ISSN: 0852-0682, EISSN: 2460-3945
Forum Geografi, Vol 31 (2) December 2017: 220-231
DOI: 10.23917/forgeo.v31i2.5290

FORUM GEOGRAFI
Indonesian Journal of Spatial and Regional Analysis

Spatial Analysis of the River Line and Land Cover Changes in the Kampar River Estuary: The Influence of the Bono Tidal Bore Phenomenon

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Received: 28 October 2017 / Accepted: 08 December 2017 / Published: 22 December 2017

Abstract. The Kampar River estuary is well known for a tidal-bore phenomenon called 'Bono waves'. The emergence of Bono waves has a significant influence on the estuary system of Kampar River. Scoured materials, resulting from the hydraulic jump of the tidal bore, are carried into the middle of the river. These materials are then deposited when the velocity of the river decreases as a result of the collision of the tidal current from the sea and the river flow. The aim of this was to determine the area of erosion and sedimentation with respect to the river line and perform land-cover change analysis for the area around the Kampar River estuary for the years of 1990, 2007, 2010 and 2016. The method employed was the supervised maximum likelihood (SML) classifications, which uses an overlay technique to yield alternate information on the river line and land-cover changes in the form of time-series data. The largest erosion occurred during 1990–2007, for which the average change reached 2.36 ha/year. The smallest erosion occurred during 2010–2016, when the change reached 0.41 ha/year. The largest land-cover change was found during 1990–2016, which occurred in the land for agriculture/plantations (11.57 ha/year), building/settlement (48.11 ha/year) and scrubland (30.88 ha/year). The other types of land cover, such as bare land and sediment deposition, varied every single year. The changes to the river line are caused by land-cover changes, and the Bono waves that lead to erosion and sedimentation that is not stable in the middle of the river and downstream.

Keywords: spatial analysis, land cover, Bono, Landsat imagery, Kampar River estuary.

Abstrak. *Muara sungai Kampar terkenal dengan fenomena Tidal Bore yang disebut 'Gelombang Bono'. Kemunculan gelombang Bono ini memberikan pengaruh yang signifikan terhadap dinamika sistem muara di sungai Kampar. Material sedimen yang teraduk karena lompatan hidrolik dari tidal bore terbawa hingga ke bagian tengah sungai. Material tersebut terendapkan ketika kecepatan arus menurun sebagai akibat dari pertemuan dua arus yaitu arus dari laut dan aliran sungai. Tujuan dari penelitian ini adalah untuk mengetahui wilayah erosi dan sedimentasi dengan menggunakan pendekatan analisis perubahan garis sungai dan tutupan lahan disekitar muara sungai Kampar untuk periode 1990, 2007, 2010, dan 2016. Metode yang digunakan adalah pendekatan klasifikasi supervised maximum likelihood (SML) menggunakan teknik overlay untuk menghasilkan informasi alternatif garis sungai dan perubahan tutupan lahan berupa data times series. Erosi terbesar terjadi pada tahun 1990 – 2007 dengan rata-rata perubahan mencapai 2.36 ha/tahun. Erosi terkecil terjadi pada tahun 2010 – 2016 dengan rata-rata perubahan mencapai 0.41 ha/tahun. Perubahan tutupan lahan terbesar ditemukan pada tahun 1990 – 2016 yang terjadi pada lahan pertanian/perkebunan (11.57 ha/tahun), bangunan/pemukiman (48.11 ha/tahun), dan semak belukar (30.88 ha/tahun). Lahan lainnya meliputi lahan terbuka, pemukiman, dan endapan sedimen yang bervariasi setiap tahunnya. Perubahan garis sungai disebabkan oleh perubahan tutupan lahan dan gelombang Bono yang memicu terjadinya erosi dan sedimentasi yang tidak stabil di bagian tengah dan hilir sungai.*

Kata kunci: *analisis spasial, tutupan lahan, Bono, citra Landsat, muara Sungai Kampar.*

1. Introduction

Riau Province has four big rivers, for which the sources are in the Bukit Barisan or Barisan Mountains. They stretch along Sumatra Island and disembogue on the east coast of Sumatra. They are the Rokan River, Siak River, Kampar River and Indragiri River. There is lot of potential to develop one of them for the benefit of water-resource management and research interests (DBWR of Pelalawan Regency, 2010). In the upstream area of Kampar River, there is a hydroelectric dam, namely Koto Panjang. The construction of the dam is part of the framework of water storage used to enhance the production of electrical energy (114 MW). However, the limited water discharge due to the Koto Panjang hydroelectric dam has triggered a decrease in the discharge of water that flows into the estuary. This condition inhibits the generation of tidal waves, which are locally called 'Bono waves'. This has much potential to attract tourists who are interested in surfing on Kampar River. The weaker the propagation of the Bono waves, the more sedimentation occurs upstream.

In the estuary, the velocity of the wave propagation is higher than the speed of the river flow from upstream. It induces the tidal bore generation. It triggers the hydraulic jump of the tidal bore due to the difference in pressure. Bono waves move upstream to Tanjung Pungai, which is about 60 km from the estuary (Rahmawan *et al.*, 2017). According to Edison *et al*. (2009) the high concentration of sediment transported in the downstream is caused by the amount of sand sediment carried by the Bono waves. Sediment in the upstream will be carried by the water flow. It is then deposited. According to Setiady (2010), the increase of erosion and additional sedimentation can lead to the retreat or advance of the river line. Erosion can occur naturally through the scouring of the Bono waves.

The existence of Bono waves is highly controlled by the sustainability of the forest along the river. Bono waves have a pattern that is formed because the waves bounce off the banks of the river. The impact of Bono waves is the erosion that occurs on the banks of the river and sedimentation in some parts of the body of the river. Conditions get worse if the forest/shrubland, which acts as a natural protector of the edge, is damaged (Rozali *et al.*, 2016). According to Cenci *et al.* (2017), who quantitatively assessed changes in the river estuary or shorelines, selected 'relatively' unstable streams in space and time; i.e. river networks that are analysed to reduce errors in interpretation, such as for the river flow line, stable-vegetation line and unstable-vegetation line. It is assumed that the changes to the selected stream flow are a representation of the relevant changes to the body of the river. In most cases, certain stream flows depend on several factors, such as the location of the river, sources and the preferences of the researcher.

The management of rivers with complex problems requires holistic, integral and coordinative management. Natural resources in the form of forests, soil and water have an important role in human survival, so their utilization needs to be managed optimally and sustainably (Harjadi, 2010). It is important to monitor the change of both geomorphology and land use in the estuary, which is geomorphologically more dynamic. The river flow and coast waves interact with each other, which makes geomorphological shifts occur faster. Moreover, land-use changes in the estuary can also affect the processes; one study finds that land-use changes have a relationship with erosion (Leh *et al.*, 2013). There are many studies that have attempted to monitor the impact of existing river streams and waves (e.g. Darwish *et al.*, 2016), but this is limited in Indonesia. Furthermore, Bono waves have destructive effects on natural resources, such as the frequent occurrence of erosion, floods, droughts, sedimentation and irrigation-channel disruption (Mubarak *et al.*, 2017). This natural process, together with enormous pressure on natural resources due to human activities, triggers rapid changes to the land. Therefore, it is necessary to conduct spatial analysis of the river-line and land-cover changes that have occurred in the Kampar River estuary and surroundings to explore the impact of Bono waves.

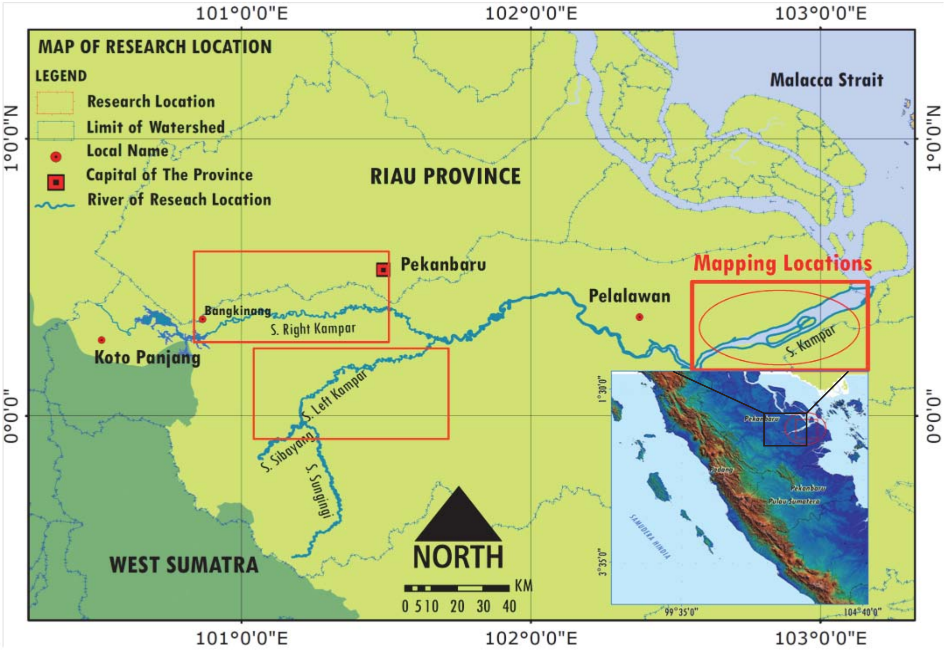

Figure 1. Map of Research Location.

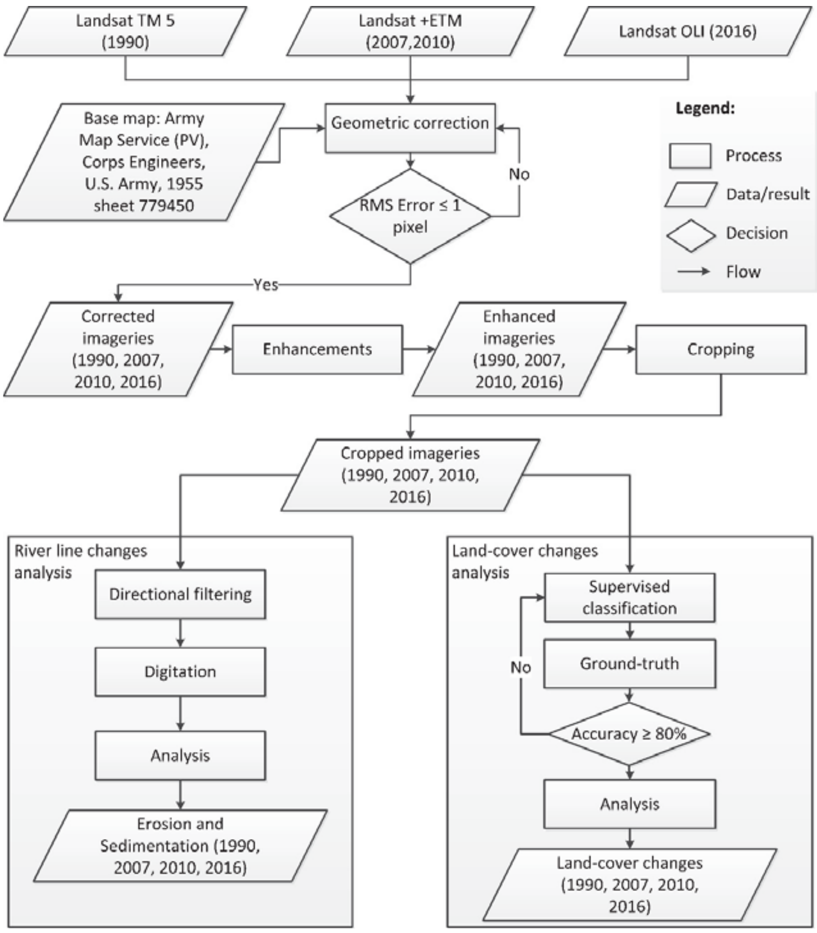

Figure 2. Research Flowchart for the Analysis of GIS/Remote Sensing.

This article aims to determine the area of erosion and sedimentation using an approach of analysing the river-line and land-cover changes around the Kampar River estuary. Spatial analysis of datasets sourced from Landsat imagery for the years of 1990, 2007, 2010 and 2016 was used to investigate changes in the river flow to determine erosion, sedimentation and land-cover changes in the Kampar River estuary, which is located between the sub-districts of Teluk Meranti and Kuala Kampar in Pelalawan Regency, Riau Province.

2. Research Method

2.1 Description of research location

Administratively, Kampar River is located between the Teluk Meranti and Kuala Kampar sub-districts in Pelalawan Regency, Riau Province at the coordinates of 00°05′00″–00°20′00″N and 102°25′00″–103°13′00″E. The total area of the mapped location is 344.479 ha (Figure 1). The Kampar River estuary is part of the alluvial estuary and has a trumpet (convergent) form, which is a prerequisite for the existence of a tidal bore. The tidal amplitude is around 2.1 to 4.5 m and it propagates for 229 km (Mubarak *et al.*, 2017).

Kampar River stretches from west to east through two administrative regions, West Sumatra and Riau Province. Starting from Bukit Barisan, Lima Puluh Kota Regency, Pasaman and Sawahlunto City in West Sumatra Province, it flows into the estuary through several administrative regions of Riau Province, such as Indragiri Hulu, Indragiri Hilir, Kampar, Kuantan Singing, Pelalawan and Siak regencies, and Pekanbaru City, arriving in the Malacca Strait with a length reaching 400 km (ARD NRCT, 2013).

Based on the data from DBWR Pelalawan Regency (2010), Kampar River has a total area of 24.548 km^2 which is then divided into two rivers; i.e. Right Kampar River and Left Kampar River (Figure 1). The two rivers then unite in Langgam and flow as a single stream to the Malacca Strait. The Right and Left Kampar Rivers flow from two different sources. Right Kampar River, for example, flows downhill from the Gunung Gadang spring in West Sumatra Province. The first stream goes to the north, and then flows east through the Batu Basurek and meets the Kapur Nan Gadang River before joining the Mahat tributary. The base slope of the river reaches 0.0008. This is different from the Left Kampar River, which is sourced from Mount Ngalautinggi and Paninjau Elok. Left Kampar River is split into two branches; i.e. the Sibayang and Singingi rivers. Sibayang River flows separately before reconnecting with the Singingi and Bibio rivers. The water flow rate is about 600 m^3/s upstream and downstream it is down to 200–400 m^3/s. Finally, the Right Kampar River and Left Kampar River reunite in Langgam.

2.2. Research data and mapping techniques

The mapping of the river line and land-cover changes was done using a deep and comprehensive analysis of natural resources and environmental aspects. The data used in this research was sourced from Landsat imagery, and multispectral imagery classification needed to be done using more than one method. As a result of using several methods for analysing the remote sensing data, errors will be experienced when detecting the objects (Putra *et al.*, 2014). The appearance of every object could provide a spectral response that causes an error during the imagery classification. Different results will be experienced using high-resolution satellite imagery compared to the object-based classification method. Kaliraj *et al.* (2017) state that the analysis of the river line and land cover can be performed more specifically and accurately with field surveys using Garmin GPS MAP 78S to collect spatial data in the field. The horizontal-positioning deviations can be up to 5 min in the open river estuary region and forest cover with strong signal accuracy. In a worst-case scenario, it can be up to 10 min in areas with canopy cover and considerable build-up where satellite visibility is much affected. Standard procedures were adopted for the geomorphological mapping from multiple spatial data sources by employing visual or digital interpretation/classification techniques.

This research activity was done in several stages: 1) the compilation of time-series data from the Landsat Thematic Mapper (TM) 5 in 1990, Enhanced Thematic Mapper Plus (+ETM) in 2007 and 2010, and Operational Land Imagery 8 (OLI) in 2016; 2) mapping the references in a comparative data analysis of the river-estuary conditions used to map "Army Map Service (PV), Corps Engineers, U.S Army" for 1955, sheet 779450, for Siak Sri Indrapura, Indonesia with a scale of 1:125.000; and 3) further data analysis with the geographic information system (GIS) using the overlay technique to obtain the information about the areas of erosion, sedimentation and land-cover changes in the Kampar River estuary. More details are shown in Figure 2, as follows:

2.3. River line changes analysis

Satellite imagery data was extracted to obtain the information on the river line by digitally employing a visual method. This method is quite precise, but it takes a long time to complete this processing step. However, because the study area is not very wide, the weakness of this method can be overcome. At the time of completing the visual interpretation, the position of the river line was recorded. Particularly, the possibility of a wetland apparition caused by the influence of river run-off was compared to the river contour line in the part of the land border (0 m) (Winarso *et al.*, 2001).

Pierik *et al*. (2016) identify another method that can improve chronology, which is using case-study models of hydrodynamical processes and sedimentation balance indicating how fast tidal inlets can develop and silt up. Additionally, studies based on stratigraphy could improve the vertical time control of deposits, which lead to improving the time resolution and rate of deposition in tidal systems. These studies require knowledge of the initial paleogeographic and geomorphological conditions, which GIS output can provide for landscape that has changed considerably.

2.4. Applying supervised maximum likelihood (SML) classifications

SML classifications are a statistical method based on measuring the distance between the sample and the pixel coordinates (Suryantoro, 2003). The assumption behind this classification is that objects are homogeneous. In this classification, a pixel is not described as a specific object because of its Euclidean distance. It is described based on the shape, size, and orientation of the sample in the feature space (ellipsoid) (Danoedoro, 2012).

SML classifications assume the statistics for each class in every band, which are normally distributed, and calculates the probability of a given pixel belonging to a specific classification (Susanti and Miardini, 2017). However, if a probability threshold is selected, all pixels will be classified. Each pixel is assigned to the class that has the highest probability (maximum likelihood). If the highest probability is smaller than the threshold specified, the remaining pixels will be unclassified. Environment for Visualizing Imageries (ENVI) software implements the SML classifications by calculating the discriminant functions for each pixel with Equation 1.

$$g_i(x) - \ln p(\omega_i) - ½\ln|\Sigma_i| - ½(x - m_i)^t \Sigma_i^{-1}(x - m_i) \quad (1)$$

where:

l = class

x = **n** – dimensional data (where is the number of bands)

$p(\omega_i)$ = probability that class occurs in the imagery and is assumed to be the same for all classes

$|\Sigma_i|$ = determinant of the covariance matrix of the data in class

Σ_i^{-1} = inverse matrix

m_i = mean vector (Richards, 1999)

2.5. Area calculation for land cover

For GIS, the land-cover changes were treated as a function of topography. Therefore, the calculation procedure entails a basic subtraction. As such, GIS can be applied to assess the change of river flow and land-cover areas. After obtaining the values for the land-cover classification results, the estimation area was then calculated. The area for a land-cover class can be determined using a modification formula according to Putra *et al.* (2015). Seenath *et al.* (2016) describe the changes model, which calculates the grid cell of Landsat imagery by using the input parameters supplied that were substituted into the equations. Therefore, a computational grid with a fine spatial resolution will result in a longer simulation runtime; in other words, the finer the grids required, the shorter the computational time steps used. As such, the changes model is mainly restricted to either detailed studies of small geographical areas or studies of large geographical areas with a coarse spatial resolution. The calculation for land cover is shown in Equation 2.

$$L = \Sigma P \times r \times 0.0001 \quad (2)$$

where:

L = area (ha)

ΣP = number of pixels

r = spatial resolution of Landsat 30 x 30 m

0.0001 = conversion into m^2 for the inside area (ha)

2.6. Rate-change analysis

The rate of river-line change determines the information required on the erosion, sedimentation and land cover by using an overlay technique for the Kampar River estuary. The spatial area can be determined by using the formula (Equation 3) given by Richards (1999).

$$V = \frac{N2-N1}{N1} \times 100\ \% \quad (3)$$

where:

V = rate of change (%)

N1 = area of first year (ha)

N2 = area of year to – n (ha)

3. Results and Discussion

3.1. River line changes (erosion and sedimentation)

The propagation of Bono waves causes erosion on the river bank around Muda Island. This condition can be seen from the satellite imagery. The present schedule of Bono waves is known by the local community. The river flow line and vegetation are damaged due to river erosion, where the Bono waves pass through the mouth of the river. The most sediment is carried by Bono waves that have a high energy. It is then deposited when the energy is reduced. As a result, physical changes in the river cannot be avoided. Several areas in the Kampar River estuary have sedimentary deposits due to estuarine sand, which initiates the formation of new islands, while some other locations experience severe erosion.

Muda Island is one of the small islands that grew because of the sedimentation process (Yulistyanto, 2009). Due to the unstable erosion and sedimentation events, the existence of the tidal bore needs to be considered; this is because the wider the river, the more the river-bed resistance is increased. This disrupts the propagation of Bono waves (Chanson, 2001). According to Wisha and Maslukah (2017), the elevation changes drastically during the propagation Bono waves, which triggers the mass transport of water that enters the river rapidly with the speed reaching 0.85 m/s. It is the one factor triggering the sedimentation and erosion events along the Kampar River. Landsat imagery analysis has been done to cover the years of 1990, 2007, 2010 and 2016. River-line changes are later identified for each year using the overlay technique to obtain much information regarding erosion and sedimentation in the Kampar River estuary. Furthermore, the process of filtering on each Landsat image uses a high pass filter (Goslee, 2011). After completing the filtering process, the imagery is sharpened with the aim to clarify the appearance of river-flow patterns.

The appearance of erosion and sedimentation in the Kampar River estuary is identified using the overlay technique based on river-line changes on the Landsat imagery. After comparing Landsat images from TM 5 in 1990, +ETM in 2007, 2010 and OLI 8 in 2010, it shows the river line shifts northward and southward along the centre section of the Kampar River estuary (Figure 3). The length of the river line in the research location reached 344.48 ha, including the digitization result for several small islands (Untut, Kepiting, Baru, Muda, Tigo, Sempit and Kapak). The river-line length changes are shown in Table 1, where the highest river-line length change occurred during 2010–

2016, when it reached 21.33 km and the rate of change was 3.56 m/year. The lowest change occurred during 1990–2007, which was 2.48 km and the rate of change reached 0.15 m/year.

The river's meanders changed dramatically during 1990–2007. In 2007, erosion occurred in the southern part of the river and sedimentation occurred the northern part of the Kampar River estuary that is formed near Muda Island. During 2007, there was a constriction of the river flow at Muda Island. From 2010 until 2016, erosion happened again in the southern part of the Kampar River estuary.

The changes in the river flow that happened were triggered by the transportation of sediment that occurred during the Bono-wave events. The emergence of Bono waves in the river caused the river's meanders to become wider in the northern part of the Kampar River in 1990. To determine whether an area experiences erosion, sedimentation or a balance, two streamline water digitizations of Landsat imagery from different years can be integrated. Based on the results of the digitization of Landsat imagery in the form of time-series data, the biggest erosion event occurred during 1990–2007, where the erosion area reached 22.84 ha and the change rate was 1.34 ha/year. The smallest erosion happened during 2010–2016, where the erosion area reached 2.48 ha and the change rate was 0.41 ha/year. However, the biggest area of sedimentation is found during 1990–2007, where it reached 17.00 ha and the change rate was 2.22 ha/year, and the smallest area occurred during 2007–2010, where it reached 6.65 ha and the change rate was 1.00 ha/year (Table 2 and Figure 4).

3.2. Land-cover changes

The land-cover conditions near the river line severely influence the erosion level occurring. The area that is critical as a result of the erosion can be analysed visually and digitally using the GIS approach (Harjadi, 2009). Mapping the borderline with pixel-level accuracy can be achieved through sub-pixel mapping, in which finer resolution data is extracted from the original imagery, while at the same time the spatial location of the erosion and sedimentation phenomena within the original pixels are obtained.

Valjarević *et al.* (2014) analysed the quality of land cover with respect to the phenomena of erosion and sedimentation in the Kampar River estuary using pixel data from the Landsat imagery (overlay), the topographic map and the map of existing land cover. The method of sub-pixel mapping is a suitable solution for locations that can be analysed sufficiently accurately. This method has already been applied to some satellite recordings. Therefore, this may help to calculate qualitatively the extent of erosion and sedimentation, both for the sustainable planning and for short-term planning.

The changes to land cover in the cropped area reached 344.479 ha. It is dominated by agricultural land / plantation fields and shrubland that is damaged by the overland function and the occurrence of Bono waves. The definition of land cover, according to Berrios (2004), is the physical objects covering the surface of the land, which consists of natural vegetation, manmade buildings, bodies of water, rocks and sand surfaces, while the land cover is the land utilized by humans for specific purposes.

Based on the research conducted by Anna *et al.* (2010), the overland function taking place in the river-stream area is significantly impacted by its hydrological parameters. It causes the limited over of water resources, which seep into the ground. The Kampar River estuary is a part of the coastal region, where the development of settlements is not a major priority. However, it is concerned with utilizing the area for agriculture/plantations and aquaculture/ponds. This is opposite to the existing conditions where the area of the Kampar River estuary has been decreased due to the open fields utilized for agriculture and plantations. This has also been caused by the forest-fire event in 2015. Jaya (2013) reveals that either different land-cover types can be used for the same activity or similar land-cover types can be utilized for different types of area. Based on the spatial analysis of land-cover changes, the land cover has changed significantly from 1990 to 2016 (see Table 3 and Figure 5).

Table 1. The Rate of River-Line Changes in the Kampar River Estuary.

Location	1990	2007	Change (m)	Rate (m/yr)
	289.02	286.54	2.48	(0.15)
Kampar River estuary	2007	2010	Change (m)	Rate (m/yr)
00°05′00″–00°20′00″N	286.54	282.76	3.78	(1.26)
102°25′00″–103°13′00″E	2010	2016	Change (m)	Rate (m/yr)
	282.76	261.43	21.33	(3.56)

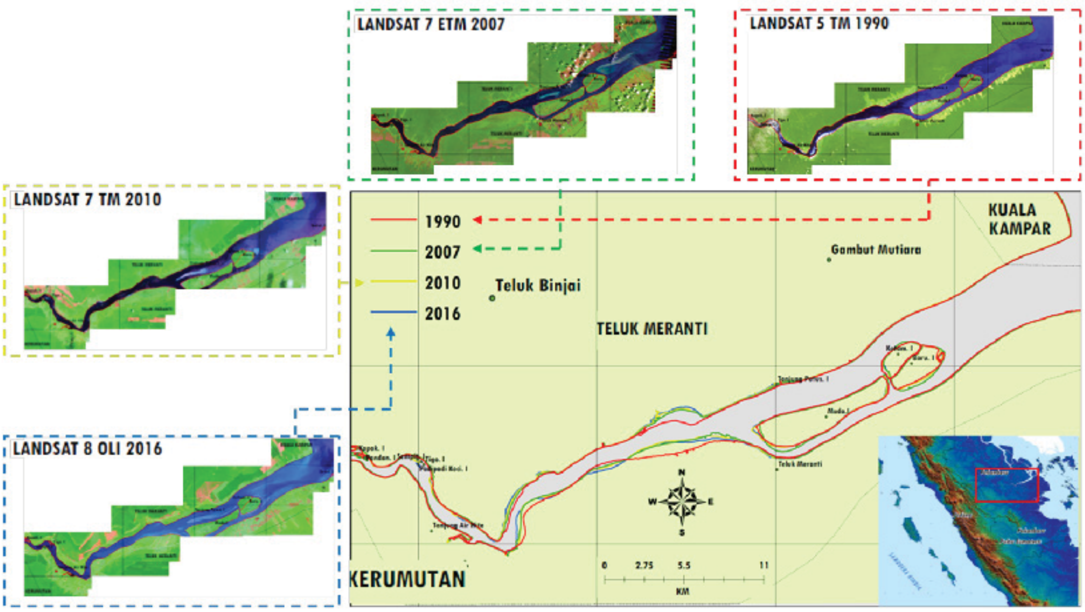

Figure 3. Map of Landsat Imagery Overlay Results (Analysing the Erosion and Sedimentation in the Kampar River Estuary).

Table 2. The Rate of Erosion and Sedimentation Changes in the Kampar River Estuary.

Year		Rate of Change (ha/year)					
Erosion		Rate	Sedimentation	Rate	Balance	Rate	
1990	2007	22.84	1.34	17.00	1.00	–	–
2007	2010	10.38	3.46	6.65	2.22	–	–
2010	2016	2.48	0.41	8.38	1.40	–	–

The maximum replenishment of the land-cover area is found during 1990–2016, when changes in the agricultural and plantation area reached 11.578 ha/year. The development of buildings and settlements changed by around 1,251 ha during those years at a rate of 48.11 ha/year. The area of scrubland changed to around 802.94 ha at a rate of 30.9 ha/year. Whereas, the other types of land cover, such as open fields, sedimentation areas and bodies of water, have not changed significantly. It varies every single year.

In Teluk Meranti, the development of settlements increased during 2010–2016, when the area changed reached 100 ha. This indicates that the allocation of settlements along the river line is not a priority in the development of local settlements due to the effects of Bono waves. This is supported by the forest-fire event in 2015. It also shows that the area along the Kampar River is not an ideal location for the development of settlements due to the potential for river-line disaster. The type of soil, the availability of fresh water and accessibility are all obstacles to development in that region.

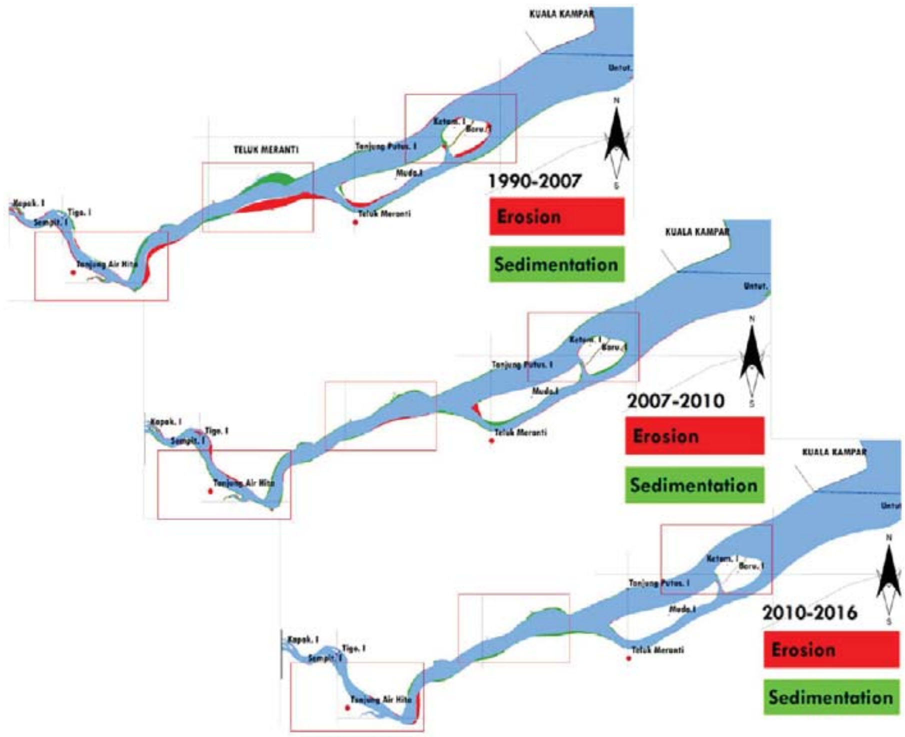

Figure 4. Map of the Erosion and Sedimentation Areas in the Kampar River Estuary.

Table 3. Areas for of Types of Land Cover in the Kampar River Estuary.

Land-cover type	1990	2007	2010	2016	Total	Rate(ha/year)
Agriculture/plantations	0.00	82.88	92.85	125.30	301.04	11.58
Scrubland	281.36	180.99	188.89	151.69	802.94	30.88
Bare land	14.36	15.73	24.23	27.23	81.55	3.14
Settlements	152.00	173.00	513.00	413.00	1,251.00	48.11
Sedimentation area	12.83	2.87.00	1.58	3.29	20.56	0.79
Bodies of water	24.02	31.13	36.40	36.55	128.10	4.93
Frame/empty data	11.84	30.65	0.00	0.00	42.49	1.63

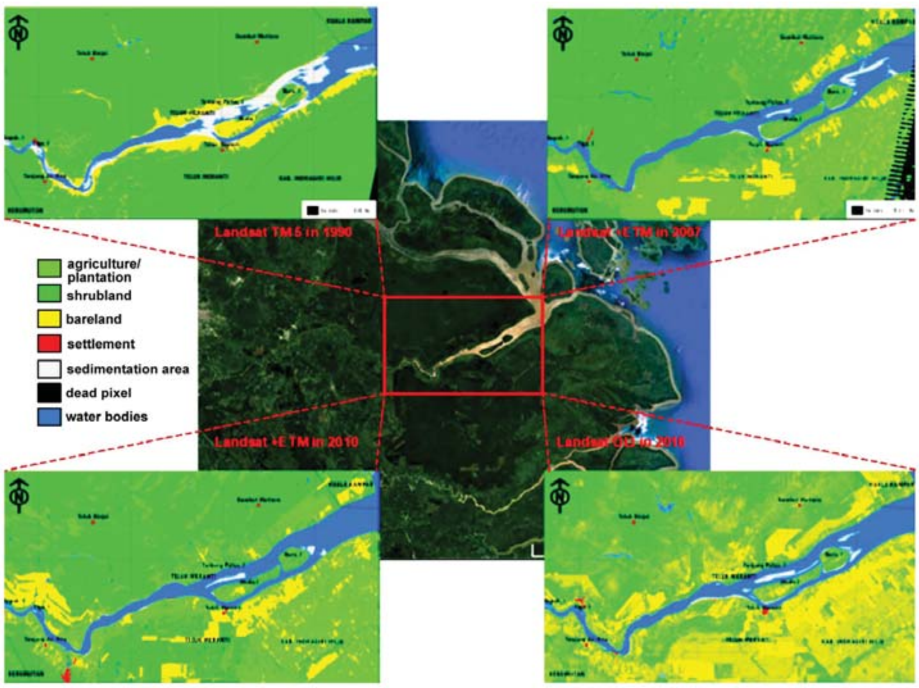

Figure 5. Map of Land Changes in the Kampar River Estuary for the Last 26 Years.

4. Conclusion

Bono waves are destructive, and cause erosion and sedimentation in some areas of the Kampar River estuary. They have damaged the river line of the Kampar River estuary, where erosion and sedimentation occur in an unbalanced way, and create a buffer along the river flow. The largest amount of river erosion occurred during 1990–2007 and the smallest amount happened 2007–2010. However, the largest amount of sedimentation took place during 1990–2007 and the smallest amount transpired during 2007–2010. The occurrence of erosion and sedimentation effected changes to land cover along the Kampar River estuary, where the largest land-cover changes occurred during 1990–2016, which changed area of agricultural/plantation land. The smallest change happened to scrubland. Other land-cover types, such as bare land and settlements, varied each year. The settlements were concentrated in Teluk Meranti, which is the sub-district centre, and this area rose from 513 ha in 2010 to 413 ha in 2016. This indicates that the allocation of settlements along the Kampar River estuary is not a major priority for development, and the Bono-waves phenomenon that occurs in the Kampar River estuary is the main factor causing less construction of community settlements to be allocated to the Kampar River estuary area.

Acknowledgements

Acknowledgements are given to the Head of LRSDKP Bungus Padang who has supported us during this research. We also express our gratitude to all those who have helped with the administration process, as well as those who helped us in the field, especially students from the Marine Science Department of Riau University.

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