Sequential Band-Ratio in Landsat 8 OLI/TIRS to Enhance the Suspended Sediment Direction Monitoring in Urban Coastal Area

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Abstract

Various environmental processes as impacts of urban areas related to coastal dynamics require continuous monitoring using the Geographic Information System (GIS). Among such consequences, the spread pattern of suspended sediment in urban coastal areas indicates urban flood risk. This research aimed to determine the spread pattern of suspended sediment in the urban coastal area of Kendal Regency, Indonesia. The primary research method employed ENVI to analyze the sequential band-ratio from Landsat 7 TM to Landsat 8 OLI/TIRS satellite images. The results show that the distribution patterns effectively use band 3/2 of Landsat 8 OLI/TIRS with ca. 0.1 higher for the DN value compared to the band 4/3. This finding indicates different cases in other regions that mostly enhance the band ratio of 4/3 – sequentially match with band 3/2 in Landsat 7 TM. By receiving clear visualization from a band ratio of 3/2, the potential major distribution of suspended sediment was seen in the northeast during the west-east transitional season. However, the East-West's transitional season shows the sediment's circulation at certain points that could become the potential benchmark locations for the siltation occurrence because of sediment concentrations.

Introduction

Indonesia is a sizeable archipelagic country with over 17,000 islands (Tran et al., 2017). Bearing such endeavor, with total seas cover 70% of the total area of this country (Dahuri et al., 2001) and, thereby, the area experienced intensive geomorphic processes along its coastal area (Mutaqin et al., 2013). These geomorphic processes are parts of coastal dynamics that include two main processes, namely erosion, and sedimentation (Muh Aris Marfai, 2011). Sedimentation, which is part of the main process in coastal dynamics (Muh Aris Marfai, Sekaranom, et al., 2015), mainly for the deposition process, creates siltation in the estuary including the Bodri River in Kendal Regency (Trihatmoko, 2017). Siltation can change upstream to downstream, indicated by the shifts of a river mouth, as occurred in Opak River, Bantul Regency (Sunarto, 2000). Along with the downstream, the urban flood or coastal inundation is likely to occur following erosion and deposition of the estuary during high tides and or high precipitation seasons. In addition, rapid urbanization processes within coastal areas promote rapid sedimentation rates. It happens at particular land use and or specified locations.

The geographic information system or GIS is a technology that can monitor the processes occurring in the environment (Seenath et al., 2016), one of which is sedimentation. GIS technology allows for detecting the early-stage of sedimentation process through the spread of suspended sediment in the observed seas (Pethick, 1984). This early detection is considered a disaster reduction towards urban floods (Widianto & Damen, 2014). The conditions of every season greatly affect the sedimentation process. It directly impacts sea current and wave pattern formed by the propagation of wind's kinetic energy (Bishop, 1984; Hadikusumah, 2009). Waves and currents are the major forces in the distribution of suspended sediments (Pethick, 1984).

There are several fundamental arguments to select the urban coastal area of Kendal as a research area (Fig. 1). First, the area has been a very active node for the regional hub, provided with the densest national transportation lines for the Northern Coast of Java, namely the North Coast Road (Muh Aris Marfai, Hizbaron, et al., 2015). Second, such rapid infrastructure development induces rapid urbanization, following the development of the national priority development zone in economic sectors (KEK), namely Kendal Industrial Park. Over time the rural coastal area of Kendal subtly turned to a pseudo-urban coastal area and recently into the urban coastal area of Kendal. Pseudo-urban coastal area is a phenomenon where coastal area slowly transforms and increases its function as urban areas with existing physical expression (Lin et al., 2019). This indicates that the coastal areas have been exposed to more human activities than before similar research on urban sediment had been conducted in Semarang, an urbanized coastal area at the North Sea of Java, located at the heart of Central Java Province. Semarang suffered from the high concentration of metals within its urban sediments (Widianarko et al., 2000). The metals such as Cadmium (Cd), Lead (Pb), Copper (Cu), and Zinc (Zc) are generally associated with improper management of industrial waste, garbage, and or effluent which contributes significantly to poor water quality in urban areas. Third, as stated by the second fundamental argument, Kendal coastal area will soon suffer the effects of suspended sediment but there is no research related to this problem precisely using band ratio analysis.

Taking such consideration, an early detection towards its deposition is before Kendal area where the main land use activities are heavy industrial activities, such as manufacturing and freights. To add, the Development Planning Agency of Kendal has set the area along the coastline as a strategic area that inevitably supports the local economy (Sesotyaningtyas & Manaf, 2015). The presence of human intervention in the coastal area certainly provides a significant adverse impact on sedimentation (Marfai 2011). Built-up areas induce a huge amount of overland flow and create an intensive erosion in coastal areas as the impact of environmental change (Ward et al., 2011). It causes deposition in the lower areas of the river mouth or nearshore zones.

The purpose of this study was to determine the spread pattern (direction) of suspended sediment in the study area and, then, to perform a comparison between the spread patterns formed in different seasons. The selected seasons were the west-east transitional season in March 2016 and the east-west transitional season in November 2015.

Materials And Methods

GIS utilization in this study was deemed effective because it had been applied in related studies in coastal areas and oceanography (Gopikumar et al., 2022; Nurrohmah et al., 2016; Septriayadi & Hamhaber, 2013; Zhibing et al., 2022). This study relied mainly on band ratio processing, part of GIS technology for the top atmospheric corrected imageries (Fig. 2). Band ratio has been widely used for its high effectiveness in identifying shoreline changes (Madani & Madani, 2014; Sutari et al., 2020; Trihatmoko, 2017). The band ratio R formulation derived from the ratio of the digital number DN of the particular band m to the other band n as follows:

$$R_{mn} = \frac{DN_m}{DN_n}$$

1

However, it has never been applied to determining the spread pattern of suspended sediment in the research location. Landsat imageries powered this study. Landsat imagery is widely used in various studies related to dynamic coastal monitoring received from the United States Geological Survey (USGS). This research used the modification of sequential band ratio of 3 to band 2 (blue and red) in Landsat 7 ETM for monitoring the suspended sediment (Aydın & Uysal, 2014; Madani & Madani, 2014; Muh Aris Marfai, 2012; Muh Aris Marfai et al., 2007; Perwitagama et al., 2016; Salghuna & Bharathvaj, 2015) to be implemented in Landsat 8 OLI/TIRS. This research was conducted in 2015–2016 in Landsat 8 OLI/TIRS with 30 m spatial resolution on path 120 on the row 65, covering Central Java and Yogyakarta (Fig. 3). Additionally, this imagery allows observing urbanization represented by the spatial distribution of the built-up environment along the coastal area of Kendal Regency. This comparison was conducted due to the commonly used band's red and green sequence (Khakhim et al., 2005; Sutari et al., 2020; Trihatmoko, 2020). On the other hand, the research location contains massive soil suspension (Trihatmoko, 2020). This fact reveals that to distinct the soil contamination, the enhancement of the blue band needs to be considered (USGS, 2017).

The calculation of band ratio was conducted using Landsat 8 OLI/TIRS images in November 2015, representing the temporal dimension for east-west transitional season, and in March 2016 for the east-west transitional season. The temporal dimension is important to avoid the failure in detecting the visualization of distribution of sediment (Zhibing et al., 2022). The transitional season is essential to be considered because it means a seasonal anomaly that induces the different spread pattern of the suspended sediment rather than the other seasons (Kirono, 2004; Sunarto, 2000).

Analysis of the physical aspects of the research area was carried out to strengthen the interpretation of sediment distribution. Several physical aspects were analyzed, including flow or drainage density, morphological aspects of the research area, and land use patterns. Drainage density (DD) is closely related to the distribution of sediment in the nearshore zone at the research as the medium for transporting sediment (Aldharab et al., 2019; Smith, 1950). While the consideration of land use determines the type or amount of sediment that will be transported through channels or drainage. The drainage density classification as shown in Table 1. Drainage density is formulated by comparing the total length of river *L* to the total area of *A* watershed. The formula is as follows:

$$dd = L\,/\,A$$

2

Table 1
Drainage Density Classification

Drainge Density (km/sq)	Texture	Effect
< 2	Very coarse	Very high inundation potential
2–4	Coarse	High inundation potential
4–6	Moderate	Normal
6–8	Fine	High erosion potential
> 8	Very fine	Very high potential erosion
(Aldharab et al., 2019; Smith, 1950)		

Results And Discussion

The analysis of suspended sediment using Landsat 7 ETM + images with the 3/2 band ratio had been done previously specified in the exact location (Khakhim et al., 2005). Bands 3 and 2 in Landsat 7 ETM + images appear blue and red, respectively (USGS 2017). When their wavelengths are modified or aligned in Landsat 8 OLI/TIRS image, they comprise bands 4 and 3 that appear green and blue, respectively. Khakhim, Dulbahri, and Mardiatno (2005) explain that bands 3 and 2 in Landsat ETM + image are the best bands to determine the turbidity level of suspended sediment. However, the 3/2 band ratio of Landsat ETM + image or the 4/3 band ratio of Landsat 8 OLI/TIRS image show a biased result when used to determine the distribution pattern of suspended sediment (Figs. 3). On the contrary, the 3/2 band ratio of the Landsat 8 OLI/TIRS image produced a clear distribution pattern. The visualization of suspended sediment in the sea of Kendal Regency using bands 3 and 2 of Landsat 8 OLI/TIRS images indicates a clear distribution pattern of suspended sediment represented in a grey color. It can clearly be distinguished from the clear water represented in black color.

Based on the fact that revealed from the clearest visualization of suspended sediment, the alignment of bands 3/2 on Landsat ETM + to bands 4 and 3 Landsat 8 are no longer accepted linearly. As evidence, Fig. 4 shows the digital number of suspended sediments for eight samples of the post-processing imageries. As shown in Fig. 4, the digital number representing the histogram threshold from 3/2 band ratio with a digital number value for suspended sediment area ca. 0.9, then representing the band ratio modification for 4/3 band marked the digital number value ca. 0.8. The closer the number is to the value of 1, the more easily it can be identified. Since the range value of the greyscale image is from 0 to 255, the 0.1 could be hundreds of pixel values and number different (Petrou & Costas, 2010).

Transitional seasons were chosen as the research period because of a seasonal anomaly called *pancaroba* and its frequent impact on coastal areas. The effect of seasonal anomaly is essential to mention due to its high intensity of energy changing in unpredictable time, moreover in the tropical region as done in this research area. The increased effects of seasonal change are also mentioned in previous research, which distinguished the morphological changes of Jishawan Beach in Taiwan (Ho & Lin, 2018). In Indonesia, panca roba is known as a disease period between the west and east season or otherwise. In the case of suspended sediment of Kendal Coastal Area, this research found that in the west-east transitional season, the suspended sediment spread toward the northeast, while the spread pattern in the east-west transitional season tended to be heterogeneous. In the east-west transition, the heterogeneous pattern showed patterns without suspended sediment identified along with the coastal areas. This could be an anomaly because the early west season, which means the east-west transition, typically shows a spread of suspended sediment due to the early annual rainfall (Kirono, 2004; Sunarto, 2000). Logically, after a long period of the east season in a dry condition, the surface materials should more easily be eroded and brought to the coastal areas by the sedimentation processes.

The exciting part of the 3/2 band ratio modification of the Landsat 8 OLI/TIRS image was the predominance of sea current heading northeast. Based on the results, the morphology of the coastal area in Kendal Regency, particularly the shape of the shoreline, showed a prominent area on the east side of the Kendal Regency coastal area seemingly in Fig. 3. In other words, the morphology of the eastern coastal area is more developed by gradual deposition, which was proofed by the presence of headland that shapes the spread pattern of suspended sediments in Fig. 3. This phenomenon indicates that the direction of suspended sediment, indeed, occurred in the same northeast direction. Another possibility could be that even though another direction occurred, the portion of the suspended sediment into the northeast direction is more significant than the one in the other direction. Another unique value of this 3/2 band ratio is the circulation shown in Fig. 3. The circulation that appears at specific locations during the east-west transitional season can determine the potential locations for siltation due to sediment concentration (van Rijn, 2011). It can also represent an accumulation of, for instance, nutrients (Yuan et al., 2017) or even toxic wastes that threaten the marine ecosystem. This toxic waste can be correlated with the accumulation of metals as found in Semarang Coastal Areas (Widianarko et al., 2000). Kendal Coastal Area and Semarang Coastal Area are one sediment cell, which means the transport of suspended sediment or any materials united in one cell, which is Kendal-Semarang Sediment Cell (Khakhim et al., 2005).

The result of the band ratio modification could indicate the sedimentation before it is deposited in reality. This method has, however, never been used before for shoreline activities monitoring. The earlier research had been done only by identifying the shoreline changes (Dewi et al., 2016; Gokceoglu et al., 2014; Muh Aris Marfai, 2011). So, the identification of the earlier research can be said to be slightly late as it is more challenging to mitigate the effect of sedimentation rather than acting before it affects the shoreline. In other words, by this research, the urban coastal protection processes of Kendal Regency could be put in place earlier before the sedimentation processes occur and affect coastal population and ecology.

The massive distribution of sediment in the coastal area has a strong linkage to the existence of urban areas (housing or industrial allocation) and productive land such as fish ponds in Kendal mainland.

The urban area in Kendal mainland impacts the increasing urban runoff accumulated in the stream of Bodri River, including surface material (Burniston et al., 2016). The high potential of inundation also alters the dredging surface materials from the urban area since the Bodri Watershed has a drainage density up to 1.39 classified into very coarse drainage density (Fig. 5). Drainage density can be portrayed as a way of evacuating water from both surface and subsurface of an area. On this case the total length of the streams was calculated up to 1352.49 km with the watershed in 972.41 km^2.

The drainage density map was extricated utilizing hydrological tools of ArcGIS and National DEM as the input data. Dendritic patterns are conspicuous within the considered area. The very coarse drainage density indicates that the inundation potential massively occurs.

The high land clearing rate due to production and urbanization has less attention to the importance of vegetation to withstand the rate of overland flow or urban runoff. Furthermore, vegetation, especially mangroves, not only could decrease the wave energy (Akbar et al., 2017) but also decrease the toxic suspension from the wastewater of the municipal areas (Gopikumar et al., 2022), even for metals. As mentioned in the previous research, the metal suspension was found in coastal areas of Semarang City. Eventually, the exact condition is likely to happen in coastal areas of Kendal Regency (Widianarko et al., 2000). The recording of Unmanned Aerial Vehicle (UAV) in the coastal area of Kendal Regency showed heterogeneous suspension colors, which could be the toxic suspension (M A Marfai et al., 2018). It was correlated with the high intensification of urban building or productive land.

The topography condition triggers the urban runoff or overland flow which accumulated with the surface material. Kendal Regency mostly has a flat slope and provides a sedimentation opportunity to form more quickly than the erosion process (Fig. 6). Thus, it can be said that the distribution of sediments formed in the Kendal Regency coastal area is strongly derived from Kendal Regency itself, both from the pattern of sediment distribution in the coastal area and the morphology of the mainland of Kendal Regency from the upstream to the downstream (Fig. 7). As shown in Fig. 7, it could be interpreted that the built-up area, namely as settlement or industrial area and productive land, is dominating the mainland of Kendal Regency.

As shown in the result in Fig. 3, the suspension distribution of the sediment input does not only come from one accumulation point but occurs along the shoreline with some sediment inputs. Thus can be interpreted that the built-up area and productive land, namely fishponds and cropland in the coastal area, contribute a significant portion of sediment input. So, the sediment inputs come from the more remote land carried by the flow of the Bodri River and the coastal area itself.

In addition to profile data, the dominance of the built-up area and productive land was also proven in data obtained from the Geospatial Information Agency (BIG) (BIG, 2020), as presented in Fig. 7. Based on land use data obtained from the Geospatial Information Agency (BIG), the built-up area provides the most significant land use composition in Kendal Regency. Fishponds rank second as dominant land use after the built-up area. And indeed, both dominant land uses are massive in the coastal area, as shown in Fig. 1

and Table 1. The massive sediment inputs that occur along the coastline in Kendal Regency show that land use in the coastal areas gives enormous control over the distribution of suspended sediments in the areas. This land use issue becomes a critical consideration in preparing the coastal zone plan (RZWP), which is also considered on the spatial plan of Kendal Regency (RTRW).

The percentage calculation of land use in Table 2 shows that productive land in the form of cropland and settlement becomes dominant land use with each achievement is 57.34% for wet farm and 20.88% for the dry farming area, then for settlement reaches 12.44%. Although the fishponds only get a percentage of 3.76%, as shown in Fig. 7. they are the dominant land use along the coastal district of Kendal. Vegetation controls to decrease sedimentation rates proved to be minimal, reaching only 2.64% for forests and 0.03% for mangroves.

Table 2
Land uses in Kendal Regency

No	Land use	Area (km2)	Percentage
1	Settlement	172.42	12.44
2	Building	6.53	0.47
3	Cultural heritage	2.51	0.18
4	Bridge	0.00	0.00
5	irrigated ricefield	794.63	57.34
6	Grassland	25.18	1.82
7	Orchard	5.97	0.43
8	Lake	0.08	0.01
9	Rainfed Cropland	289.38	20.88
10	Forest	36.63	2.64
11	Mangrove	0.36	0.03
12	Fishpond	52.15	3.76
	TOTAL	1385.84	100.00
Source: Geospatial Information Agency, 2018			

Conclusion

Band ratio modification for monitoring suspended sediment in this research was more effective with the 3/2 (green and blue) band because the suspended sediment is more visible and easier to interpret with these bands. The Profiles of Marine Notches in the Baron Coastal Area-Indonesia spread direction of suspended sediment in Kendal Regency is mainly northeastward, as evidenced by the presence of headland on the east side of the coastal area. The comparison between two different seasons shows that the suspended sediment spreads toward the northeast during the west-east transitional season, whereas it spreads with heterogeneous direction during the east-west transitional season. Despite the heterogeneous direction, the deployment of suspended sediment showed the circulation of sediment in specific locations that have the potential to shoal at the circulation point. On the other hand, sediment inputs are found along the shoreline. These sediment inputs are highly predicted by the effect of the high growth of the built-up area and less vegetation along the coastal area.

Declarations

Data Availability

The data that support the findings of this study are openly available (free access) in USGS (https://earthexplorer.usgs.gov/, reference number 37), and BIG (https://tanahair.indonesia.go.id/portal-web and https://tanahair.indonesia.go.id/demnas/#/, reference number 3 and 4).

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Contributions

Edy Trihatmoko: design the study, and performed simple raster analysis processing; Junun Sar-tohadi and Muh Aris Marfai: verified and validated the processes and supported the theoretical review; Juhadi: provided a computer processing laboratory; Elok Surya Pratiwi: provided general ideas and summarized the back-ground studies: Misdianto Wongsokarto: emphasized the computerized base model.

Ethics Declaration

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

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Figures

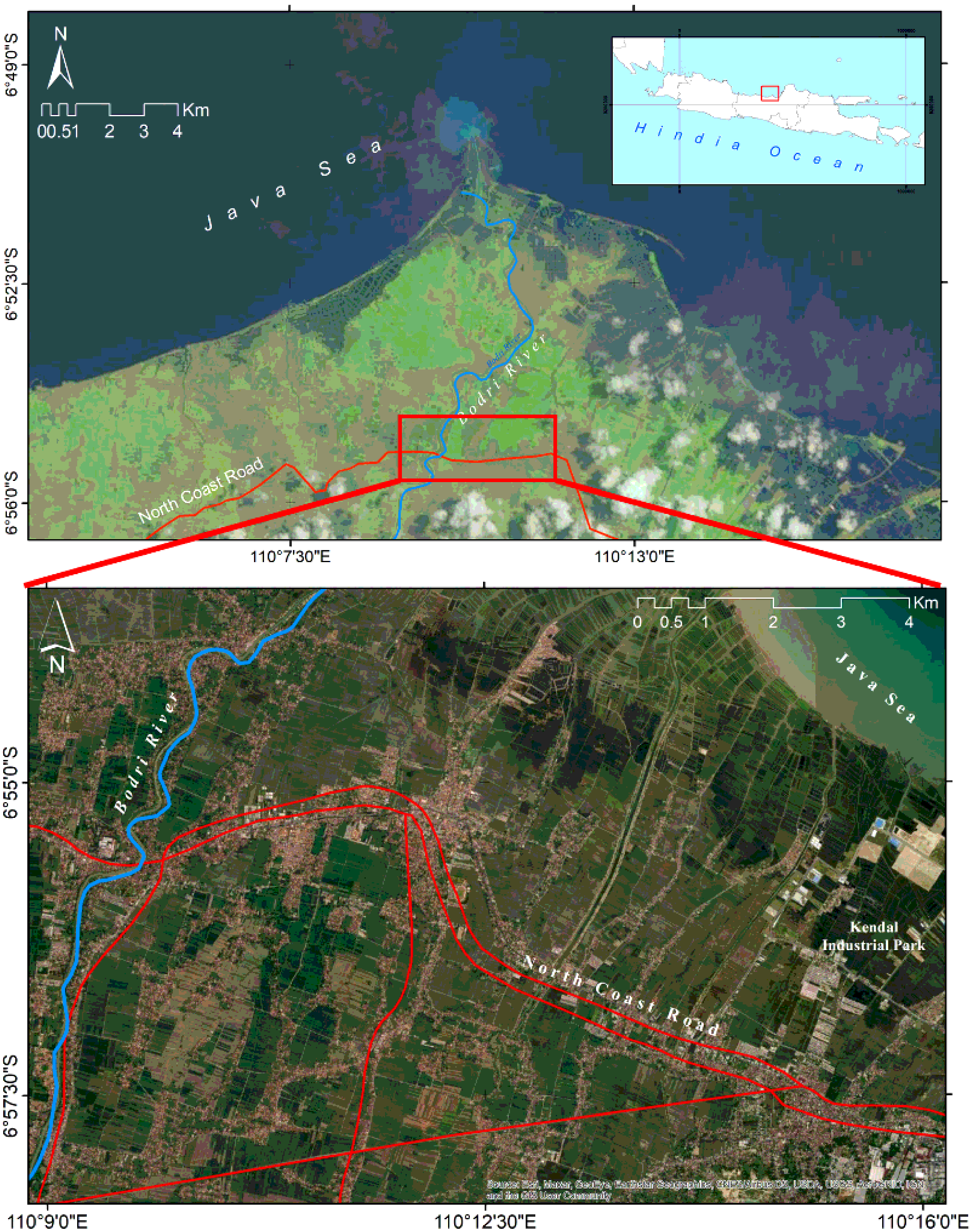

Figure 1

Map of the coastal area in Kendal Regency, Central Java, Indonesia. This map shows the North Coast Road as the densest national transportation line for the Northern Coast of Java (satellite image source: USGS (USGS, 2021))

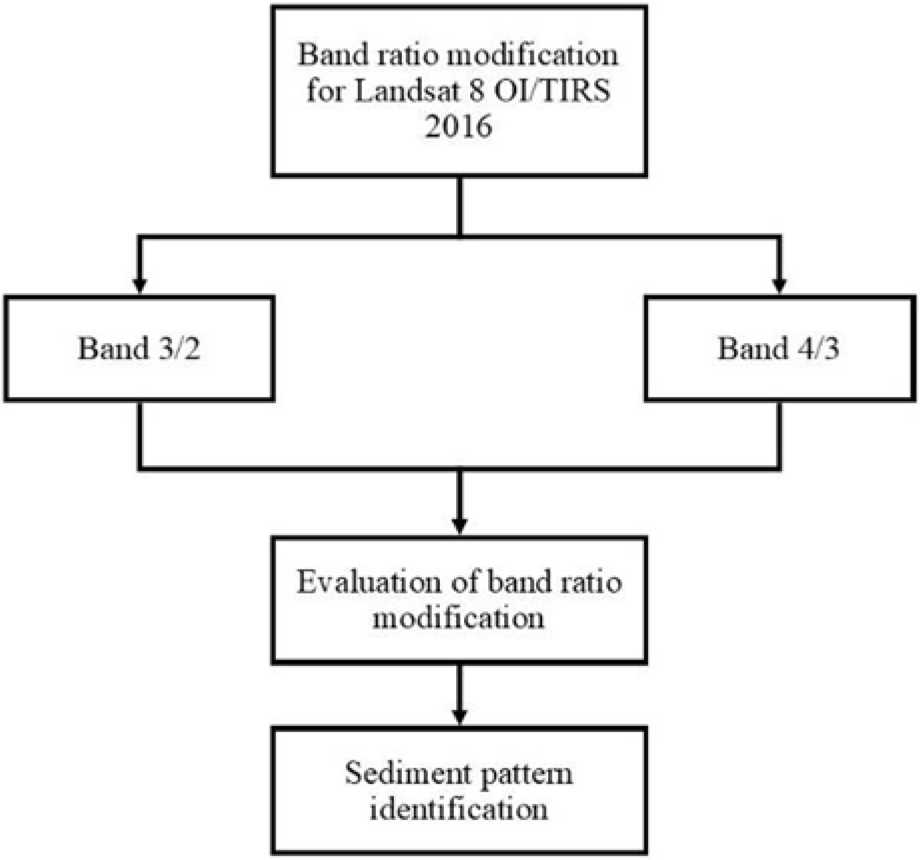

Figure 2

Research flow diagram. Briefly tells the process from band ratio modification to the evaluation of band ratio modification and the last to show the sediment pattern.

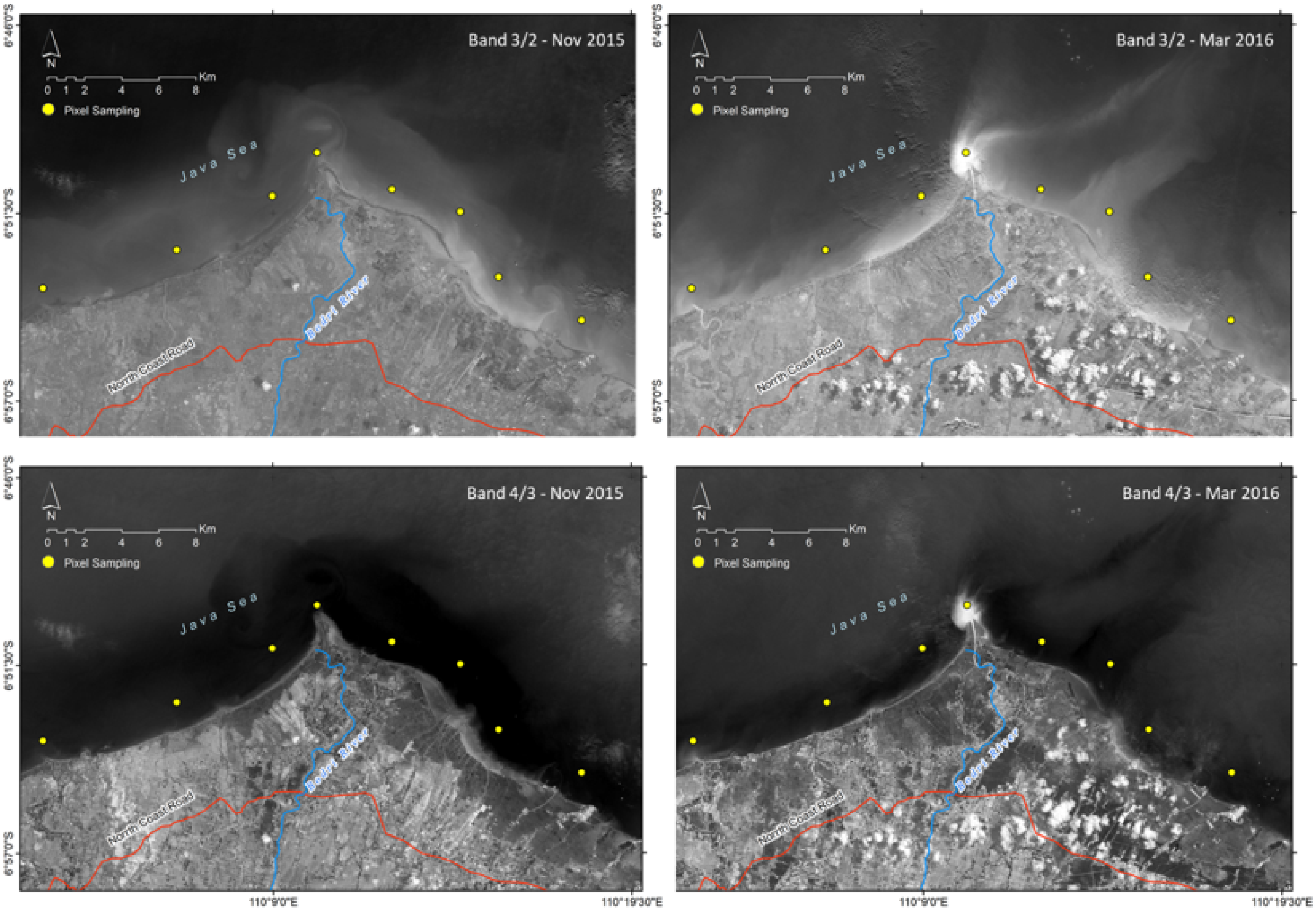

Figure 3

The comparison of Band Ratio analysis in band 3/2 and 4/3 in the transitional season both for east to west (Nov) and west to east (Mar) (satellite image source: USGS (USGS, 2021))

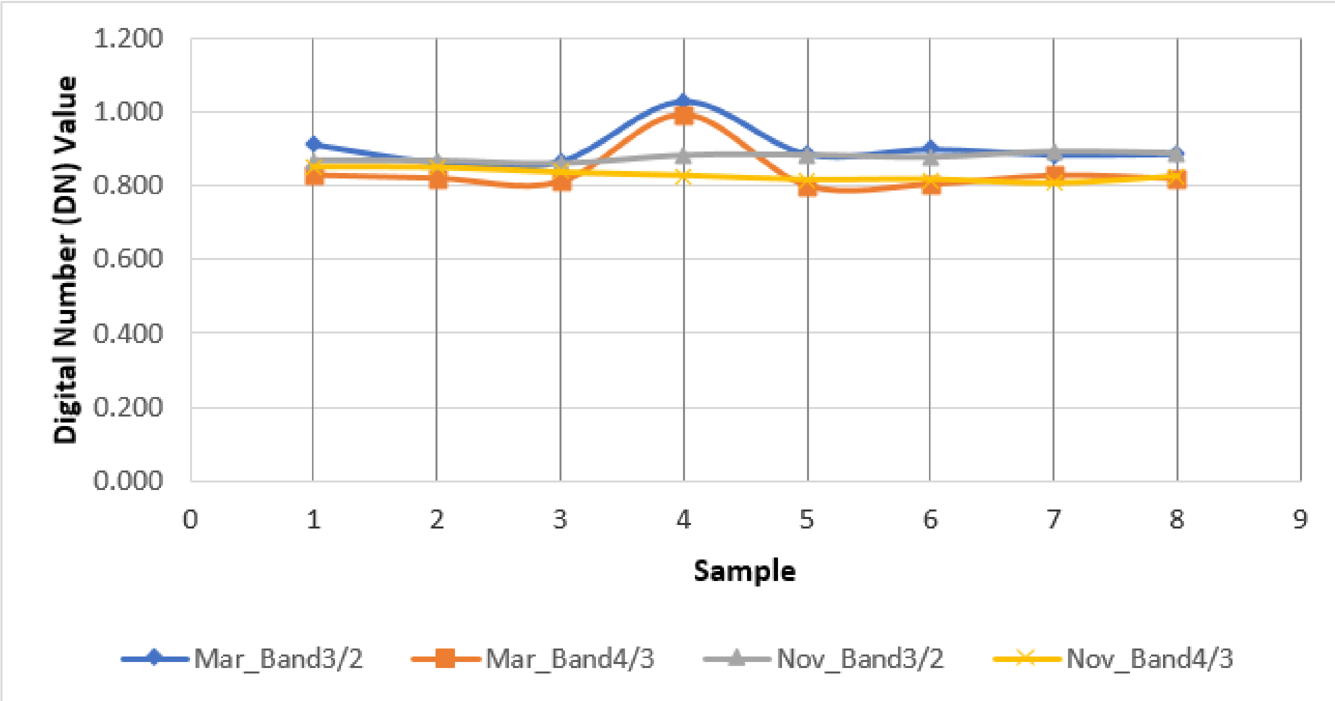

Figure 4

The digital number of the different band ratio modificationfor bands 3/2 and bands 4/3. The band ratio for bands 3/2 for each season ismore visible to indicate the suspended sediment.

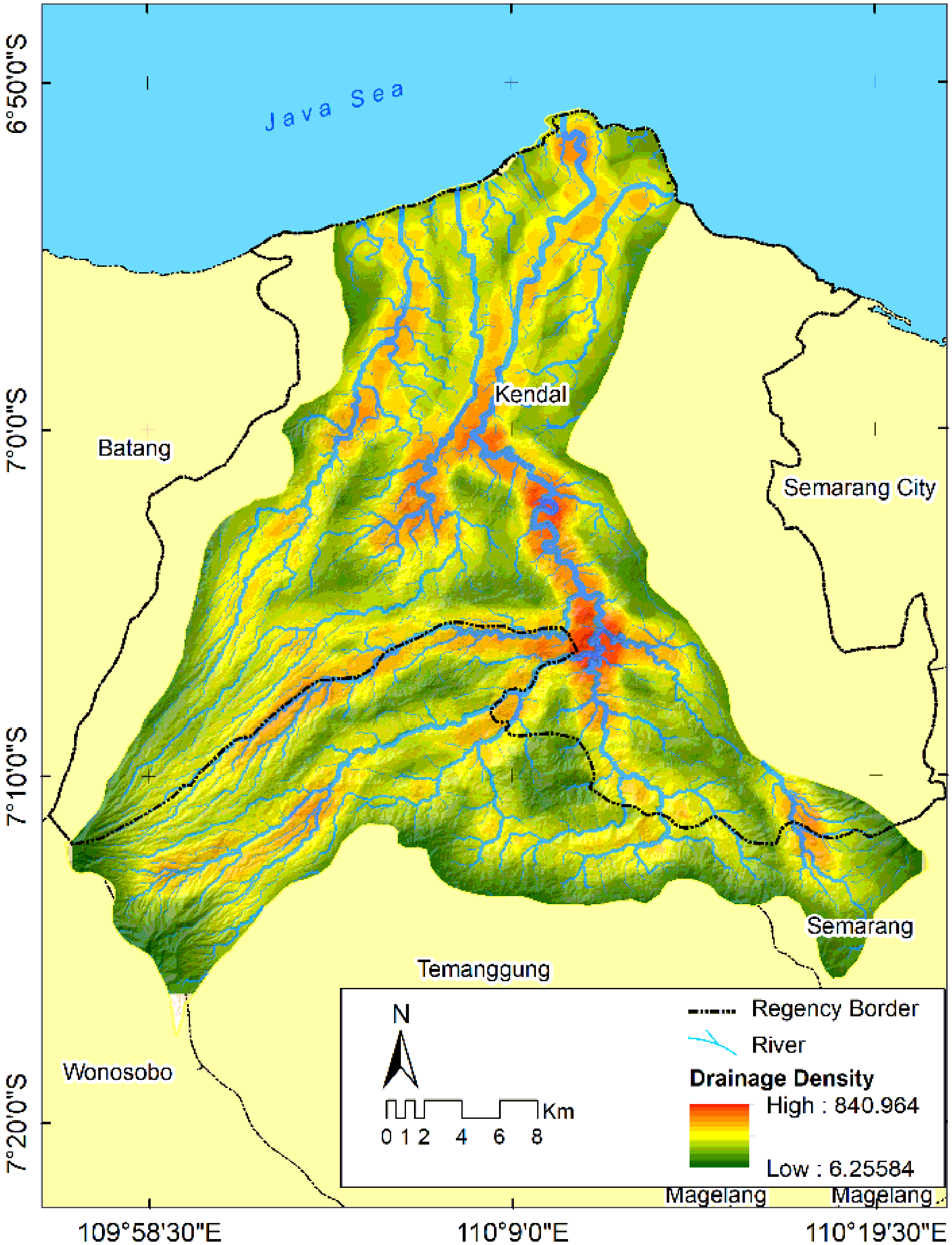

Figure 5

Upstream to the downstream profile of Kendal Regency (data source for processing: BIG (BIG, 2021))

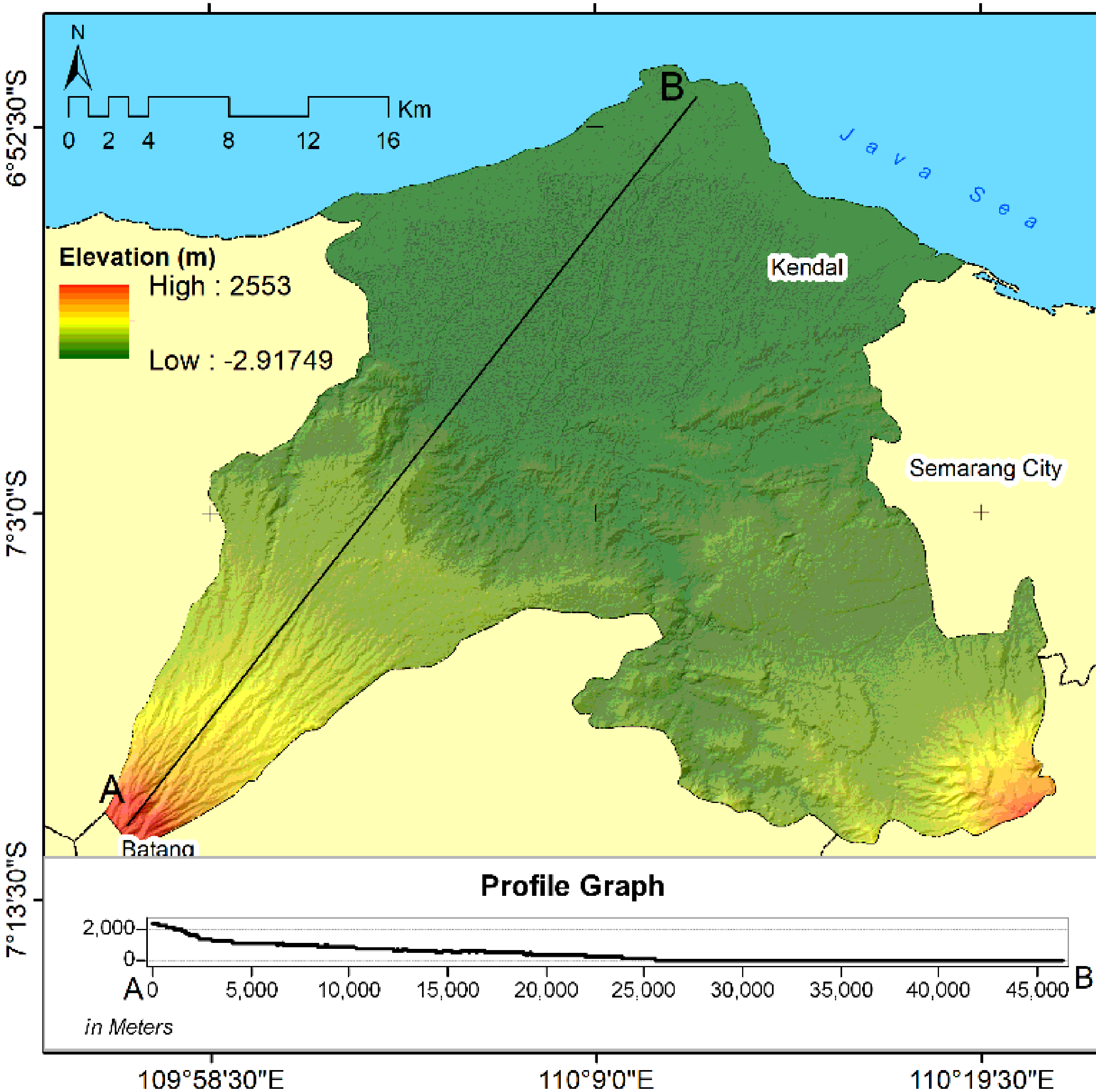

Figure 6

Upstream to the downstream profile of Kendal Regency (data source for processing: BIG (BIG, 2021))

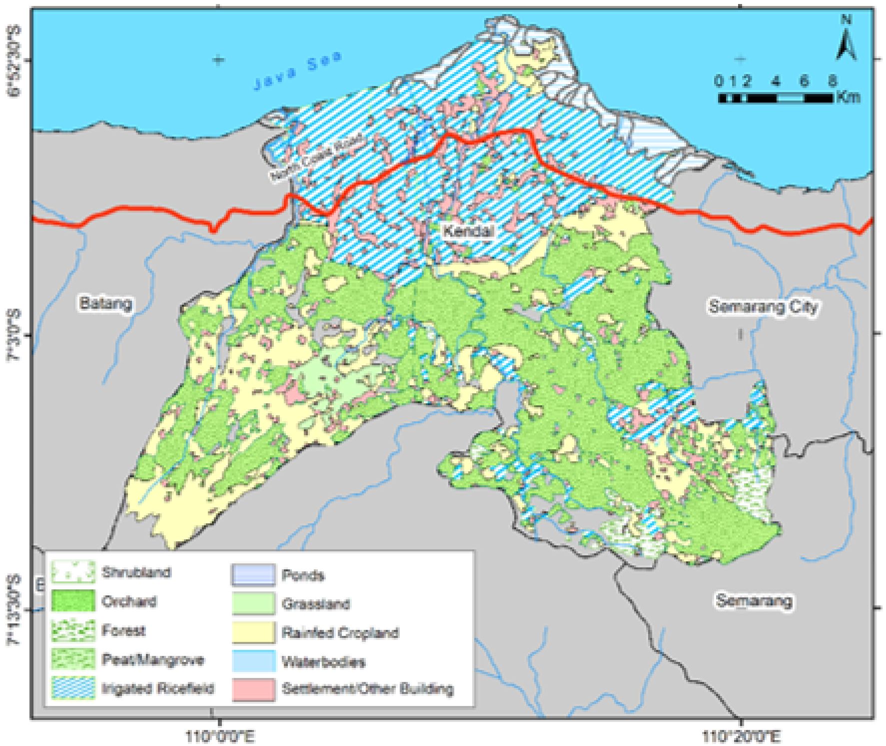

Figure 7

Land use map composition of Kendal Regency. The map shows 57.34% dominated for the cropland and settlement (data source for processing: BIG (BIG, 2020))