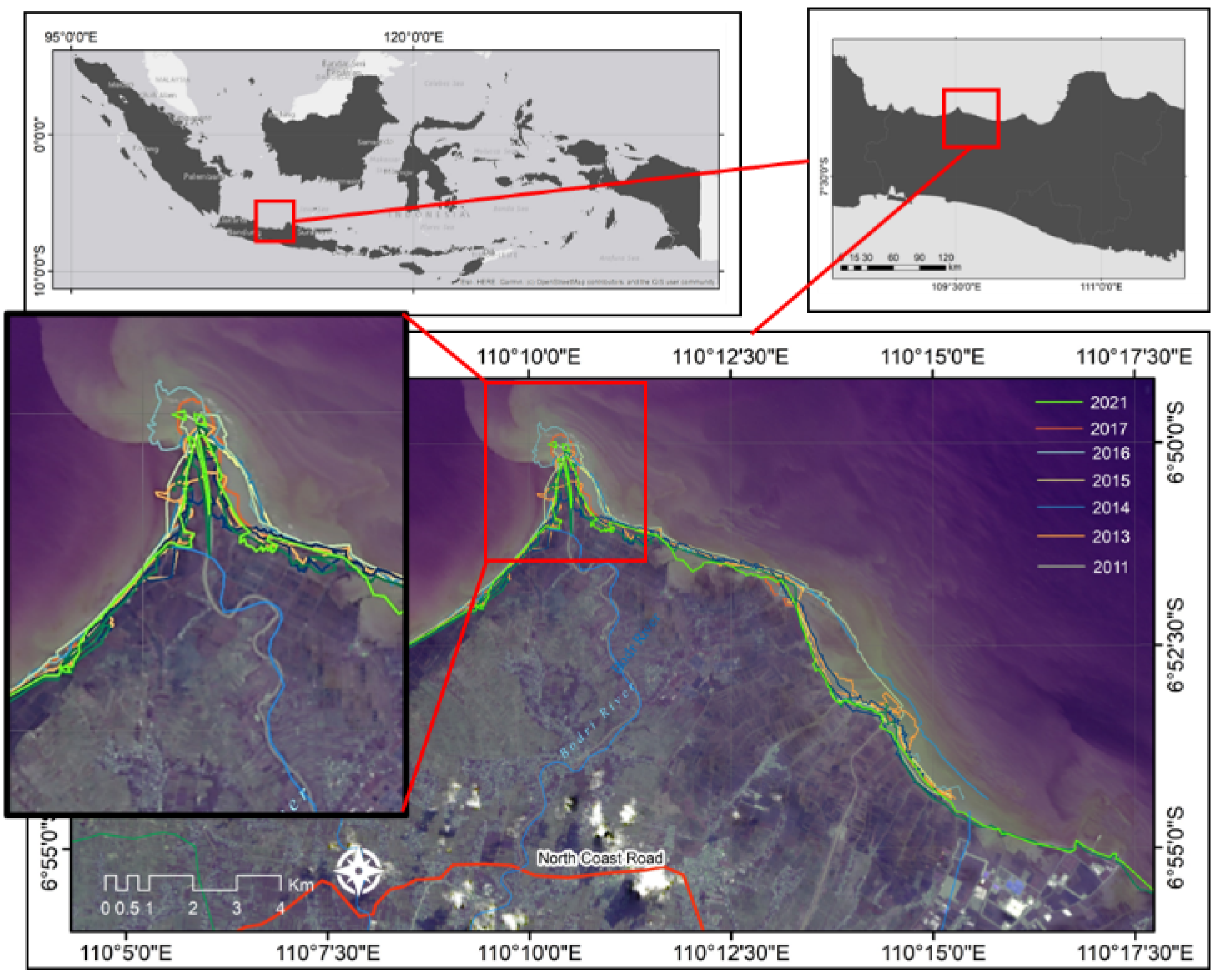

Figure 4

Map of shoreline change in Kendal Regency, based on the results of ratioing method (green for 2021 shoreline, yellow for 2011 shoreline, red-dotted line for an optimum change), shows that sedimentation occurred mainly in the northern part of Kendal Regency coastal area.

Figure 5

Aerial photograph (150 meters altitude) of the sediment leak from the Bodri River estuary.