# Estuary Changes of Cipunagara and Cimanuk River Using Landsat Imagery Spatial Analysis

# *Perubahan Muara Sungai Cipunagara dan Cimanuk melalui Analisis Spasial Citra Satelit Landsat*

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**ABSTRACT:** The north coastal Java located in the West Java, especially in Cirebon, Indramayu, and Subang, occurs loss and forming new land by abrasion and accretion processes. Observation using satellite imagery can be used as an initial stage to determine the distribution of abrasion and accretion around the north coastal area. Observation of land changes was assigned using Landsat imagery from 1978 to 2020. The result shows that inland change was controlled by abrasion and accretion. It is occurred in Indramayu and Subang, especially in several areas around large rivers e.g. Cipunegara and Cimanuk Rivers. Estuary changes in the Cipunegara and Cimanuk Rivers were controlled by the high flux sediment deposition of the river mouths affecting the new land forming due to the accretion process. Monitoring through Landsat satellite imagery on the Cipunagara River from 1978 to 2020 shows that there was 205 Ha of new land. Remote sensing analysis in the Cimanuk River area shows that the estuary line from 1978 to 2020 experienced accretion or new land forming for 629 Ha.

**Keywords:** North coastal Java, accretion, Landsat, river estuary analysis, Cipunegara River, Cimanuk River

***ABSTRAK:*** *Kawasan pantai utara Jawa di Jawa Barat, khususnya daerah Cirebon, Indramayu, dan Subang, memiliki permasalahan hilang atau terbentuknya daratan baru melalui proses abrasi dan akresi. Pengamatan mengunakan citra dapat dijadikan tahapan awal untuk mengetahui sebaran abrasi dan akresi di sekitar wilayah pantai utara. Observasi perubahan daratan dilakukan dengan menggunakan citra landsat tahun 1978 dan 2020. Hasilnya memperlihatkan bahwa telah terjadi perubahan daratan, baik proses abrasi maupun akresi, di beberapa wilayah di sekitar muara-muara sungai besar seperti Sungai Cipunegara dan Sungai Cimanuk. Perubahan muara Sungai Cipunegara dan Sungai Cimanuk lebih disebabkan oleh tingginya pengendapan sedimen pada muara sungai tersebut dan membentuk lahan baru karena proses akresi. Pemantauan melalui citra satelit di Sungai Cipunagara data citra tahun 1978 sampai 2020 memperlihatkan penambahan lahan baru sebanyak 205 H. Analisis remote sensing citra di wilayah Sungai Cimanuk terlihat garis muara pantai pada tahun 1978 hingga tahun 2020 mengalami akresi atau penambahan lahan baru 629 H.*

***Kata Kunci:*** *Pantai utara Jawa, akresi, Landsat, analisis muara sungai, Sungai Cipunegara, Sungai Cimanuk*

## INTRODUCTION

Estuary is the area where rivers meet the sea and have an important role in sediment budgets, salinity, sediment transport, currents, and delta reservations (Yadav *et al*., 2019). The estuary is formed by the sediment discharge that carried by the river as sediment transport and deposited into the estuary (Yadav *et al*., 2019). Sediment is an important factor for marine changes controlled by grain size, sediment supply, and prevailing flow conditions (Hendrizan *et al*., 2020; 2017; Nitsche *et al*., 2007). In addition, Sediment is important for climate and ocean study in geological timescales (Hendrizan *et al*., 2017; Liu *et al*., 2020; Praptisih and Cahyarini, 2016). Increasing sedimentation rate in river estuary or prograding of river estuary/coastline known as accretion. It is an important issue in Indonesia's current studies (Achiari *et al*., 2019; Pamungkas and Saraswati, 2020). The addition of new land areas due to accretion in the North Coastal Java including Cimanuk River area was utilized specifically for agriculture since 2014-2018 (Pamungkas and Saraswati, 2020). Asides, problems related to the

**Contributorship:**
All authors have a similar contribution as the main contributor to the article.

coastline also occur due to infrastructure developments, fisheries, and tourism, which affected the environment in the coastal areas (Cahyarini, 2011; Pranoto, 2010). Therefore, it is necessary to study further to reconstruct the new regions formed due to the accretion process.

The north coastal Java in the West Java is a research area with several river estuaries, including the Cipunegara River in Subang and the estuary of Cimanuk River. The accretion on Indramayu, in the Cimanuk River delta is prograding (Prawiradisastra, 2003; Astjario and Astawa, 2007) and has high sedimentation activity (Hehanusa *et al.*, 1975). Measurement of the sedimentation rate in the Cimanuk River Delta based on current time-series, coastline, and the distance from the delta to the north coastlines. It indicates that the Cimanuk River Delta produces a sedimentation rate of 200 meters/year (Hehanusa *et al.*, 1975).

Thick clay sediment resulted from drilling samples and geophysical records show that the Cimanuk Delta produces a minimum sludge of 53.6 million tonnes/year (Astjario and Astawa 2007). High sedimentation rate in the Cimanuk River area led to understand the accretion possibilities in several river estuaries on the northern coastal Java besides The Cimanuk River Delta. This study aims to determine changes in the Cipunegara and Cimanuk River estuaries from satellite imagery analysis. The research area is located in the delta of the north coastal Java, including the Cipunagara River Delta in Patimban Village, Pusakanagara Sub-District, and Subang. Meanwhile, the Cimanuk River Delta is located in Indramayu District, which borders Subang District in the west, Cirebon District in the east, and Majalengka District in the south.

## Geological Setting

North Coastal Java from Subang to Cirebon (Figure 1) consists of several rock units, i.e alluvium, coastal deposit, deltaic deposit, and flood plain deposit (Abidin and Sutrisno, 1992; Achdan and Sudana, 1992; Silitonga *et al.*, 1996). Alluvium spreads largely around Cirebon and Indramayu, characterized by gravel, sand, and clay with gray color. The Alluvium is deposited along a flood plain with less than 5 meters depth. Coastal deposit is deposited around Cirebon and Indramayu, characterized by swamp deposit, silt, and clay containing mollusk shells and coral. Deltaic deposit formed in the area that contain clay, silt, and humus. Flood plain deposit consist of tuffaceous clay, silt, and fine sand.

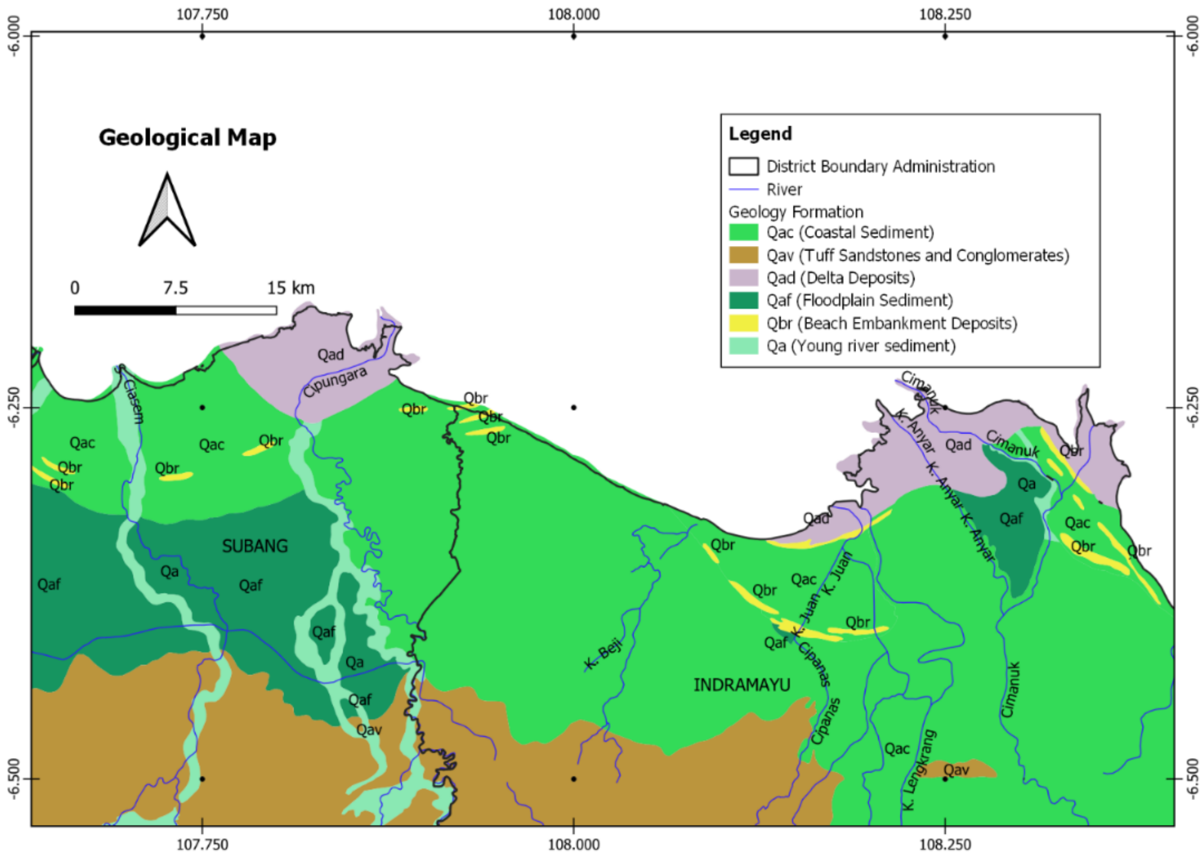



Figure 1. Geological map in the coastal of North Java from Subang to Cirebon (Abidin and Sutrisno, 1992; Achdan and Sudana, 1992; Silitonga *et al.,* 1996)

Topography on the north coastal of Java is relatively low slope to flat that resulted in the coastal plain. In several areas, there were formed swamp, mangrove, and beach sand. Several factors influence the characteristics of the coast, including sediment type (Pradiwisastra, 2003). In general, the coast characteristics are influenced by the type of material carried by the river and deposited on the coast. Therefore, the beach elements are strongly influenced by the length of the river and the catchment area.

Cimanuk River is created by smaller tributary, including Cipelas River, Cilutung River, and Cikeruh River. The upstream of Cimanuk River is located in Garut. The upstream of Cipelas River is in Sumedang. The upstream area of Cilutung River is in Kuningan, which originated from Ciremai Mountain's slope. Meanwhile the upstream area of Cikeruh River is in Majalengka. The three tributaries of the Cimanuk River flow in the young volcanic regions of the Quaternary deposit (Ratman and Gafoer, 1998). Delta of Cimanuk River Delta is divided into two parts in the east and the west. The east coast is in the Indramayu district, and the west coast is in the Krangkeng sub-district. The east coast area experienced abrasion that covered ??958 ha area (Prawiradisastra, 2003). One of the region that affected by abrasion is the Tirtamaya beach. The west coast area experienced abrasion that covered ??953 ha area (Prawiradisastra, 2003). Asides, the accretion also occurs around the Cimanuk River's mouth, which affected the sedimentation rate of 75m / year. The accretion is controlled by the growth of the new Cimanuk delta, deforestation, and the decompaction process from the quaternary sediment (Prawiadisastra, 2003).

Moreover, the influence of the climate change associated with sea level rise in Eretan, Losarang, and Indramayu regions also play a role in accretionary activities around the northern coast of Java (Rimbaman, 1992). Sediment core data of shallow sediment drilling in the area obtained sediment deposit of 10 meters thick. It is estimated to decrease 6,000 years in the last sea-level rise (Rimbaman, 1992). Eretan, Losarang, and Indramayu regions show a progressive change situation from 1946 to 1978 (Rimbaman, 1992; Astjario and Astawa, 2007). Progradation occurs along 1 km in the east Eretan region, developing Cimanuk Delta along 7 km and shoreline abrasion along 0.5 km in the Eretan region (Astjario and Astawa, 2007).

## DATA AND METHODS

Changes in coastal and river estuary can be identified through remote sensing analysis of the temporal satellite imagery (Utami *et al.*, 2018; Yadav *et al.*, 2019). The method applied in the study is Landsat satellite imagery collection, geometry and radiometry correction, layer stacking, false-color composite, image enhancement and pan sharpening, cropping the area of interest, image interpretation, and delineation, and the last step is change detection analysis (Figure 2).

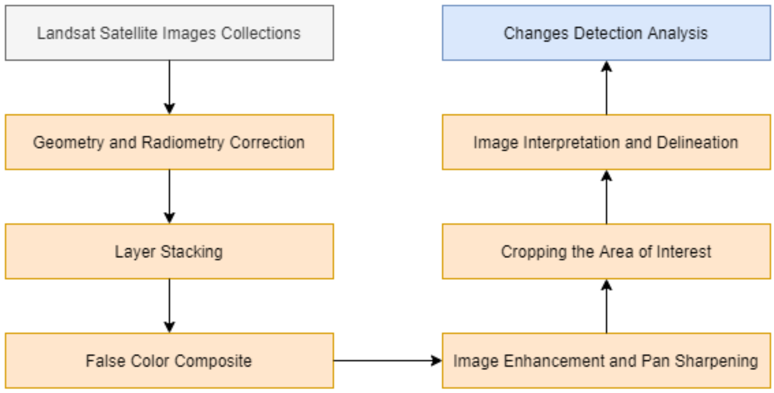



Figure 2. Method of river estuary changes in the north coastal Java

### Research stage of Estuary Changes in the Cipunegara and Cimanuk Rivers consists of:

#### *Landsat Satellite Data Collections*

Landsat was first launched in July 1972 by Earth Resources Technology Satellite (ERTS-1) or Landsat 1 as the first civilian Earth observation satellite (Figure 3). Other Landsat series was established by the United States Geological Survey (USGS) and the National Aeronautics and Space Administration (NASA): Landsat 2 in 1975, Landsat 3 in 1978, Landsat 4 in 1982, Landsat 5 in 1984, Landsat 6 in 1993 (failure), Landsat 7 in 1999, and Landsat 8 in 2013 (Ridwan *et al.*, 2018).

The analysis of river estuary changes in the north coastal Java use Landsat series form earthexplorer.usgs.gov: Landsat 3 MSS 1978, Landsat 5 TM 1992, Landsat 5 TM 1996, Landsat 5 TM 2009, Landsat 8 OLI 2015, and Landsat 8 OLI 2020 with a maximum cloud cover of 20% (Table 1). The Landsat time series was assigned to determine the estuary's history-changing by calculating changes in the erosion or accretion area.

#### *Geometry and Radiometry Correction*

Geometry correction was assigned to correct the satellite image's geometric position to match the exact coordinates. This correction was applied to overly all images in the same coordinates. Radiometric

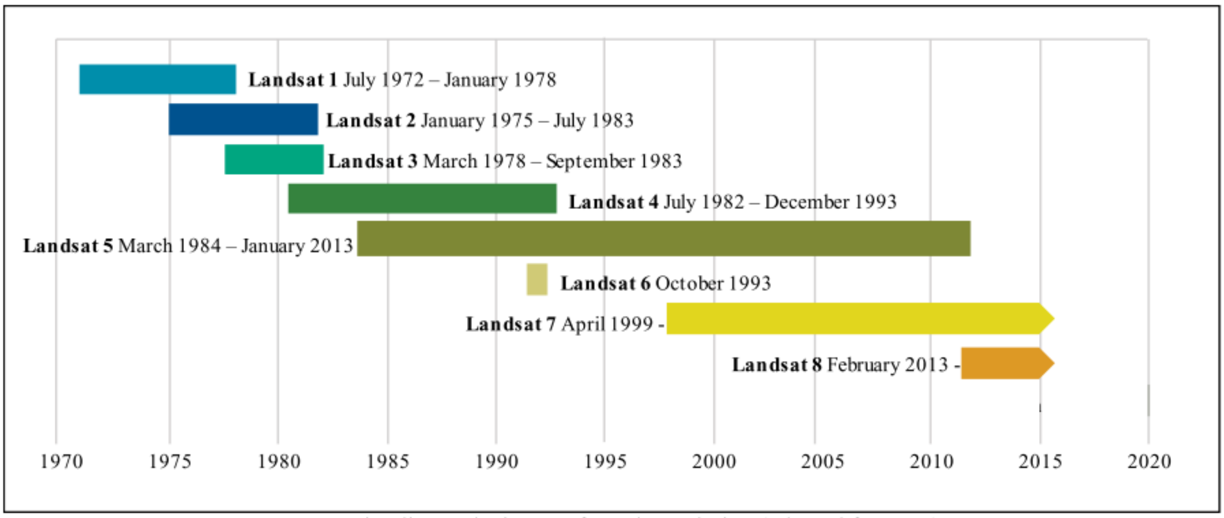



Figure 3. Landsat Mission (adapted from (Ridwan *et al.*, 2018))

Table 1. Specification of Satellite Imagery used in this study (https://www.usgs.gov/core-science-systems/nli/landsat, Oktaviani and Johan, 2016)

| No | Satellite and Sensor | Data Acquired | Path/Row | Cloud Cover (%) | Temporal Resolution | Spatial Resolution (m) | Radiometric Resolution |
|---|---|---|---|---|---|---|---|
| 1 | Landsat 3 MSS | 12/08/1978 | 130/064 | < 20 | 18 | 79 x 79 | 7 bit (band 4,5,7)<br>6 bit (band 6) |
| 2 | Landsat 5 TM | 02/11/1992 | 121/064 | < 20 | 18 | 30 x 30 | 8 bit |
| 3 | Landsat 5 TM | 15/05/1996 | 121/064 | < 20 | 18 | 30 x 30 | 8 bit |
| 4 | Landsat 5 TM | 07/08/2009 | 121/064 | < 20 | 18 | 30 x 30 | 8 bit |
| 5 | Landsat 8 OLI/TIRS | 28/01/2015 | 121/064 | < 20 | 16 | 30 x 30<br>15 x 15 (Pan) | 16 bit |
| 6 | Landsat 8 OLI/TIRS | 08/10/2020 | 121/064 | < 20 | 16 | 30 x 30<br>15 x 15 (Pan) | 16 bit |

corrections are performed to calibrate pixel values or correct errors in values. This process improves the interpretability and quality of remote sensing data. Radiometric calibration and correction are essential in comparing multiple dataset.

***Layer Stacking***

Layer stacking is a process for combining multiple images into a single image. The images should have the same extent (number of rows and number of columns), so it is important to resample other bands with different spatial resolution to the target resolution. In other words, all images/bands should have the same spatial resolution to perform layer stacking.

**False-Color Composite**

False-color composite applied to visualize the wavelengths which human eyes do not see in near infrared range. The utilization of bands such as near-infrared increasing the spectral separation and enhancing data's interpretability. False-color composite represents a multispectral image created using ranges other than visible red, green, and blue. Different false-color compositions distinguish different functions by the Landsat series. This study used a band combination of false-color composite shown in Table 2.

Table 2. False-color composite combination band

| No | Satellite and Sensor | Combination Band |
|---|---|---|
| 1 | Landsat 3 MSS | 765 |
| 2 | Landsat 5 TM | 432 |
| 3 | Landsat 8 OLI | 543 |

**Image Enhancement and Pan Sharpening**

Satellite image enhancement is the most widely required technique in satellite image processing to improve the visualization of the features (Ahuja and Biday, 2015). Pan sharpening is merging high-resolution panchromatic and lower resolution multispectral imagery to create a single high-resolution color image. Multispectral images have multiple bands and a higher degree of spectral resolution, but often lack high spatial resolution (Table 1). On the other hand, Panchromatic images only one wide band of reflectance data but tend to have a higher spatial resolution. The pan-sharpening process merges the multispectral and panchromatic images, which gives the best of both image types, high spectral resolution, and high spatial resolution. Pan sharpening done for Landsat 8, Band 5 (0.85–0.88 μm) is in the red wavelength region, Band 4 (0.64–0.67 μm) is in the green wavelength region, and band 3 (0.53 - 0.59 μm) is in the blue wavelength region. The 15 m panchromatic (Pan) band has a wavelength of 0.50–0.68 μm, putting it within the red, green, and blue spectral regions (Johnson, 2014).

***Cropping the area of interest***

Cropping the area is essential in the research area, because the extensive image map source covers many sites on the north coastal Java. Therefore, it is necessary to cut it to fit the research area. This research has two areas of interest: Cipunagara estuary and Cimanuk estuary area. Cipunagara River Delta in Patimban Village, Pusakanagara Sub-District, and Subang. Meanwhile, the Cimanuk River Delta is located in Indramayu District (Figure 4).

***Image Interpretation and delineation***

The interpretation techniques used in remote sensing applications have exploited the wealth of information on the remote-sensing data. These techniques include extracting information from spectral, temporal, and spatial domains of this data (Zaki *et al.*, 1995). Image delineation is drawing a map according to the original map so that the estuary map was obtained between 1978 and 2020. Then the delineation map will be compared using the overlay method. This stage was produced Cipunagara and Cimanuk estuary area map for 1978, 1992, 1996, 2009, 2015, and 2020. In this Landsat imagery spatial analysis method, it does not consider the tides of seawater factor.

***Changes Detection Analysis***

After the estuary map is generated, an analysis is carried out with the GIS software to display, process, and analyze spatial data (Mulyadi and Nur, 2018; Nur *et al.*, 2018). The intersection as spatial analysis and calculate by raster calculator in GIS using QGIS was used to calculate the estuary area for each Landsat period and calculate the estuary difference area's time series. The results show how much area has been reduced (erosion) or increased (accretion) each year. The value is displayed on a graph, and the regression equation is calculated so that a predictive equation was generated for the future estuary area.

## RESULT

The satellite imagery analysis using Landsat 3 MSS 1978, Landsat 5 TM 1992, Landsat 5 TM 1996, Landsat 5 TM 2009, Landsat 8 OLI 2015, and Landsat 8 OLI 2020 with a maximum cloud cover 20% of the study area. Remote sensing analysis obtained in the north coastal Java depicts changes in the estuary of the

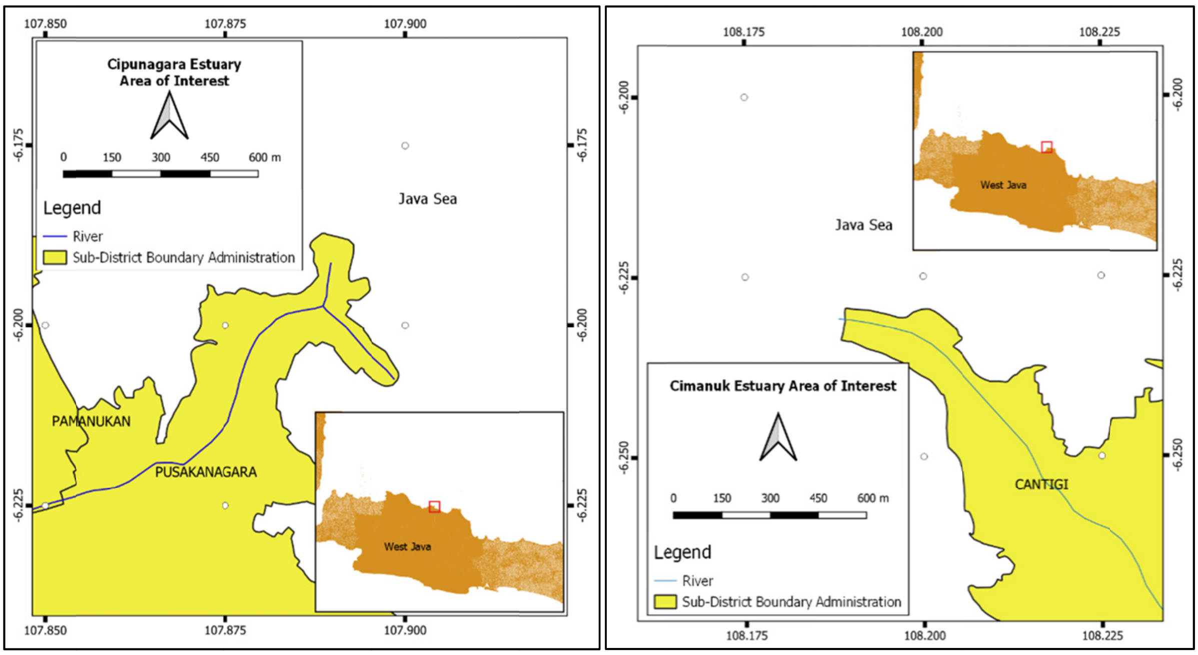


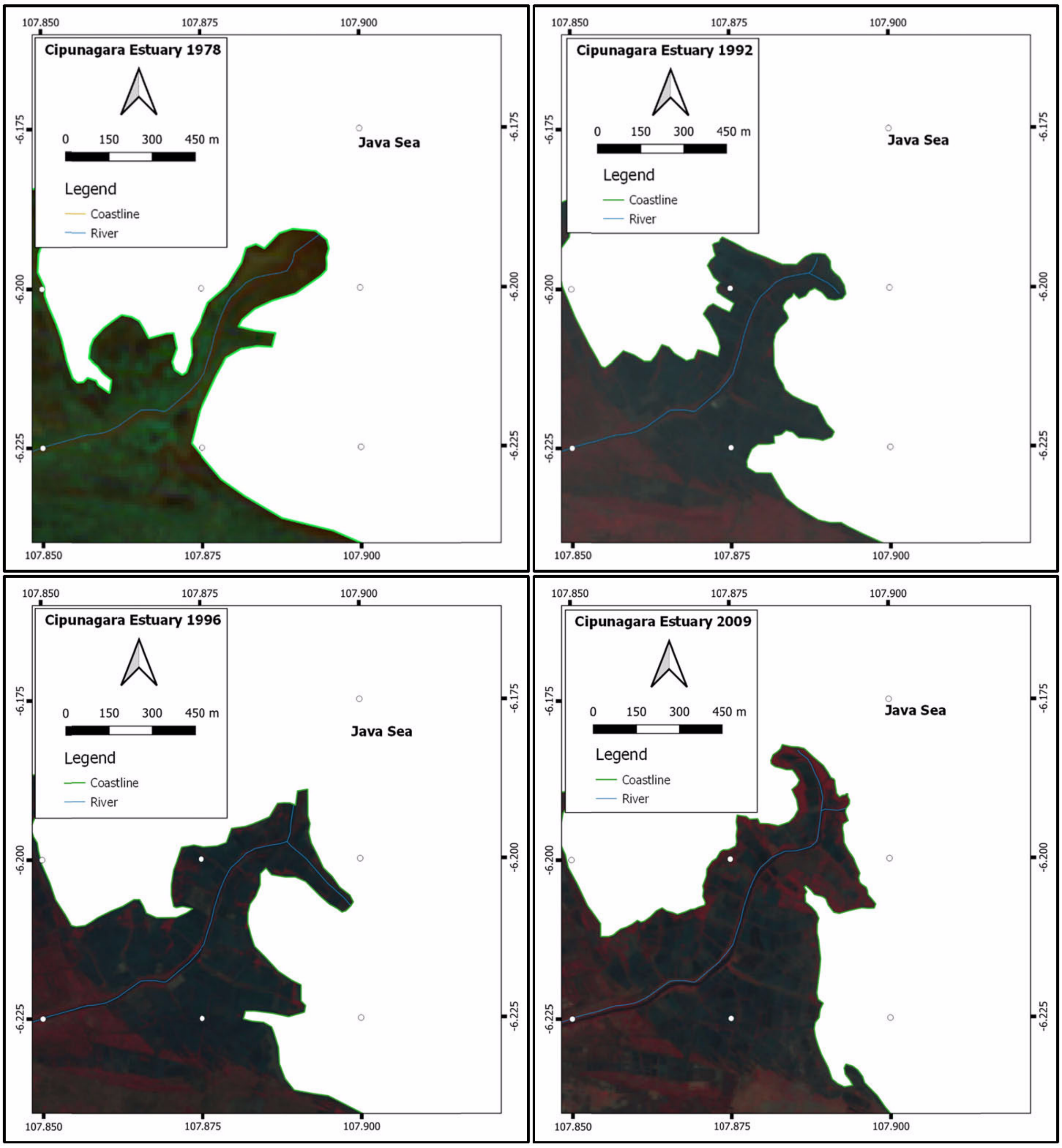

Figure 4. Area of Interest for Cipunagara and Cimanuk Eastuary River

Cipunegara and Cimanuk Rivers in 1978 and 2020. Both estuary rivers show the prolongation of new land or accretion between 1978 and 2020 in the study area. Detail depiction of the estuary of the Cipunegara and Cimanuk Rivers explained as follow:

**Estuary of the Cipunagara River**

Changes in the estuary of the Cipunegara River from 1978 to 2020 shows in Figure 5. From the analysis of Landsat images during the period 1978 - 1992 and 1992 - 1996 in the Cipungara estuary, there was a reduction in the land as abrasion. However, intensified accretion in the Cipunegara's estuary occurred since the 2000's period. accretion at the mouth of the Cipunegara River to the northeast. Estuary changes in Cipunegara River from 1978 to 1996 show reduction land or abrasion and from 1996 to 2020 shows new land or accretion which occurred in the estuary (Table 3).

The data support a previous study (Munibah *et al.*, 2010) where new land formed in 2015, followed by the growth of the new land patterns in the 1972-1990 period. Accretion resulted from 2015's satellite image followed the existence of two natural processes at the mouth of the Cipunagara River, including river flow and sea waves (Munibah *et al.*, 2010). Accretion in the Cipunegara delta was formed along 1.5 km from 1996-2015 (Figure 6) using Landsat image monitoring. It shows relevant result from the prior study of 1.7 km in the 1989-2013 period (Salim *et al.*, 2016).



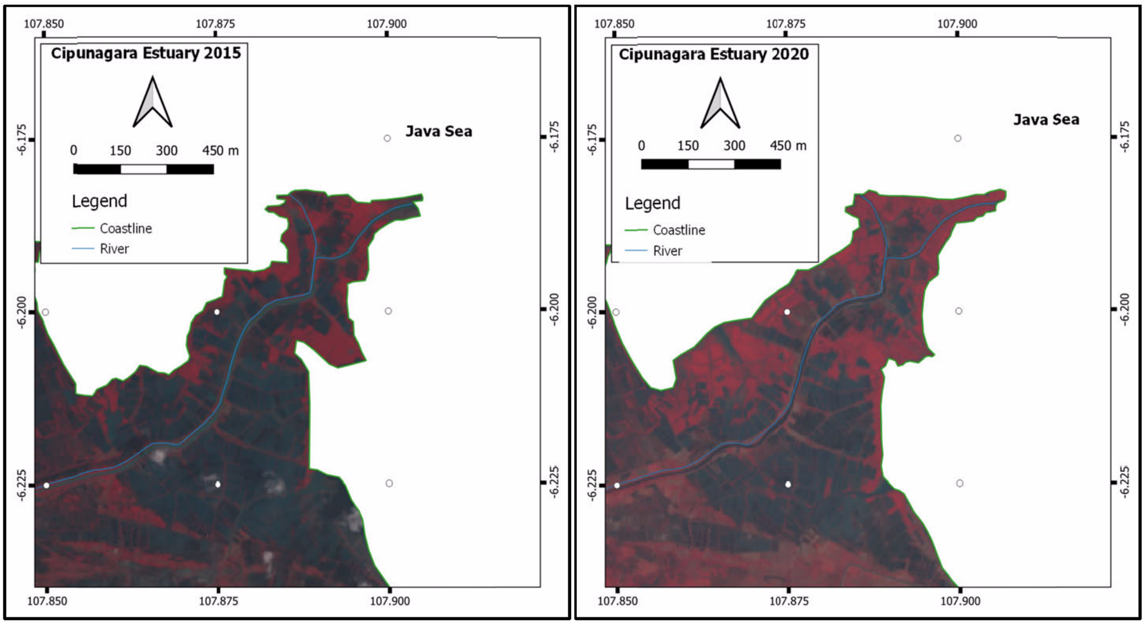



Figure 5. Estuary of the Cipunagara River

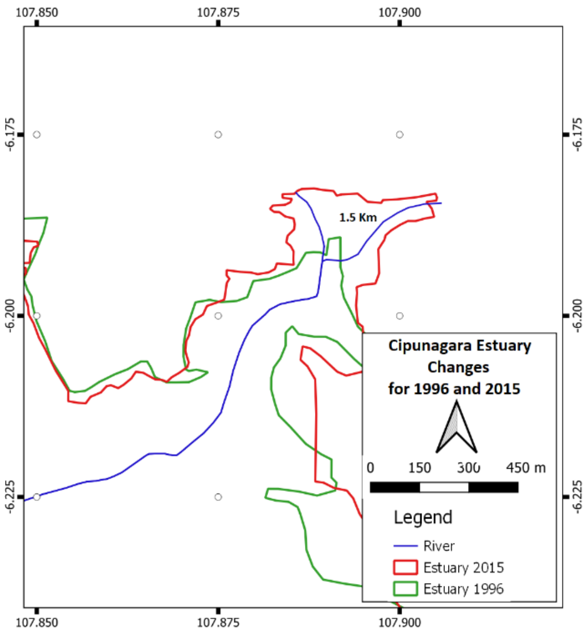



Figure 6. Cipunagara Estuary Changes for 1996 and 2015

Satellite imagery analysis from 1978 to 2020 shows that new land formed approximately 205 Ha (Table 3). The addition of new land at the mouth of Cipunagara River is considered due to the high sedimentation rate in the Cipunagara River since 1976 (Hehanusa *et al*., 1975). The addition of new land from prior studies (Munibah *et al*., 2010) shows an accretion area up to 757.3 Ha in 1990-2008. It represented in the addition of new land due to accretion was reduced compared to 1990-2008 (Figure 5). Reduction in new land areas might be controlled by increasing waves in this area.

The change detection analysis in Cipunagara estuary maps (Figure 5) shows that the estuary experienced abrasion and accretion. Figures 5 shows the change of estuary in the study area in 1978. By the spatial analysis in QGIS the area calculation can be shown in Table 3.

Table 3. The details of Cipunagara estuary (calculation with respect to 1978)

| No | Years | Area of Abrasion (Ha) | Area of Accretion (Ha) |
|---|---|---|---|
| Base | 1978 | 0.00 | 0.00 |
| | 1992 | 69.28 | 0.00 |
| | 1996 | 20.85 | 0.00 |
| | 2009 | 0.00 | 59.39 |
| | 2015 | 0.00 | 180.66 |
| | 2020 | 0.00 | 205.98 |

Figure 7 shows the chart of the changes and explains the trend of the Cipunagara estuary. The chart shows that the abrasion from 1992 to 1996 and its accretion continued from 1996 to 2020. According to the analysis, there is the addition of 205.98 Ha of the area. Changes in the coastline and the incidence of abrasion or accretion in the Cipunagara estuary resulting from the analysis are shown in Figure 8. Spatially, it can be seen most of the Cipunagara estuaries have accretion for new land.

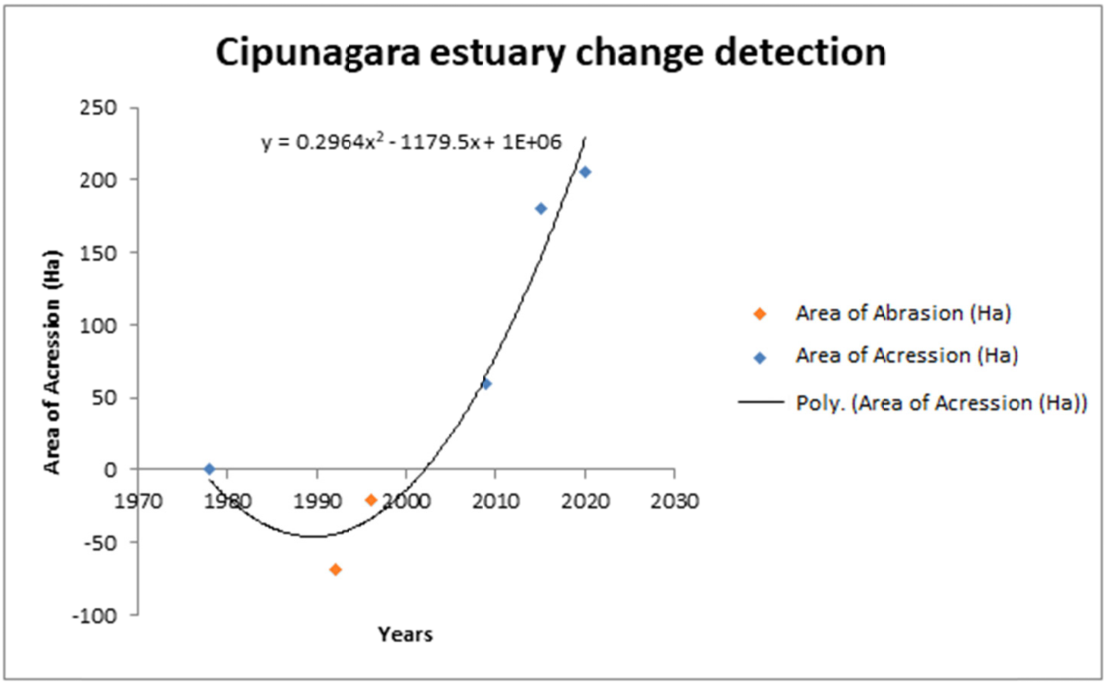



Figure 7. Cipunagara estuary change detection

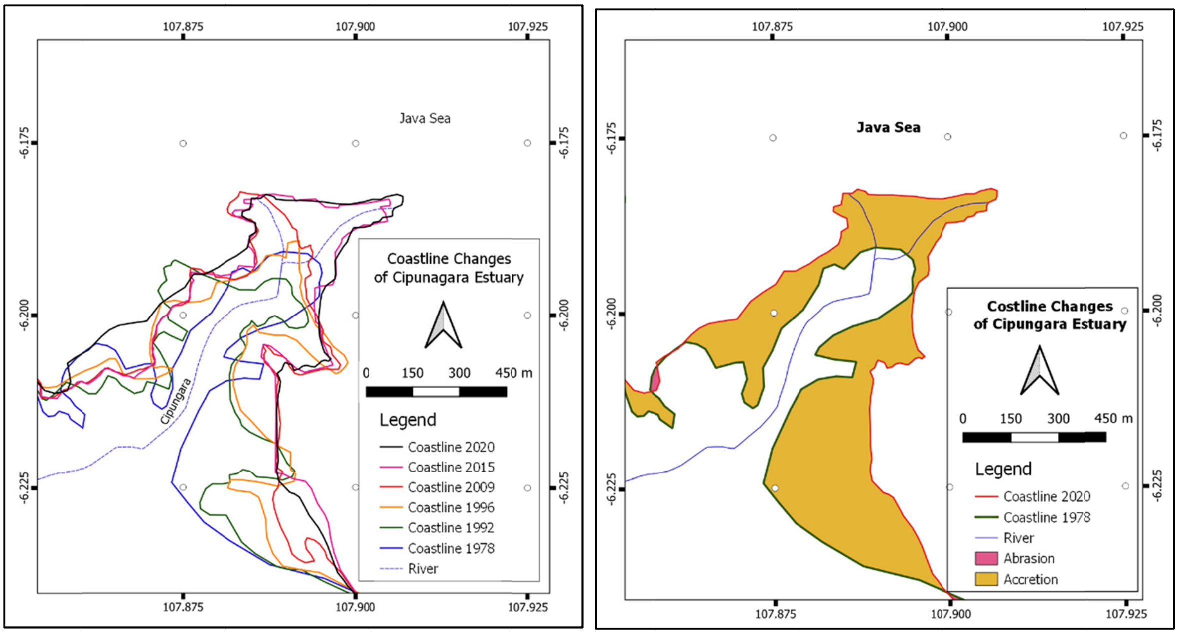
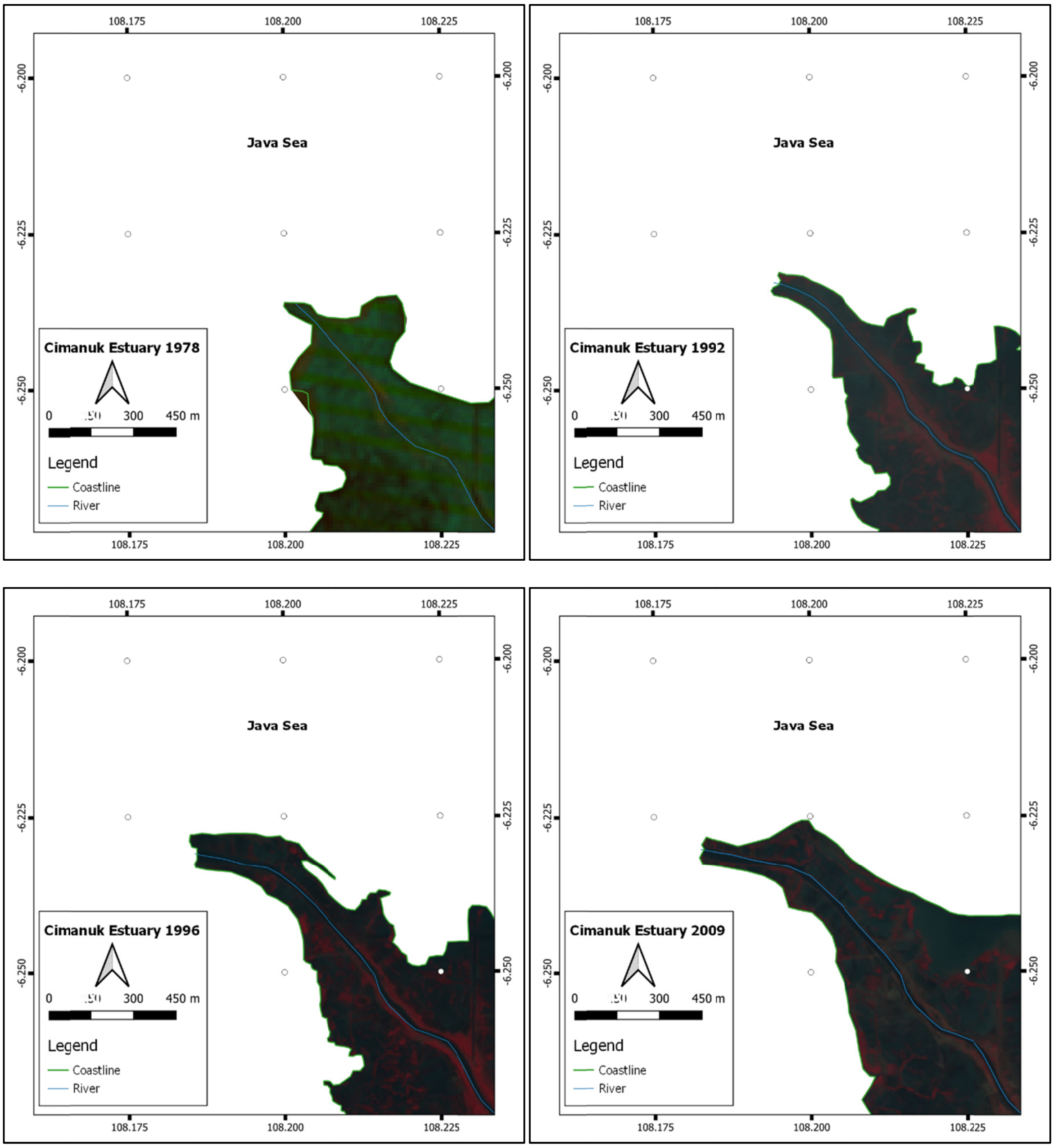



Figure 8. Coastline Changes of Cipunagara Estuary

## Cimanuk River Estuary

The results of image analysis in the Cimanuk River area show that the coastline from 1978 to 2020 experienced accretion or the addition of new land along 2.5 km to the west or to the mouth of the Cimanuk River (Figure 9). Remote sensing analysis in 1978 and 2020 in the mouth of the Cimanuk Rivers shows that the new land formed approximately 629 Ha (Table 4).

Figure 10 shows a chart of the changes and explains the trend of the Cimanuk estuary. The chart shows that the Cimanuk estuary largely experienced accretion from 1978 to 2020. According to the analysis, there is the addition for 629.54 Ha of the area. Changes in the coastline and the incidence of abrasion or accretion in the Cimanuk estuary resulting from the analysis are shown in Figure 11. Spatially, in the estuary of Cimanuk there is the addition of new land in most of the area, or it is called accretion.



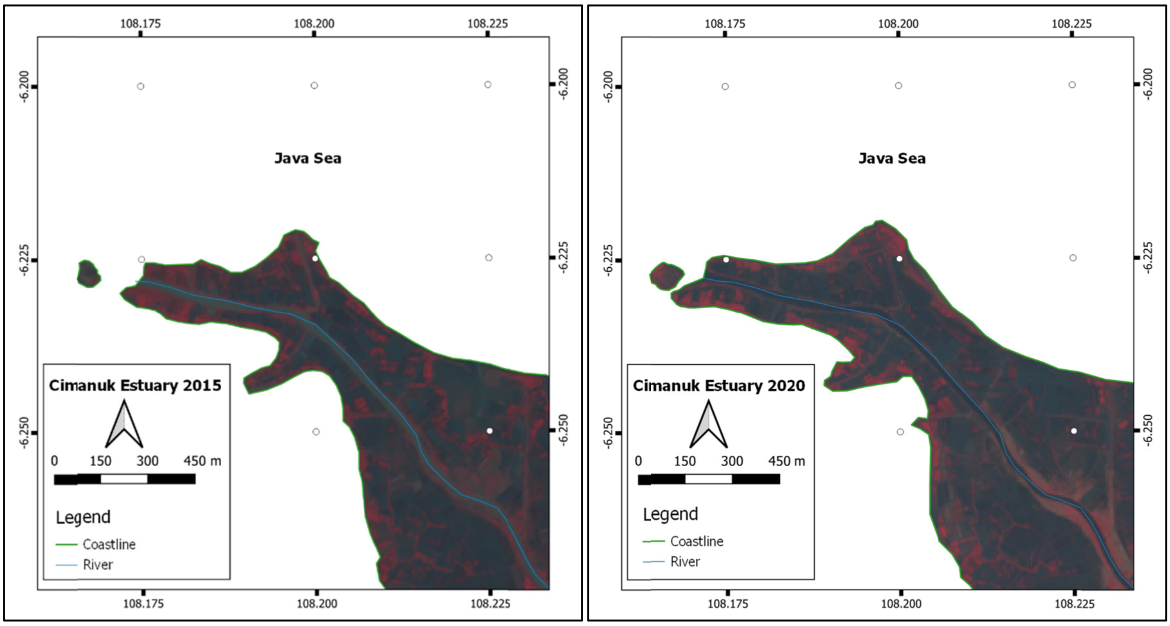



Figure 9. Estuary of the Cimanuk River

Table 4. The details of Cimanuk estuary (calculation concerning in 1978)

| No | Years | Area of Abrasion (Ha) | Area of Accretion (Ha) |
|---|---|---|---|
| Base | 1978 | 0.00 | 0.00 |
| | 1992 | 0.00 | 56.24 |
| | 1996 | 0.00 | 190.14 |
| | 2009 | 0.00 | 270.15 |
| | 2015 | 0.00 | 506.73 |
| | 2020 | 0.00 | 629.54 |

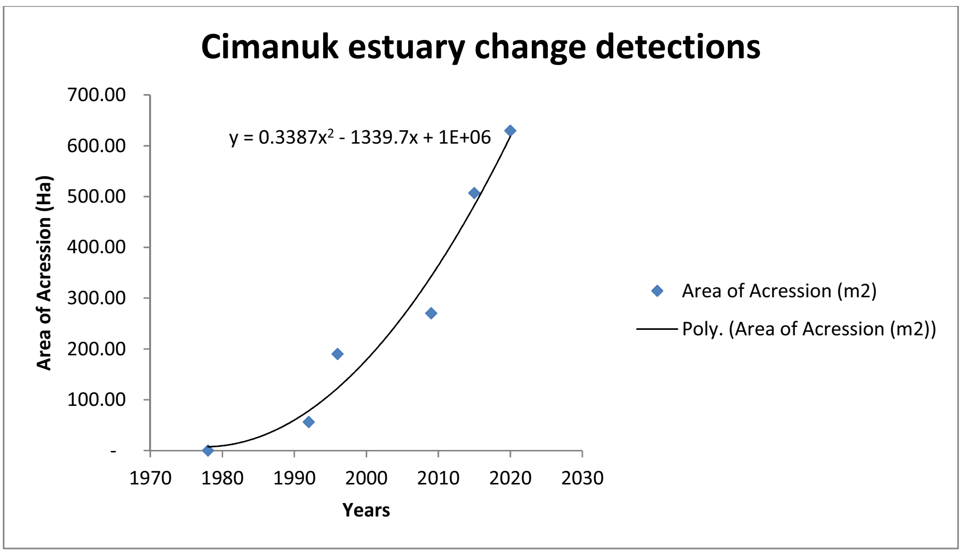



Figure 10. Cimanuk estuary change detection graphic

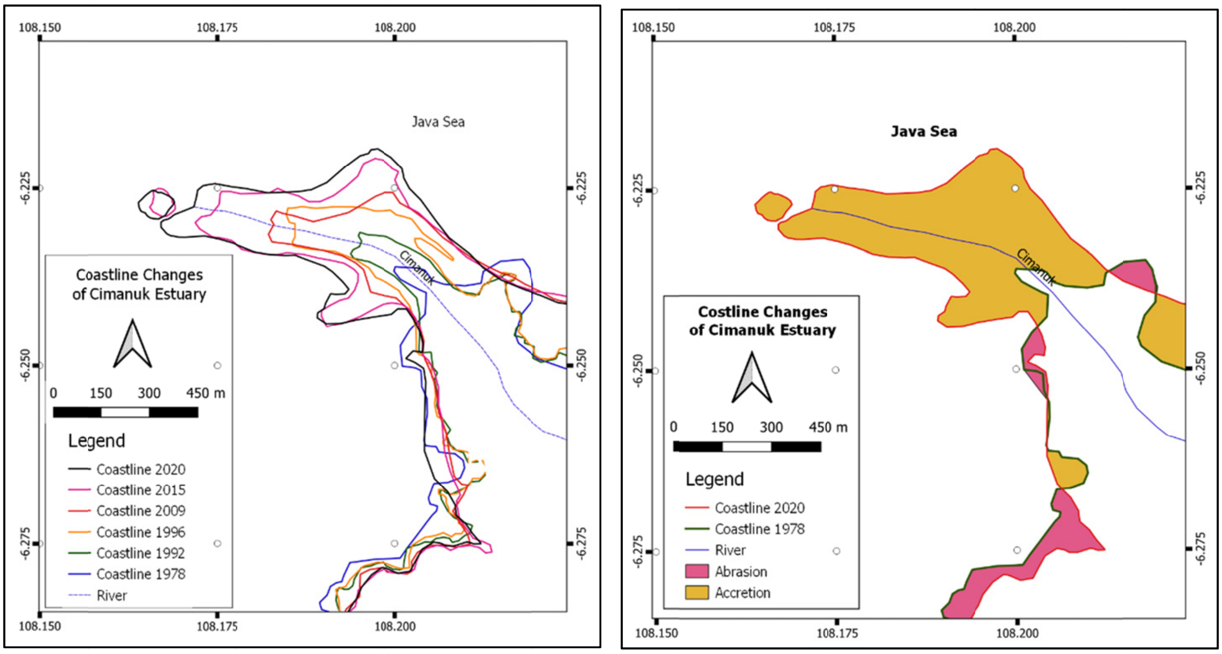



Figure 11. Coastline Changes of Cipunagara Estuary

## DISCUSSION

Observation of satellite imagery from 1978 to 2020 at the estuary of Cipunagara and Cimanuk river shows the additional for 1.5 km and 2.5 km of new land. Prolonged shorelines at the estuary indicates that the Cimanuk River's estuary experienced a larger impact on accretion than the estuary of the Cipunagara River. Measurement of sedimentation rates around Indramayu coastline shows that the sedimentation rate is quite high, even exceeding 100 g /m2 /day due to landuse for housing and ponds by residents (Adrianto *et al.*, 2017). Clay deposit was estimated for 53.6 million tonnes/year (Astjario and Astawa, 2007) to be transported by river and deposited at the mouth of the Cimanuk River. It increased the accretion level of the Cimanuk River. Cimanuk River experienced growth of landmass or accretion in the past from 1978 to 2020. Our study supports prior research (Astjario and Astawa, 2007), which mention accretion in the Cimanuk River occurred in the past. Figure 9 shows a high sedimentation rate from the upstream of Cimanuk River. It increased land growth until more than 600 Ha in 2020 for 40 years. It suppose that the Cimanuk estuary is not only related to high sediment load from the river.

However, the accretion at the mouth of the Cipunagara River was intensively increased since the 2000's period (Figure 5). It is controlled by sediment accumulation. Based on remote sensing analysis from 1978 to 2020 there is 205 Ha accumulation (Figure 11). The reduction area of accretion from the analysis in this study contradictive to the prior research (Munibah *et al.*, 2010; Achiari *et al.*, 2015). The existence of currents perpendicular to the coastline began to appear after 2006 due to the construction of the jetty around Pondok Bali Beach. It indicates the erosion and transportation of sediment around the Subang coast, including the mouth of the Cipunagara River. The structure of a pier around Pondok Bali Beach (Achiari *et al.*, 2015) seems to be quite effective in reducing accretion around the Subang coast, especially the estuary of the Cipunagara River.

The study regarding to accretion forming at the mouth of the Cipunegara and Cimanuk Rivers assumed to be related to land use changes in two rivers. The land-use for agriculture and fisheries since 1972 in upstream of the Cipunagara River (Munibah *et al.*, 2010) and broken dam in 1947 (Astjario and Astawa, 2007) has changed the sedimentation pattern in the estuary of the Cipunagara and Cimanuk rivers. We recommend to continue the monitoring of accretion from satellite imagery and field study of the sedimentation process in these two estuaries. It is necessary to determine impact of flooding in coastal areas due to sediment silting. In addition, it can be anticipated if accretion in both estuaries of the Cipunagara and Cimanuk Rivers is well monitored.

Remote sensing is both a science and an art to obtain information about the earth's surface non-invasively. It is applied by sensing and recording the energy reflection to obtain information by processing and analysing those data (Ahuja and Biday, 2015).

Remote sensing analysis can be used to calculate the estuary changes in the north coastal Java. This method can estimate the erosion or accretion in the past and predict erosion and accretion in the future. More specific research must be carried out by field survey and sampling data at the research area for more detail study.

## CONCLUSIONS

Analysis of shoreline changes was carried out between 1978 and 2020 using Landsat data at the estuary of Cipunegara and Cimanuk River. Observations from Landsat data are used to determine changes in coastlines that occur around the Subang, Indramayu, and Cirebon areas. The result show that there has been a change in the shoreline in several areas, especially around the mouths of large rivers such as the Cipunegara and Cimanuk Rivers. The estuary changes in the Cipunegara and Cimanuk Rivers due to the high sediment deposition in the river mouth. The forming of new land controlled by the accretion process. We suppose that high sediment deposits in both rivers originated from young volcanic regions of the Quaternary deposits at Ciremai Mountain. The Quaternary deposits are transported through tributaries of Cimanuk and Cipunagara rivers until the mouth of rivers. Monitoring through Landsat satellite imagery on the Cipunagara River in 1978 and 2020, shows the addition of the new land for 205 Ha of the area. Image analysis in the Cimanuk River area shows that the estuary line from 1978 to 2020 experienced accretion or forming of the new land for 629 Ha. However, continuous monitoring of accretion from satellite imagery and a study of the sedimentation process in these two estuaries is necessary to determine how far the accretion rate will be in the future.

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